COLLEGE OF DEVELOPMENT STUDIES

CENTER FOR RURAL DEVELOPMENT

IMPACTS OF THE ADOPTION INTENSITY OF IMPROVED BREAD WHEAT PACKAGE AND SEED RECYCLING PRACTICES ON SMALLHOLDER FARMERS' PRODUCTIVITY AND TECHNICAL EFFICIENCY: THE CASE OF EAST GOJAM ZONE, ETHIOPIA

Doctoral Dissertation

In Partial Fulfillment of the Requirements for the Degree of Doctoral Philosophy in Development Studies

Yirgalem Eshete Fithanegest

Advisors

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APPROVAL SHEET

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As members of the Board of Examiners of the Ph.D Dissertation Open Defense Examination, we certify that we have read and evaluated the dissertation entitled: "**Impacts of the Adoption Intensity of Improved Bread Wheat Package and Seed Recycling Practices on Smallholder Farmers' Productivity and Technical Efficiency: The Case of East Gojam Zone, Ethiopia**" submitted in partial fulfillment of the requirements for the degree of Doctoral Philosophy. This is therefore to certify that the dissertation complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

Signed by the Examining Committee

1. External Examiner ________________________ Signature________ Date__________
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DEDICATION

I dedicate this Dissertation to my late mother W/o Werkezeb Yirga and my father Ato Eshete Fithanegest who have shown me the light at the end of the tunnel. My achievements in life would have been impossible without their daily prayers, strong affection, unwavering material, and moral support

STATEMENT OF THE AUTHOR

I, the undersigned, declare that this is my original work, has never been presented in this or any other University, and that all the resources and materials used for the dissertation, have been fully acknowledged.

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This dissertation has been submitted for examination with my approval as University supervisor.

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ACKNOWLEDGMENT

The fruition of this dissertation is realized with the technical, financial, logistics, and moral support of different individuals and institutions. Out of all these, I am highly indebted to the Ministry of Science and Higher Education and Debre Markos University for sponsoring the full cost of this study. Besides, I would like to express my gratitude to seed multiplication and marketing cooperatives, Farmer Training Centers, Ethiopian Seed Enterprise, Amhara Seed Enterprise, Bureau of Agriculture in East Gojam Zone, Debre Elias, and Baso Liban Woredas for their optimal cooperation in providing all the information required and for their continuous cooperation in facilitating the data collection activities.

Above all, I would like to extend my profound sense of appreciation and gratitude to Dr. Bamlaku Alamirew (Major Advisor) and Dr. Zewdie Bishaw (Co-Advisor) for their sagacious guidance, encouragement, constructive critics, and regular follow-ups. Both of them have bestowed me an immense interest, inspiration, academic guidance, and technical support well beyond their formal duties and responsibilities, for which I am highly indebted.

I would also like to take this privilege to the Development Agents who meticulously gather the data used in this study. I am also highly indebted to the respondents of the study involved in providing the required information. Particularly, I would like to convey my thanks and heartfelt appreciation to the men and women elders of Debre Elias and Baso Liban districts who actively takes part in the focus group discussion and key informants' interviews scarifying their precious time and energy, amidst the Corona Virus shutdown.

My particular thanks and regards are also due to my friends Ketemaw Melkamu, Solomon Zewdu, Daniel Aklilu, and Kedir Hussein for their invaluable assistance, moral, and technical support in the process of preparing this dissertation. Last but not least, I would like to convey my thanks to my wife W/o Rediet Tilahun, my daughter Heyab Yirgalem, my brothers Tadesse Eshete, Shumet Eshete, Nathanel Eshete, and Daniel Dessie for the love, care, logistic, and moral support in my life. Without their inexhaustible help, kind encouragement, and moral support, this academic journey would have not been completed.

TABLE OF CONTENTS

List of Tables

List of Figures

List of Annex Graphs

List of Appendix Tables

List of Abbreviations

AI	Adoption Intensity
AIC	Akaike Information Criterion
ANRS	Amhara National Regional State
ATA	Agricultural Transformation Agency
BIC	Bayesian Information Criterion
BWP	Bread Wheat Production
CBA	Cost Benefit Analysis
CD	Cobb-Douglas
CIMMYT	International Maize and Wheat Improvement Center
CSA	Central Statistical Agency
CSA	Climate Smart Agriculture
DAP	Di Ammonium Phosphate
DAs	Development Agents
DEA	Data Envelopment Analysis
DMU	Decision Making Unit
EGSs	Early Generation Seeds
ETB	Ethiopian Birr
FTCS	Farmer Training Centers
GoE	Government of Ethiopia
Ha	Hectare
IBWS	Improved Bread Wheat Seed
Kg	Kilogram
LDCs	Least Developed Countries
LR	Likelihood Ratio
MLE	Maximum Likelihood Estimates
NPV	Net Present Value
PhD	Doctor of Philosophy
PPS	Probability Proportional to Size
PS	Propensity Score
PSM	Propensity Score Method
PSNP	Productive Safety Net Program
Qt	Quintal
RuSACCOs	Rural Saving and Credit Cooperatives
SFA	Stochastic Frontier Approach
SFPF	Stochastic Frontier Production Function
SoP	Standard Operation Procedure
SR	Seed Recycling
SSA	Sub Saharan Africa
TE	Technical Efficiency
TL	Translog
TLU	Tropical Livestock Unit
TPB	Theory of Planned Behaviour
USD	United States Dollar
VIF	Variance Inflation Factor

Abstract

This study was conducted with an overall objective of investigating the impacts of the adoption intensity of Improved Bread Wheat Package (IBWP) and seed recycling practices on smallholder farmers' productivity and Technical Efficiency (TE). The first article examined the yield effect of plot – level seed rate application and compared the costs and benefits of fresh and recycled seed use in Bread Wheat Production (BWP). The second article investigate the determinants of smallholder farmers' adoption intensity of the IBWP and its impact on productivity. The third article estimates smallholder farmers' level of TE in BWP, identify sources of technical efficiency, and analyze the impact of seed recycling on smallholder farmers' TE and productivity. The researchers hypothesized that poor agronomic management practices, such as improper seed rates and multiple seed recycling, are major contributors to low productivity. The researchers also hypothesized that smallholder farmers' adoption of only specific components of the IBWP has a thwarting effect on their productivity and TE. Moreover, it was hypothesized that seed recycling substantially contribute to smallholder farmers' technical inefficiency and productivity. The study collected both quantitative and qualitative data via interviews, focus group discussions, and observations from 450 sample respondents. Various statistical models, including dose-response, Cragg's double hurdle, Stochastic Frontier Analysis with a translog function, and regression adjustment treatment effect models along with the Cost-Benefit Analysis (CBA), were employed to analyze the data. Farmers' seed rate applications were found to vary, and the study identified that the highest average wheat yield was associated with a seed rate of 50 kg/ha above the recommended level. A one-time bread wheat seed recycling after five consecutive times was found to reduce yield by 665 kg ha^{-1} compared to non-recycled seeds. The CBA indicated that while seed recycling reduces seed costs, the economic gains associated with using fresh improved bread wheat seed were significantly higher, resulting in improved yields and net income. The study identified various determinants of adoption intensity and found that access to improved fresh seed, membership in improved seeds multiplication and marketing cooperatives, age, longer years of experience; low dependency ratio, higher family size, Tropical Livestock Unit (TLU), and frequency of extension contact were significant reasons for the adoption of the entire package. Additionally, adopters of the entire bread wheat package had 8.24 quintals higher productivity per hectare than non-adopters. The analysis also revealed that several variables, including age, family size, Tropical Livestock Unit, dependency ratio, hand weeding frequency, row spacing, amount of credit, and membership in seed multiplication and marketing cooperatives, significantly impacted TE. The study also found that farmers using recycled seed had lower TE compared to those using fresh seed, highlighting the negative effects of seed recycling on TE. Overall, findings of the study provides a comprehensive understanding of the yield and cost implications of plot level seed rate application and seed recycling practices; the determinants of IBWP adoption intensity, impact of IBWP adoption intensity on smallholder farmers productivity and TE, and sources of smallholder farmers technical inefficiency in BWP. Generally, findings' highlight the importance of using fresh seed, increasing access to improved seed, promoting full package adoption, and improving smallholder farmers' TE in BWP. Creating wider access to fresh seeds by establishing agricultural credit schemes for seeds procurement, land consolidation through voluntary land exchange, and targeted price subsidies are strongly recommended to enhance farmers' TE and Productivity. Besides, encouraging full package adoption by reinventing the existing practices in the package to suit the local context is strongly recommended. Implementing Farmer – to – Farmer extension method is strongly suggested to facilitate knowledge and experience sharing among farmers.

Key Words: Bread wheat package, seed rate, seed recycling, adoption, technical efficiency, productivity

CHAPTER 1: GENERAL INTRODUCTION

1.1. Background and Justification

Agriculture has remained the mainstay for developing countries. It is a major source of employment for 60% of the African population (Oluwatayo and Ojo, 2016). In Ethiopia, it accounts for 41% of the country's GDP, 70% of the nation's industrial raw materials, 85% of the nation's food supply, and 80% of all jobs. However, this vital sector has stagnated in its traditional economic equilibrium where both the demand and supply of agricultural innovation remain the same for several centuries. As a result, the agriculture sector in the Least Developing Countries (LDCs) in general and in Ethiopia, in particular, is characterized as traditional, rain-fed, subsistence, and low-tech. LDCs' vicious and generational cycle of destitution is largely attributed to the economic equilibrium of traditional agriculture (Abate et al., 2018, Schultz, 1966). Therefore, increasing agricultural yield is not only essential but also a requirement for ending the vicious poverty cycle that has gripped the majority of people in LDCs for millennia. When it comes to securing global food security, wheat production plays a crucial role. In addition, the food security initiatives of Ethiopia have considered wheat as a strategic crop (Bishaw and Atilaw, 2016, Kebede et al., 2017, Mideksa et al., 2017, Yirga et al., 2013). In Ethiopia, wheat contributes 19.14% (57,801, 306.00 quintals) to the total cereal production (302, 054, 260.6 quintals) during the 2020/2021 production season. The national average wheat productivity was reported to be 30.46 qt ha^{-1} against 28.31 qt ha^{-1} for the Amhara region. The average wheat productivity for the East Gojam zone was reported to be 32.12 qt ha^{-1} which is relatively higher than both the national and regional average (CSA, 2021b).

The use of Improved Bread wheat Seeds (IBWSs) along with the application of best agronomic management practices substantially improves bread wheat productivity and the fight against food insecurity (Mango et al., 2020, Louwaars and De Boef, 2012, Bishaw and Atilaw, 2016). Among other agronomic management practices, the seed rate and the frequency of Seed Recycling (SR) determine the ability of the crop to capture the available resources and hence increase yield. In most cropping systems, seed rate is a factor under the farmer’s control and has remained to be a vital crop production factor and one of the best decisions required to be carefully made. However, the optimum seed rate for maximum Bread Wheat Production (BWP) greatly varies between regions according to climatic conditions, soil types, sowing time, cultivars, spacing, and other agronomic practices. Yet, seed rate recommendations in Ethiopia often failed to be location and context-specific that often remain the same across a long period (Krishna et al., 2014, Bekele et al., 2013). As a result, farmers in the study areas usually apply either below or above the recommended seed dose per hectare for a longer period of time and the yield impacts of such seed rate application has to be empirically studied. This is likely to have a paramount significance in terms of revising seed rate recommendations that best realize the existing contexts of the study areas. Smallholder farmers' usually rely on recycled seeds for wheat production due to unaffordable seed prices, supply shortage, farmers' perception of yield similarity between fresh and recycled seeds, and lower costs associated with recycled seeds. Yet, recycled seeds are susceptible to impurity and admixtures that reduces productivity (Zecevic et al., 2014). The impacts of seed recycling on costs saved or reduced, yield, and quality was one of the objectives of this study. The first manuscript of this dissertation has therefore dealt with yield effects of plot – level seed rates and the CBA bread wheat seeds recycling. The dose-response model was applied to investigate the plot – level impacts of different seed rates (doses).

In Ethiopia, cereals dominate the crop production sector in terms of the amount of land allocated for their production and their contribution to food security. '*Tef*', maize, sorghum, and wheat are the leading cereals in the crop production sector. Different wheat varieties including bread wheat, Durum, and Emmer are grown in the highlands and transitional areas of Ethiopia. The share of different grain types to the general crop production sector and/or to the national economy varies on a temporal basis, agro-climatic conditions, and other artificial variables such as inputs price and supply. For instance, the share of wheat from the total grain areas was reported to be 13.38% while it contributes about 15.17% to the total cereal production (CSA, 2018a). However, studies indicated that wheat accounts for 17% and 19% of the total planted area and cereal production, respectively. The national average wheat productivity is 2.76 tons per hectare, which is significantly lower than the average productivity in many countries (CSA, 2018a, Jaleta et al., 2018, Lema and Degebassa, 2013).

Many nations were able to register meaningful production increase due to wider adoption of the Green Revolution technologies. Improved seeds, agro-chemicals such as fertilizers and pesticides, together with best agronomic practices have played a conspicuous role in countries effort to raise their productivity (Ali, et al., 2018, Dorosh and Mellor, 2013, Mideksa, et al., 2017). Improved seeds lead to augmented crop production only if they are used in combination with other complementary inputs and best agronomic practices. However, very little proportion of smallholder farmers' (nearly 10%) in Ethiopia use improved seeds. Even these few smallholder farmers' make use of improved seeds without a parallel adoption of other complementary inputs and best agronomic practices (Bishaw and Atilaw, 2016, Idrisa et al., 2012). Thus, there is high need to investigate the determinants of the adoption intensity of the IBWP as a package than the adoption of piecemeal components of the package and this study aimed at addressing this need. Intending to answer why farmers' make a partial than a complete IBWP adoption, the current study has employed a mixed research design that heavily inclined to quantitative research design. The determinants of the AI of IBWP was investigated using Cragg's Double Hurdle model.

It is now widely acknowledged that crop production productivity can be augmented through various means. The frontier model of agriculture that calls for allocating additional parcels of plots into the existing production represents the first possible way of enhancing crop production. Nevertheless, this approach has become unfeasible in developing nations due to the limited land size that rarely align with the rapidly expanding population. Moreover, adopting the frontier model of agriculture would result in augmenting production at the expense of cultivating marginal areas (Manjunatha et al., 2013, Rada and Fuglie, 2019). Wider adoption of improved agricultural innovation is the second option for augmenting agricultural production and productivity. Yet, creating innovations and disseminating them among the farming community is a lengthy process that demands significant capital investment for research and extension. Consequently, this second option also contradicts the dearth of financial resources and the pressing demand for production improvement in developing countries. Given the paucity of resources available to smallholder farmers and the necessity of increasing production in the short term, the optimal utilization of available resources is the most effective approach to enhancing production, especially in the short run. Thus, this third option for augmenting productivity is attainable by achieving the optimal level of resource utilization, which is of paramount importance (Ahmed et al., 2013; Bezabeh et al., 2014; Wudineh & Geta, 2016). The efficient utilization of inputs (more input for a given level of output) or technological advancements and managerial expertise in input utilization can both enhance wheat production and productivity (more output from a given mix of inputs). This improvement in the ability of farmers or decision-making units (DMUs) to enhance productivity without utilizing additional inputs is referred to as efficiency. Realizing the declining production and productivity of crops and the problems inherent in the different options available to enhance crop production and productivity trends, improving plot level Technical Efficiency of wheat production should be the heart of the food security strategy in Ethiopia. Thus, increasing wheat production and productivity among smallholder producers requires a good knowledge of the current efficiency or inefficiency level inherent in the sector as well as factors responsible for this level of efficiency or inefficiency. Given this background, the current study aimed at estimating the TE levels of bread wheat growers and investigating the various factors contributing to the inefficiencies. It has also scrutinized the effect of seed recycling on the TE and productivity of BWP.

1.2. Concise Literature Review

The purpose of this subheading is to highlight some brief general information that pertains to the key objectives of the study. It provides a brief overview about the status and determinants of bread wheat production, yield effects of plot-level seed rates, the costs and benefits associated with seed recycling, adoption of improved bread wheat seed along with other associated inputs and best agronomic management practices, and economic and technical efficiency of smallholder farmers. This sub-heading is further divided into theoretical, empirical, conceptual, and methodological literature reviews and presented as follows:

1.2.1. Theoretical Literature Review

1.2.1.1. Theories related to adoption

This study has used multiple theories that are closely linked to its objectives, research questions, and the problems it want to bridge. In this study, these theories are used as a framework to get an insight about the factors that shape farmers' behavior and action in adoption of the IBWP, seed recycling practices, seed rate application, and other best agronomic management practices. The researchers' consider multiple theories with strong conviction that theoretical pluralism best contribute to design effective strategies of promoting agricultural innovations adoption. With this realization, the various theories of adoption and the theory of the economic equilibrium of traditional agriculture theories were used. Adoption theories refers to the models and frameworks that are largely applied to explain the potential variables that act as hindering and facilitating factors for adoption, dis-adoption, and non-adoption of agricultural technologies (Wisdom et al., 2014). The most common theoretical frameworks that are relevant to this study are briefly summarized and presented below:

1) **Theory of Diffusion of Innovations**: This is one of the most frequently used theory to explain how an innovation (innovations) spread through a community on a range of time. According to this theory, the adoption of an agricultural innovation is a function of a single or multiple variables that are linked to the innovation itself, the way it is disseminated to the community (channels of communication), characteristics of the community and the social system to which the innovation is diffused, and the time lag between technology generation and adoption (Manzano and Pérez, 2023, Ham, 2020). According to Rogers (2003), there are five stages of adoption, which are not always linear. These stages of adoption includes knowledge, persuasion, decision, implementation, and confirmation.

2) **Economic Theory of Adoption**: This is a theory that advocates for agricultural innovations that bring a substantial economic return to the rural community. It state that farmers' economic rationale dictates their behavior of adoption of agricultural innovations. According to this theory, farmers' go for agricultural innovations adoption only if it increase their profits or reduce their costs. The better adoption of improved crop varieties and agro-chemicals on large, irrigated, and mechanized farms has been explained by the economic theory of adoption (Medoff, 1993, Leathers and Smale, 1991).

3) **Network Theory of Innovations Adoption**: This theory emphasize the importance of cosmopolitanism and the impact of social capital in the adoption and adoption process of agricultural innovations. This theory suggest that farmers' with better social network to other farmers in their own village and/or beyond are more likely to adopt innovations sooner than those who are less connected (Bentivoglio et al., 2021). Social network dynamic based theoretical framework has been suggested to analyze the role of networks and social capital in the adoption of CSA (Climate Smart Agriculture), conservation agriculture, improved crop varieties, and precision agriculture (Adnan et al., 2019, Barnes et al., 2019).

4) **Theory of Planned Behavior (TPB)**: This is also an important theory that asserts adoption of agricultural innovations is shaped by the psychological traits of individual farmers'. According to this theory, the most important predictors of technology adoption are individual's subjective judgment, their aspirations, attitudes, subjective norms, their worldview, and perceived behavioral control (Ajzen, 1991). This theory has been used as a theoretical framework in investigating the adoption of land fertility reclamation strategies, energy efficient technologies, and best agronomic management practices (Dong et al., 2022, Manzano and Pérez, 2023, Wisdom et al., 2014).

5) **Technology Acceptance Model (TAM):** This model is used to get an explanation about how ultimate agricultural technology users (farmers') came on board in accepting and continue in making use of it. According to this theory, the perceived relative advantage of the technology (perceived usefulness) and its perceived simplicity (relative ease to use) are the most key variables that shape farmers' decision to adopt or relinquish a technology (Ali and Soar, 2018). There is also an extension of this model, which is referred as the "***Chocolate Model***" of technology adoption. This model capitalize on the TAM by adding two extra variables that have significant influence on adoption of agricultural innovations. According to this theory, the first additional factor in influencing adoption is related to the suitability of the technology to the local context and/or its adaptability to the specific requirements and needs of the adopters. The second additional factor pertains to the social impact of the change produced because of adopting the technology (Ham, 2020).

6) **Hall's Concerns – Based Adoption Model:** This model tries to explain agricultural technologies adoption, dis-adoption, and non – adoption from the vantage point of the farmers'. It emphasizes the concerns and needs of the farmers that ultimately makes use of the technologies (Ham, 2020).

1.2.1.2. Concise Literature Review on Technical Efficiency

The amount of yield per hectare is one of the simplest ways of measuring the efficiency of a farm. But, this approach overlooks the fact that farm output is influenced by multiple inputs, making it a rather simplistic measurement that only takes into account land as a single input for production. The conventional econometric analysis is another technique, which typically assumes that all producers consistently optimize their production processes. However, there can be incongruences between production quantities and amount of inputs used, even when different Decision – Making Units (DMUs) or producers face identical technological constraints. Such variation arises from differences in productive capabilities and the less favorable utilization of resources by certain DMUs (Farrell, 1957, Gebrie and Mada, 2018, Mesay et al., 2013).

Measuring the production and technical efficiency of an industry is vital to both the economic theorist and economic policy makers. Particularly, for economic planning in a particular sector such as agriculture, it is important to know how far a given sector can be expected to increase its output by simply increasing its efficiency, without absorbing further resources (Farrell, 1957, Gaviglio et al., 2021, Tesfaye et al., 2015). Economic, allocative, and Technical Efficiency (TE) are important parameters to evaluate the performance of production activities (Ahmad et al., 2021, Asfaw et al., 2019). Economic efficiency in agriculture consider costs of the various factors of production and the revenue generated from the production. TE denotes the ability of farmers to produce the maximum output from the combination of a given set of inputs. An agricultural enterprise or individual is technically efficient if it produces the maximum output from the minimum quantity of inputs such as seed, fertilizer, labour, capital, and technology. Wheat is a dominant crop grown in many parts of the world. In order to meet the growing demand for wheat, it is important to improve the technical efficiency of wheat production. In the context of wheat production, TE is the ratio of actual output to potential output, given the level of inputs used. A technically efficient wheat producer is one who is using the best available technology and practices to produce the maximum amount of wheat from a given set of inputs (Baglan et al., 2020, Wanke et al., 2020, Mamo et al., 2018, Vishal et al., 2121).

In a nutshell, if all inputs and outputs are accurately measured, it becomes feasible to estimate various types of efficiencies for a Decision Making Unit (DMU). For instance, according to Farrell (1957), the TE of a DMU employing two factors of production to produce a single output under conditions of constant return to scale conforms to the realities depicted in Figure 1.1 below. This figure assumes the existence of an efficient production function that reveals the maximum output a perfectly efficient DMU can achieve from any given input combination. Moreover, the assumption of constant returns to scale will lead to the construction of an "isoquant" that provide all the pertinent information vital to estimate the various efficiencies of a DMU.

According to Farrell (1957), Point "P" in Figure 1.1, denotes the observed inputs of the two factors that the DMU employ per unit of output. The isoquant SS' illustrates the various combinations of inputs employed by a perfectly efficient DMU to produce one unit of output. Point Q symbolizes an efficient DMU that employs the two factors in the same ratio as point P. It implies that a DMU at point Q generates the same output as P but utilizes a fraction of OQ/OP of each factor. Alternatively, one can consider that it produces OP/OQ times more output from the same inputs. Therefore, the technical efficiency (TE) of firm "P" can be defined as the ratio of OQ to OP (OQ/OP), which serves as a measure of efficiency with desirable properties. A perfectly efficient firm will have a value of unity (100%), which diminishes as the amount of inputs used per unit of output increases indefinitely. Additionally, all other factors being constant, if the slope of the inputs combination (SS') is negative, an increase in input per unit of output for a single factor indicates inefficiency (lower TE).

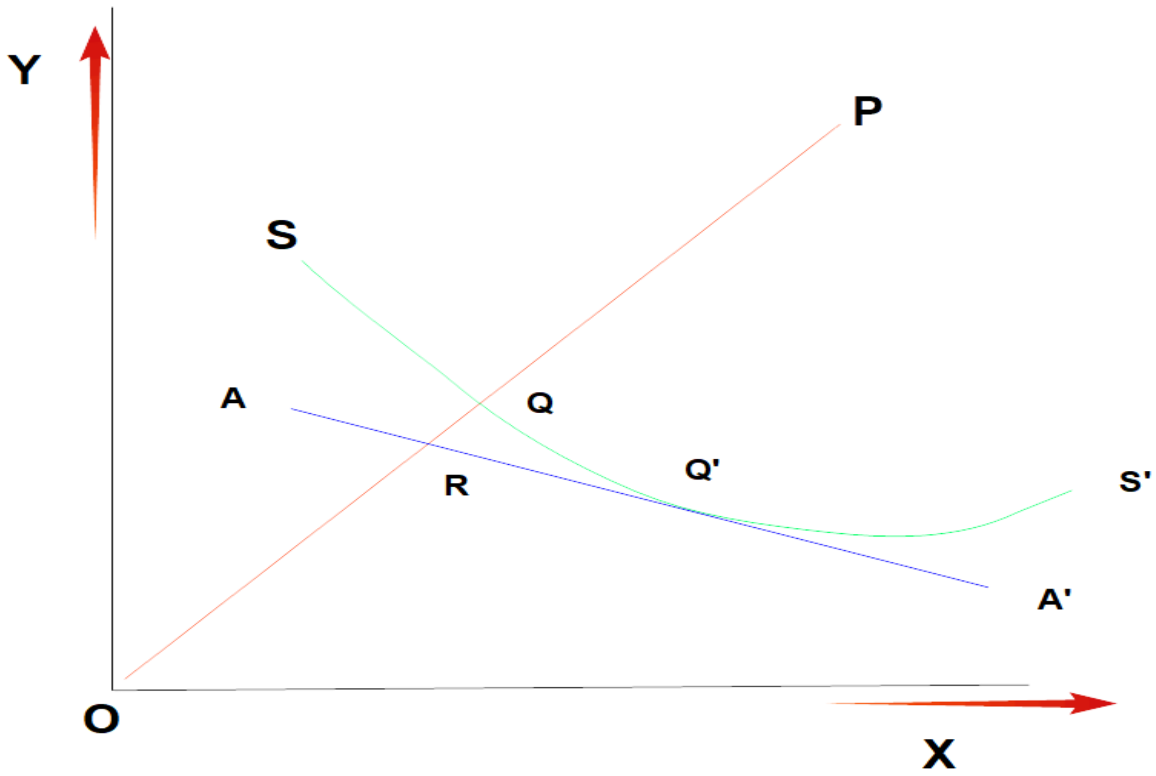

Figure 1: Simple Efficiency Measures
Source: (Farrell, 1957)

On the other hand, when assessing efficiency, it is important to consider how effectively a firm utilizes its mix of production factors in relation to their prices. The diagram presented in Figure q below illustrates that if the slope of AA' is equal to the ratio of input prices, the optimal production method is represented by Q' rather than Q. While both Q' and Q indicate 100 percent technical efficiency (TE), the production cost at Q' is only a fraction of OR/OQ compared to Q. What is more, if the DMU adjusts its input proportions to match those represented by Q' while maintaining constant TE, its costs would decrease by a factor of OR/OQ, assuming prices remain unchanged. This ratio can also be used to measure the price efficiency of the observed firm P. Although this argument is not definitive because the impact on TE when changing input proportions is uncertain, it is currently the best available measure. Additionally, this ratio ensures that DMUs using factors in the same proportions receive the same price efficiency (Coelli et al., 1998, Farrell, 1957, Zoundji et al., 2023).

A variety of techniques is used to estimate the TE of DMUs. The conventional least square based regression techniques has been used in earlier times. These techniques attribute all deviations from the optimum level of efficiency solely to random stochastic noise that calls for the need to shift away from the traditional functions towards the frontiers (Kumbhakar and Lovell, 2003). Thus, production frontier characterizes the minimum input bundles required to produce a given level of output or the maximum possible level of production of output from a given level of inputs, commonly called technical efficiency. Even though there is some similarity between terms production efficiency and technical efficiency, however, they are not same. The simplest way to differentiate production and technical efficiency is to think of productive efficiency in terms of cost minimization by adjusting the mix of inputs, whereas TE is output maximization from a given mix of inputs (Coelli et al., 2005; Kumbhakar and Lovell, 2003). In general, using frontier models offer a more accurate understanding of technology and allows for benchmarking and evaluating the efficiency of firms within an industry. These same authors argued that fitting a frontier model rather than the OLS offer the following advantages:

i. Estimation of an average function will provide a picture on the shape of technology of an average firm, while the estimation of the frontier function will be most heavily influenced by the best performing firm and hence reflect the technology they are using.
ii. The frontier function represents a best practice technology that serves as a benchmark for measuring the efficiency of firms within the industry. This application of frontiers has led to their widespread use in estimating frontier functions.

Several studies have investigated the technical efficiency of wheat production and have found that it varies significantly across countries and regions. Most of these findings reported that TE is generally lower in developing countries than in developed countries (Teferi et al., 2020, Wanke et al., 2020, Mamo et al., 2018). Improving the TE of BWP in the context of Ethiopia is vital for several reasons. First, it is produced in almost all crop-growing regions of the country and improvement in its production efficiency will have a nation-wide impact. Second, it can lead to higher yields, which assist the fight against food insecurity. Third, it encourages wheat import substitution. Fourth, improving TE can reduce the costs of production, which can make bread wheat more affordable for consumers. Fifth, it leads to an increase in farmers' income, which can help to reduce poverty (Dorosh and Mellor, 2013, Habtewold, 2021, Mamo et al., 2018). There is high need for research to enjoy the multiple benefits of enhancing farmers' TE and to design the most effective interventions of improving wheat productivity and TE. The research should focus on identifying the sources of technical inefficiency in different contexts and across different temporal arrangements so that to develop and test interventions that are effective in improving TE.

1.2.2. Empirical Literature Review

1.2.2.1. Status and Determinants of Bread Wheat Production

Ethiopia's overall development strategy choice since 1992 has been on agriculture. As a result, Agricultural Development - Led Industrialization (ADLI) has become the foundation for the national economic policy of the country. Despite the policy emphasis on the agricultural sector, the country has witnessed a relative stagnation on cereals yield induced by external inputs use. It is undeniable that there has been a mild increase in cereals production of few crops like maize and wheat in some regions of the country up until early 2000s attributable to expansion of production land (Anbes, 2020, Dorosh and Mellor, 2013, Gashaw et al., 2018, Rada and Fuglie, 2019). Studies have provided several explanation for the dissatisfactory improvement in wheat and other cereals yield. For instance, according to Dorosh and Mellor (2013) cereals are widely grown in the Ethiopian highlands where there is relative land shortage that has thwarted the amount of production. Drought, insufficient input supply, growing inputs price unparalleled to the purchasing power of the rural poor, weak seed sector, technical inefficiency, unwise farming practices, weak linkage between research, extension, and farmers were found to hamper the production of bread wheat and other cereals in Ethiopia (Anbes, 2020, Assefa et al., 2014, Clayton et al., 2009, Debebe et al., 2015, Gashaw et al., 2018, Kassa and Alemu, 2016).

Ample empirical findings have identified several producers' related variables that have restricted wheat and other cereals production. For instance, gender and being female-headed household, farm experience, age, plot size, family size, fragmented parcels, high dependency ratio, small livestock ownership, poverty, illiteracy, poor land management practices, annual income, and lack of alternative livelihood sources were found to significantly reduce wheat production (Chinado and Jang, 2018, Demissie et al., 2015, Gebre et al., 2018, Marenya and Barrett, 2007, Omer, 2015, Pailler et al., 2015). Market failure for agricultural commodities is one of the most frequently mentioned factors affecting bread wheat and other cereals production. High transaction costs and information asymmetry in agricultural commodities marketing acts as a disincentive in wheat production. The highest cost for transport and marketing both for domestic and international markets makes both cereals production and trading unprofitable enterprise. However, there are certain exceptions in terms of wheat import for some years (Anteneh and Asrate, 2020, Dorosh and Mellor, 2013). Ethiopia has been importing different agricultural commodities. As indicated in Annex Graph 4, wheat is the highest imported commodity both in terms of amount (tons per year) and capital investment in the past ten years (https://intracen.org/resources/data-and-analysis/trade-statistics).

Multiple authors also found several institutional factors contributing to lowest bread wheat production. Lack of access to agricultural credit and micro-insurance services, supply driven agricultural extension advisory service and research systems, insufficient price support, and exploitative agricultural commodities value chain that operates against farmers have significantly restricted bread wheat and other cereals production (Assefa et al., 2014). Rural Saving and Credit Cooperatives (RuSACCOs) have played a pivotal role in enhancing wheat production as members enjoy timely and affordable agricultural inputs. RuSACCOs have also assisted member farmers' to enjoy better market prices for their products (Benti, 2019). However, RuSACCOs in Ethiopia provide limited products and services for their members. The amount of credit from RuSACCOs in Ethiopia is insufficient to meet farmers' capital requirement for agricultural production (Altaye and Mohammed, 2013).

1.2.2.2. Determinants of Technical Efficiency in Wheat Production

The World's most important staple food crop is wheat. The demand for wheat has grown tremendously due to the rising population and expanding wheat processing industries. Despite the growing demand for wheat, wheat producers' TE has remained very low in developing countries (Abate et al., 2018, Abid et al., 2019, Mburu et al., 2014). The sources of technical inefficiency vary on temporal and spatial basis. For instance, poor quality input utilization is one of the most frequently mentioned factor responsible for the lowest TE in the SSA countries. Farmers' who make use of high quality external inputs such as drought and disease resistance varieties and agro-chemicals, were reported to be highly technically efficient than those who rely on local and low – quality inputs (Gaviglio et al., 2021, Ayele, 2016). Other studies found that the level of technology utilization has a noticeably high impact on farmers' TE. The use of modern agricultural innovations and best agronomic management practices has enhanced farmers' TE in various crops production. For instance, farmers who use modern technologies such as irrigation and mechanization found to be better in their TE than those who rely on rainfall and traditional ways of doing agriculture (Habtewold, 2021, Mohammad, et al., 2012).

Institutional factors such as access to credit and other agricultural inputs, information, input subsidy, technical support and guidance, and access to micro-insurance services have assisted farmers' to improve their production and technical efficiency. For instance, access to credit and other resources bestow farmers' with better incentives of investing in high quality inputs and technologies, which in turn has led to higher TE (Anteneh and Asrate, 2020; Martey, et al., 2015; Abate, et al., 2014) . Besides, availability of other institutional set-ups such as the availability of agricultural extension advisory service along with its quality and frequency of contact has a vital role in enhancing farmers' production and TE. The suitability of the methods used by the extension workers together with their skill, knowledge, and attitude have significantly contributed to the betterment of farmers TE (Assefa et al., 2014, Kassa and Alemu, 2016). Land tenure security had an important implication on farmers' level of TE. Farmers' who do not have tenure security rarely have the incentive to invest in soil reclamation and soil fertility management activities. This has contributed to land degradation and soil erosion that in turn has reduced crop production and farmers' TE (Assefa and Hans-Rudolf, 2016, Gashaw et al., 2018).

There are also ample empirical evidences the have identified the socio-personal, economic, behavioral variables that determine the TE of different agricultural commodities. For instance, farmers' risk aversion behavior had restricted early adoption of multiple agricultural technologies. As a result, farmers' were unable to enjoy the fruits of improved technologies as early as possible. This has kept farmers' level of TE at its lowest level and has delayed the time required to improve agricultural productivity and escape from poverty (Barnes et al., 2019, Kalsa, 2019). Farmers' knowledge, skill, and attitude also have an impact on their production and TE. Farmers who have the skills and knowledge to use inputs efficiently had better TE than those who do not. Education had a significantly negative impact on the TE of bread wheat growing farmers (Fatima and Khan, 2015). The mean TE of wheat producing farmers vary across regions. For instance, wheat producers TE at Debre Libanos and Soro districts was reported to 78.5% and 72%, respectively (Ayele, 2016, Hunde and Abera, 2019). Other authors found the effect of experience in specific agricultural commodity on farmers' TE. Farm inefficiency has reportedly declined as the years of experience increase. Plot size, plot fragmentation, distance between plots, number of family members, dependency ratio, number of oxen, proximity to urban centers, participation in government welfare program, participation in off-farm and non-farm activities, and gender of the household head were reported to have a notably substantial impact on the TE score of farmers (Gebrie and Mada, 2018, Hunde and Abera, 2019, Baglan et al., 2020).

1.3. Conceptual Framework

Based on findings from multiple sources, discussions with agronomic experts and development agents, and the experience of the authors the current study considers bread wheat production as a function of different factors. This study assumes that both production and technical efficiency of bread wheat is contingent upon the adoption intensity of the multiple components of the improved bread wheat package and its determinants as depicted in Figure 2 below. Ample empirical evidences revealed that the adoption intensity of improved crop varieties is a function of several factors. The socio-economic variables of the farm households including land size and tenure security, availability of sufficient family labor, number of animals owned, access to diversified income sources, agricultural experience, educational status of the household head, etc were found to have a marked effect on adoption intensity of agricultural crop varieties (Atinafu et al., 2022, Siyum et al., 2021, Zecevic et al., 2014). Besides, adoption intensity in bread wheat package entails the use of improved seeds along with the associated best agronomic management practices. Among others, seed rate, tilling frequency, weeding frequency, sowing methods, fertilizer rates, and sowing time are agronomic recommendations that affect bread wheat production and technical efficiency (Walker and Alwang, 2015, Zecevic et al., 2014, Wassie, 2014, Yohannis et al., 2020).

Adoption intensity is also affected by institutional variables like input price subsidy, agricultural perils insurance, market infrastructure and value chain, access to affordable financial sources, participation in multipurpose cooperatives, access to research and extension services, social network, and pro-poor policies, and strategies (Shikur, 2022, Wang et al., 2015, Alston and Pardey, 2017). It is also a function of technological attributes such as technical complexity, affordability, complexity, and testability. Adoption of an improved variety is cost effective only when it is compatibly used with other inputs such as fertilizers, pesticides, and machinery. Adoption intensity was found higher for improved crop varieties that assist farmers to synergize with complementary inputs, optimizing resource use and minimizing production costs, can foster higher adoption intensity (Fisher et al., 2015). Behavioral factors such as farmers’ attitude towards technologies, risk aversion behavior, and perception towards technologies also affect the adoption intensity of improved crop varieties (Ham, 2020, Kalsa, 2019).

This study aimed at investigating the impact of the adoption intensity of improved bread wheat production package on farmers’ production and technical efficiency. It is also hypothesized that variations in wheat productivity among farmers’ is explained by differences in their technical efficiency. Bad agronomic practices such as seed recycling are expected to harm farmers’ level of productivity and technical efficiency. The following conceptual framework is prepared to highlight the key concepts, variables, and relationships considered under this study.

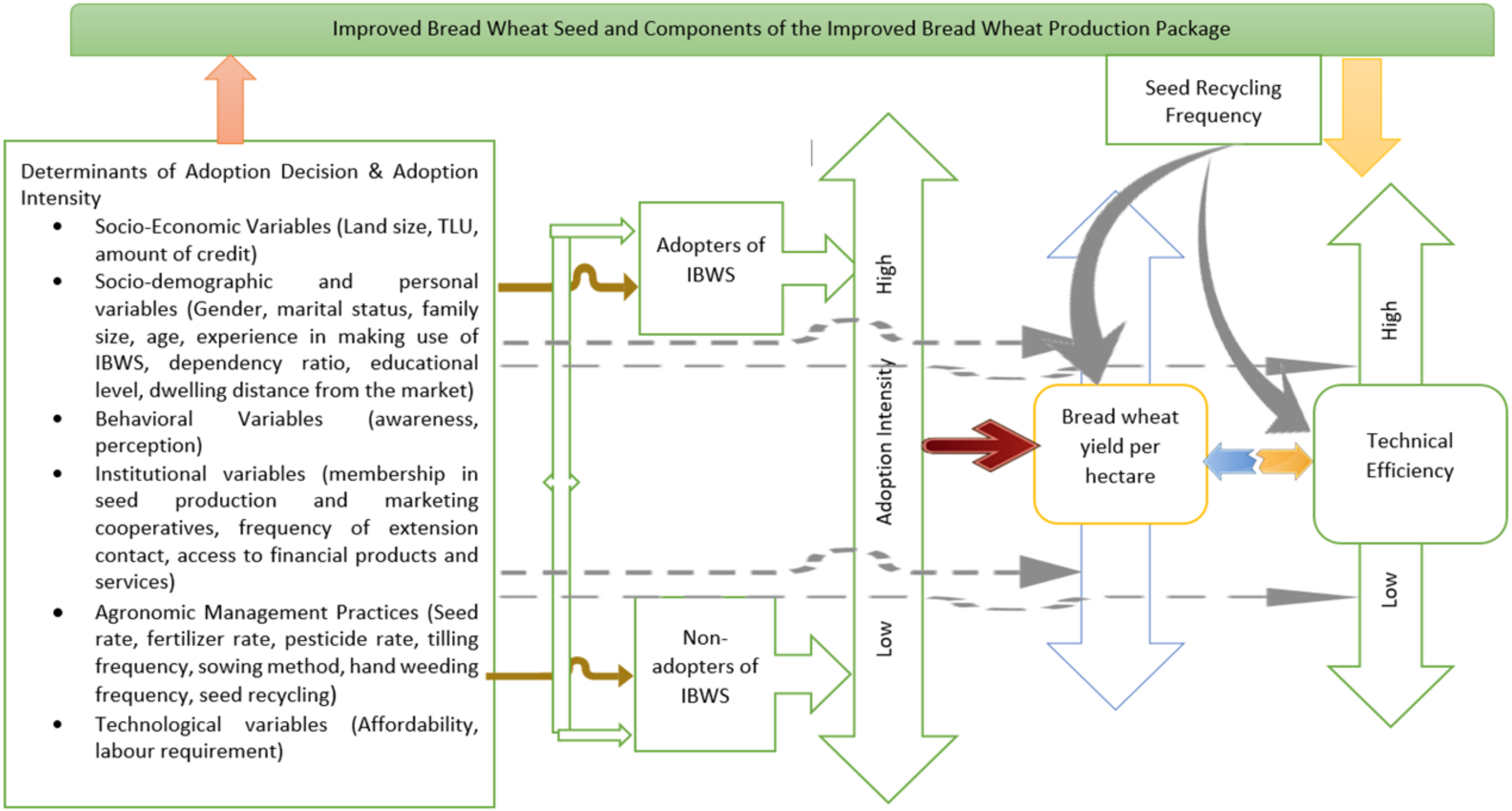

Figure 2: Overall Conceptual Framework of the study

1.4. Statement of the Problem

The sheer application of improved seeds of any crop varieties without a parallel use of complementary inputs, proven scientific recommendations, and agronomic management practices do not contribute to a desired yield outcome (Clayton et al., 2009, Etwire et al., 2016, Lollato et al., 2019). Farmers in the LDCs rarely stick to recommendations and technologies released from research centers and widely available in the market. This is mainly due to factors attributable to the recommendations (technologies) and characteristics of the farming community. For instance, complexity of the technologies, supply shortages, blanket recommendations, weak technical support, and unaffordable prices pushed farmers to reject and/or abandon the application of scientific recommendations. Lack of awareness about the recommendations, risk aversion behavior of the farmers, poor purchasing power, and lack of access to alternative income and livelihood sources have significantly curtailed the wider application of recommended seed and fertilizer rates (Abboye and Teto, 2020, Alemu and Abera, 2013, Atilaw et al., 2016, Chandio et al., 2019, Kalsa, 2019, Lema and Degebassa, 2013, Mehring, 2016, Shikur, 2022, Tigabu and Asfaw, 2016).

Despite recommendations made by the scientific community, plot level seed rate application is a decision left to farmers. Thus, there is dissimilarity in terms of seed rates applied by farmers in different locations and contexts. Hence, there is no sufficient information about the yield effects of location and context specific seed rates application. As a result, farmers do not have a clue if they could increase their productivity by applying seed rates different from their current seed rates application. The first chapter of this study aimed to bridge this research gap. In addition to their rates, wheat seeds can boost productivity if they are used afresh or optimally recycled based on their expected utility. Nonetheless, 90% of farmers' in Ethiopia reportedly rely on own saved seeds that has been recycled for several previous production seasons. Recycled and/or own saved seeds are cheaper and easily accessible than fresh and improved seeds. Heavy reliance on recycled seeds was largely explained by farmers' motive to maximize benefits through cutting seed cost expenditure (Bishaw et al., 2012, Mango et al., 2020, Akinyi et al., 2022). However, the perceived economic gains due to the use of recycled seeds or the economic loss due to making use of fresh and IBWS has remained beyond the horizon of empirical investigation. As a result, farmers keep on relying on recycled seeds without having a clear picture of the costs and benefits of seed recycling. The first chapter of this study is aimed at bridging this gap by conducting the CBA of recycled and fresh bread wheat seeds.

Rain-fed, subsistence, and traditional agriculture dominates the national economy of Ethiopia. Yet, it is a major livelihood source for more than 83% of the population (Dorosh and Mellor, 2013). Cereals are the leading grain types in the crop production sector of Ethiopia. Among the cereals, the GoE has targeted wheat as major strategic food security crop. Wheat has been an important economic and livelihood crop for the wider sections of the general populace in all regions of the country (Alemu and Bishaw, 2015, Kebede et al., 2017, Teshome and Abate, 2013). Despite favorable situations for bread wheat production, its productivity in Ethiopia in general and the study area in particular is markedly lower than what has been achieved from several scientific experiments and woefully insufficient to feed the growing population. As a result, the country has remained one of a net wheat importer (USDA, 2021). These facts imply how important bread wheat is to the economy and the food security situations of the community.

Earlier studies revealed that the dissatisfactory adoption of IBWSs is a major reason for the lowest level of productivity (Atilaw et al., 2016, Bekele et al., 2014, Chandio and Jiang, 2018, Demissie et al., 2015, Kebede et al., 2017). However, these previous studies have not looked into the adoption intensity of the IBWP in its entirety by including the various important components included as a package. Besides, earlier studies have used the proportion of land covered by improved wheat seed in relation to the total wheat cropland owned by a farmer as a proxy indicator for adoption intensity (Abeyo et al., 2020, Abid and Abdul, 2014, Atilaw et al., 2016, Bekele et al., 2014, Chandio and Jiang, 2018, Dessale, 2019, Omer, 2015, Shikur, 2022, Tavva et al., 2017). This is likely to obscure important findings required about the adoption of a mix of inputs, scientific recommendations, and best agronomic practices of the wheat production package and the factors affecting their adoption. As a result, recommendations, policy briefs, and insights that pertains to the multiple components of the package were excluded. For instance, smallholder farmers likely to allocate only small parcel of their land at the trial stage of any improved variety before using it on larger scale. Thus, it is erroneous to consider plot size covered by a technology as an indicator for an adoption intensity (Baglan et al., 2020). Therefore, the major objective of the third chapter of this study is to investigate the major determinants of adoption intensity of IBWS and the associated agronomic practices including seed rates, fertilizer application, row spacing, seed recycling, agro-chemical use, sowing method, and tilling frequencies.

Moreover, smallholder farmers in the SSA and Ethiopia are suffering from worsening poverty, insufficient agricultural inputs supply, price expensiveness, high transaction costs, poor access to credit and other institutional support. These problems have contributed to farmers' inability to improve their productivity through more agricultural investment and additions of extra inputs use. As a result, the production of cereals in general and bread wheat in particular failed to be commensurate to the growing population and declining resources (Mango et al., 2015, Oluwatayo and Ojo, 2016, Rada and Fuglie, 2019, Sultan and Ahmed, 2014, Tavva et al., 2017). The majority of smallholder farmers' in Ethiopia are below the poverty line or closer to it. Thus, they can't afford to purchase new inputs and superior technologies that augments their production, even when the technologies are cheap. It is therefore quintessential to design a strategy through which these smallholder farmers can raise their productivity without incurring additional costs and inputs. This situation essentially calls for improvement in smallholder farmers TE or reduction in levels of technical inefficiency by investigating the optimum inputs combination for bread wheat production. Enhancing farmers TE usually end-up in a double blessing. First, it increases the gains from technology adoption. Second, it raises the yield response of existing (local) inputs. Especially in a situation where the capacities of generating and disseminating locally-adapted modern technologies is limited, attempting to attain the maximum possible output with the existing local inputs (increasing efficiency) can have substantial contribution to the growth of agricultural outputs (Tavva et al., 2017, Alemu and Abera, 2013, Abate et al., 2014).

The factors affecting farmers' technical inefficiency are quite heterogeneous. This calls the need to identify and analyze location, context, and crop specific sources of technical inefficiency. The fourth chapter of this study aimed at addressing this need. Besides, the current study has assumed that heavy reliance on seeds recycled multiple times could fully offset the benefits that could be obtained from highly superior crop varieties and improved seeds (Akinyi et al., 2022, Ali and Jan, 2017, Atilaw et al., 2016, Okusaa, 2017). Yet, there is paucity of empirical evidences about the nexus between bread wheat seed recycling and its effect on farmers' TE and productivity. This study therefore aimed at investigating these determinants of the TE of bread wheat production with especial emphasis on the nexus between seed recycling, productivity, and TE.

1.5. Objectives of the study

With the background and statement of the problem discussed above, the dissertation has the following general and specific objectives.

1.5.1. General Objective

Broadly, this study aimed at investigating the impacts of the adoption intensity of IBWP and seed recycling practices on smallholder farmers' bread wheat productivity and TE in the East Gojam zone, Ethiopia.

1.5.2. Specific Objectives

The following are the list of specific objectives of the study:

1. To investigate the yield effects of plot-level seed rates in the East Gojam zone, Ethiopia.
2. To conduct the Cost – Benefit Analysis (CBA) of seed recycling in the East Gojam zone, Ethiopia
3. To analyze the determinants of the adoption intensity of IBWP in the East Gojam, Ethiopia and its contribution in productivity.
4. To estimate smallholder bread wheat producers level of TE
5. To investigate the sources of technical inefficiency among smallholder bread wheat producers in the study areas
6. To assess the impacts of seed recycling on the TE of smallholder bread wheat producers' in the study areas.

1.6. Research Questions

Given the objectives presented in sub-section 1.5, this study is conducted to answer the following major research questions:

1) What is the yield impacts of plot – level bread wheat seeds rate application in the study area?
2) How seed recycling affects the costs and benefits of smallholder bread wheat producers' in the study area?

3) What are the major determinants of the adoption intensity of IBWP in the study area?
4) Do varying levels of adoption intensity has an effect on bread wheat productivity of smallholder farmers' in the study area?
5) What is the level of smallholder bread wheat producers' technical inefficiency in the study area?
6) What are the sources of smallholder bread wheat producers' technical inefficiency in the study area?
7) Does bread wheat seed recycling practice has an impact on smallholder farmers' TE and productivity?

1.7. Significance of the Study

The measurement of TE in BWP is vital, as it gives a practical evidence to make wise decision in the use of scarce resources, revise recommendations contributing to inefficiencies, and reformulate crop production policies. Besides, there is dynamism is rural and social development that there is a need to update the already available data and information based on the current efficiency and productivity of smallholder farmers. Moreover, measuring smallholder farmer's inefficiency along with identification of sources of their inefficiency has a paramount significance in Ethiopia in general and the study place in particular. This due to the fact that enhancing bread wheat productivity through addition of extra resources and/or innovation and dissemination of new yield enhancing technologies are not feasible and require long – term investment while we have an urgent demand for production improvement. Thus, the efficiency measurement of the different improved bread wheat production practices may be significant in indicating the possibility of increasing bread wheat production without committing extra resources and inputs or reducing the existing level of input use and hence maximize the bread wheat output by minimizing costs of production. Identification of the relatively best efficient farmers along with the factors contributing to higher level of efficiency also have important implications for development workers and extension advisory service providers. The extension service providers can use the identified efficient farmers as model farmers from whom others can take lessons and improve their productivity. This F2F (Farmer – to – Farmer) extension service can have multiple benefits. First, farmers trust their neighbor farmers than outsiders. Thus, the extension service can best relay bread wheat production recommendations through farmers. This may also help the extension workers to reach as many farmers as possible by reducing its frequency of visit. In addition, the finding from the existing technical efficiency analysis of bread wheat production can be duplicated for other commodities (crops) with similar production process and agronomic practices recommendation.

Analysis of the yield impacts of the existing location specific seed rate application would have a tantamount importance to smallholder farmers of the study area. The finding of such analysis will assist smallholder farmers to boost their production by modifying their current seed rate application. It could also help them to reduce seed costs by lowering the amount of seed rate they apply per hectare. Similarly, results of the cost – benefit analysis of using fresh and recycled seeds will assist farmers to make two key decisions; i). Whether they canreduce their seed cost through seed recycling ii). Whether their yields can be improved by using fresh or unrecycled IBWS as compared to recycled seeds. The authors also believe that the findings from the existing study can serve as source of information for future studies and can be an addition to the insufficient literature about the nexus between technical efficiency and agronomic practices pertinent to bread wheat production. What is more, the study has analyzed the potential constraints to the adoption intensity of IBWP. The researchers strongly believe that these findings on the potential hindrances to IBWP adoption intensity may assist applied researchers to adapt the components of the IBWP to the local farmers' context (reinvention).

1.8. Scope and Limitation of the Study

While there are 11 zones in the Amhara National Regional State (ANRS), this study has covered only two districts of the East Gojam zone. Besides, farmers of the study area continue to grow multiple crops in two major production seasons ("*Meher*" and "*Belg*"). However, the scope of the current study is limited only to bread wheat production during the main production season in 2021 ("*Meher*"). Moreover, smallholder farmers' cultivate bread wheat using different varieties. Yet, this study revolves around a major bread wheat variety commonly grown in the study area. Thus, the scope of this study is limited in terms of location, production season, commodity (crop) type, and specific bread wheat variety. The scope of this study is limited to one agricultural commodity (bread wheat). Yet, the researchers' are aware that smallholder farmers' may face difficulties to make simultaneous adoption of multiple commodities and technologies (for instance, mixed crop and livestock technologies, multiple crops or multiple livestock technologies). This is largely due to their inability to afford the costs associated with multiple technologies and the need to avoid risks of severe penalty that may arise from multiple technology failures. As a result, farmers’ sequentially adopt different commodities or make simultaneous adoption of multiple technologies in fewer proportion, both of which have a compound effect on smallholder profitability, productivity, livelihood, and food security (Akinyi et al., 2022, Assefa et al., 2014, Kolapo et al., 2022).

Furthermore, the analysis was carried out based on a cross – sectional data. The use of cross - sectional data collected at one point in time in AI and TE analysis may not show the dynamics on temporal basis to craft a long – term agricultural development strategy. In addition, adoption of improved bread wheat practices and the level and sources of inefficiency among smallholder farmers may be influenced by the input supply and the specific climatic situation of the particular year considered for the study. As a result, productivity and efficiency differences may be attributed to environmental and other stochastic variables that are not hypothesized under this study. Besides, the TE analysis of this study was made using the SFA (Stochastic Frontier Analysis) method. According to Coelli et al. (1998) the efficiency scores of the frontier method are only relative to the best farm in the sample that inclusion of more efficient or inefficient farm may inflate or reduce the efficiency scores. Therefore, as the efficiency score under the current study are relative values compared with the best farmers in the study area, comparison with other smallholder farmers in other locations of the country and the region may paint a misleading picture. In addition, this study has dealt with the cost and technical efficiency of selected improved bread wheat production practices such as seed rate and seed recycling frequency at the expense of the allocative efficiency due to time, personnel, and budget constraints.

1.9. Research Methodology

This section briefly describes the research paradigm along with the ontological and epistemological foundations of the study, the research approach, research design, sampling design, and data collection methods.

1.9.1. Research Paradigm

1.9.1.1. Alternative Research Paradigms

The choice of a research paradigm is a key component of any research work as it bestow a philosophical framework that guides the research process and the methodology. A research paradigm refers to a philosophical framework. It includes a set of beliefs, understandings, and assumptions that assist researchers in shaping their approach. The choice of the research paradigm influences not only the choice of a superior approach but also the research question, the way data is collected, analyzed, and results are interpreted (Ugwu et al., 2021, Rehman and Alharthi, 2016). There are four common research paradigms. The first one is referred as the "positivism" paradigm. The positivist research paradigm basis itself on a strong belief that knowledge can be obtained through objective observation and measurement. "Interpretivism" is the second paradigm and has a diametrically opposite belief to positivism. It has a strong assertion that reality cannot be objectively obtained and emphasize the importance of people subjective judgements, experiences, and meanings. Interpretists view that reality is socially constructed, subjective, and may change multiple times. Positivists incline to adopt a pure quantitative approach while interpretists tend to stick to qualitative approach (Hussain et al., 2013, Rahi, 2017). Realism is the third research paradigm that posits the existence of an objective reality independent of human perception, but is interpreted through social conditioning (critical realist). Pragmatism is the fourth research paradigm that assumes reality as dynamic that changes on temporal, spatial, and other context basis. It rejects the notion of a fixed and universal reality and emphasizes the importance of context, experience, and action in shaping researchers understanding of reality (Al-Ababneh, 2020, Haack, 2011, Misak, 2019).

This study opt for a mixed research approach that blends both qualitative and quantitative methods. Due to their exclusive reliance on a single approach (either qualitative or quantitative), both of the research paradigms explained above are not a good fit in this study. The assertion in this study is that the reality to be investigated should be approached in different ways rather to get a clearer and broader understanding of the phenomena being investigated. This calls the need for a research paradigm that bridges the gap between positivism and interpretivism. This need leads to go for a pragmatism research paradigm. The pragmatic research paradigm is an approach that involve operational decisions based on what will work best to get answers and explanations for the research questions. It suggests that there is no a single way of interpreting the world and investigating reality. Pragmatism focuses on method pluralism and practicality in addressing real-world problems and generate socially, economically, and environmentally useful knowledge and insight (Kaushik and Walsh, 2019, Morgan, 2014). Therefore, pragmatism is the philosophical research paradigm of the current study. The ontological, epistemological, and axiological foundations of the different research philosophical paradigms are summarized and presented in the sub-heading below.

1.9.1.2. Ontological and Epistemological Foundations

Ontology and epistemology are two fundamental philosophical concepts that have significant implications in research, as they shape the researchers understanding of the nature of reality and the methods by which reality (knowledge) is obtained and justified. Ontology and epistemology act as guiding frameworks of research inquiries by assisting researchers delve into the nature of reality and the acquisition of knowledge (Al-Ababneh, 2020, Wills and Lake, 2020). Furthermore, the choice of research methodology in social science is contingent upon the nature of reality and what exists in the world (ontology) and the nature of knowledge (epistemology) that pertains to how knowledge is acquired, validated, and justified. In general, ontology asks questions about the fundamental nature of existence, being, and the categories of entities that exist. Researchers understanding and conceptualization of the phenomena they study is guided by their ontological assumptions. Epistemology help researchers to explore questions about the sources, limits, and methods of knowledge generation. Axiology on the other hand explains the role of values in the research (Hothersall, 2016, Hussain et al., 2013).

Based on the characteristics of the various research paradigms borrowed from multiple sources and discussed above along with additional comparison of the research philosophies are summarized and presented in Appendix Table A12. We found that the ontological, epistemological, and axiological foundations of the pragmatist philosophy best suits to the objectives and research questions of this study. The pragmatic philosophy is chosen due to its ontological foundation that states there is no single reality where the views of both the study respondents and the researchers' best enable answering of the research questions. Its epistemological foundation that focuses on practical applied research that integrates different perspectives in interpretation of observable data and subjective meanings led to the choice of the pragmatic paradigm. Its stance in method pluralism (qualitative and quantitative) as witnessed in this study also favors the adoption of the pragmatic paradigm.

1.9.2. Research Approach and Design

The research questions and objectives of this study are primarily related to the identification of the underlying causes of certain conditions such as seed rate, seed recycling, and adoption of IBWP along with bread wheat producers' subjective judgment of seed recycling and other agronomic practices. This calls the need to employ a mixed methods approach. We have therefore used a convergent parallel mixed methods approach. According to Tashakkori and Teddlie (2022), the convergent parallel mixed methods approach allow researchers to collect both qualitative and quantitative data simultaneously, analyze them separately, and then compare the results to see areas of convergence or divergence. In terms of design, this study has used a quasi-experimental research design that allows the manipulation of one variable (explanatory variables) and measuring its effect on another variable (dependent variable). This design was chosen as it enable us to make comparative analysis between different categories of the study (Recycled and fresh seed users, and adopters and non – adopters) without random assignment of individuals to groups.

1.9.3. Sampling Design

This study has employed a blend of multi-stage probability and non-probability sampling designs in the selection of sample study areas and individual household head respondents. The unit of analysis is the head of the household head. The details of the sampling design together with sample size determination formula, sampling methods, and sampling procedure are provided in the fourth article (section 3.4).

1.9.4. Summary of Data Collection Methods

This section briefly outlines the data types, data sources, operational definition of the variables, and data collection methods employed in this study.

1.9.4.1. Data Types, Data Sources and Data Collection Methods

This study relies on cross-sectionally collected qualitative and quantitative types of data. Sample respondents, Kebele administrators, DAs, agricultural officers and experts at different levels were considered as primary data sources. Secondary data sources such as published and unpublished articles, government and NGO reports, statistical abstracts, training manuals for improved crop varieties production, policies and strategies were also consulted. Structured interview schedule was employed to gather data from sample household head of the study. The structured interview schedule includes the socio-demographic, personal, economical, institutional, and agronomic management practices related to questions. It was standardized, translated, and pre-tested in the nearby villages closer to the study areas before commencing the actual data collection. Semi-structured checklist was used for KIIs and FGDs. Checklist based in-depth interviews and observations were also employed to collect data from model farmers. The three articles have their own dependent and explanatory variables, which are summarized and presented in the sub-heading below.

1.9.4.1.1. Definition, Operationalization, and Hypotheses of the Study

This sub-section briefly summarizes the definition, operationalization, and hypothesis of the study. It outline the major dependent and explanatory variables considered under the three articles, which are presented in the coming two headings.

Summary of Variables and Hypothesis of the study

The Dose – Response model that considers seed rate as a dose (treatment) and productivity ($\mathrm{Qt\ ha^{-1}}$) as a response (dependent variable) of the first article. Hence, the first dependent variable of the first article was bread wheat productivity. It was measured in terms of the amount of bread wheat yield in quintals per hectare ($\mathrm{Qt\ ha^{-1}}$). Similar definition was adopted in multiple studies (Anbes, 2020, Bekele et al., 2014, Clayton et al., 2009, Fatima and Khan, 2015, Reed et al., 2021, Wondimu et al., 2015). Seed rate was the only explanatory variable in the dose – response function and it refers to the total amount of bread wheat seed applied by respondent households' per hectare ($\mathrm{kg\ ha^{-1}}$) for bread wheat production. It is measured in terms of kilograms. Agronomic trials and empirical evidences have shown that higher seed rates beyond what is recommended reduces crop productivity due to competition between plants for minerals, sun - light, and water (Sisay et al., 2017, Tigabu and Asfaw, 2016, Zecevic et al., 2014). Given these agronomic trials and empirical evidences, this study hypothesize a significant negative relationship between bread wheat seed rate and productivity.

The second dependent variable of the first article was the net income obtained as a result of making use of fresh and recycled seeds. Costs and benefits comparison of fresh and recycled bread wheat seeds was done using the prevailing market price for inputs during the 2020/2021 specific production season and for production (bread wheat output) during wheat harvest time. The entire costs and benefits associated with Bread Wheat Production (BWP) were calculated in terms of Ethiopian Birr per hectare (ETB ha^{-1}). Fresh bread wheat seed in this study is defined as seeds that has never been used before for production and/or has been used less than five times (recycled less than five times) for production. This definition was adopted from the recommendations of the ATA and research findings (Abeyo et al., 2020, ATA, 2015). According to these authors, in Ethiopia, making use of freshly purchased improved seeds and improved seeds recycled for a maximum of five seasons are considered as improved seed use. It was hypothesized that multiple seed recycling more than the recommendation significantly decrease the profitability (net income) associated with BWP.

The second article has two important outcome variables. The first dependent variable is the adoption of Improved Bread Wheat Seed (IBWS) that assumes a simple yes or no (adopter or non-adopter) answer, which is a classic dichotomous variable. The second dependent variable is the Adoption Intensity of the IBWP, measured using adoption index scores. The adoption index for each respondent is calculated using equation 1 below following the formula by Tiruneh et al. (2015) and slightly modified to fit the realities and technologies considered under the current study.

$$AI_i = \sum_{i=0}^{n} \left[\frac{\frac{ATF}{RTF} + \frac{ASP}{RSP} + \frac{AHW}{RHW} + IWSU + \frac{ASR}{RSR} + \frac{ANPSRATE}{RNPSRATE} + \frac{AUREARATE}{RUREARATE}}{TNP} \ \ldots\ldots [1] \right]$$

Where,

- AI_{1i} -is the adoption index of the i^{th} farmer measured based on the level of adoption of each recommended component divided by the Total Number of recommended Practices considered in this study (TNP),
- $\frac{ATF}{RTF}$ - Refers to the ratio of Applied Tilling Frequency to Recommended Tilling Frequency,
- $\frac{ASP}{RSP}$ - Ratio of Applied Row Spacing to recommended Row Spacing,
- $\frac{AHF}{RHF}$ - Ratio of applied Hand Weeding frequency to Recommended Hand Weeding Frequency,

- IWSU-refers to Improved Bread Wheat Seed Use (1 if s/he has used, 0 otherwise),
- $\frac{ASR}{RSR}$ - ratio of Applied Seed Rate to Recommended Seed Rate,
- $\frac{ANPSRATE}{RNPSRATE}$- Ratio of Applied NPS Rate to Recommended NPS Rate,
- $\frac{AUREARATE}{RUREARATE}$ - Ratio of Applied Urea Rate to Recommended Urea Rate.

As defined and operationalized in Table 1 below, the second article had 14 explanatory variables hypothesized to determine respondents' adoption decision and adoption intensity respectively. It also includes the dependent and independent variables of the first article. The last article considers total bread wheat output produced (measured in quintals) during the 2021 "*Meher*" production season and the estimated technical inefficiency scores as dependent variables. The details of the Stochastic Frontier Production Function and estimations of smallholder farmers' technical inefficiency are presented in Chapter 4 of the third article (Sub – heading 3.6.2). It provides the definition and hypothesis of the variables used both in the production function and determinants of technical inefficiency. The estimation of the Translog production function was made after all the inputs and output are transformed into their corresponding log values. However, some respondent household heads had reported a zero value for some inputs such as fertilizer, pesticide, and IBWS. The logarithmic value of zero is undefined. Therefore, before transforming the data into their logarithmic form, the dataset for the reported zero input values were changed into nearly zero values (0.0001). Bread wheat output was the major dependent variable in the estimation of production function and is measured in quintals. Inputs that include seed, fertilizer, pesticides, labour (man-days), land, and machinery were used as explanatory variables estimating the stochastic production function

Gender: This refers to the sex of the household head. Literatures revealed that the decision to adopt and extent of adopting agricultural inputs and new ways of doing agriculture is shaped by farmers' gender. For instance, ample empirical evidence have shown that women and female-headed households stick to old agricultural technologies against new or recently introduced technologies. The lower propensity for adoption and extent of adoption was explained by female – headed households' lack of access to and control over productive assets, labour shortage, and policy biases (Fatima and Khan, 2015, Siyum et al., 2021, Almaz and

Begashaw, 2019). Besides, gender stereotypes, lack of inclusive extension system, patriarchal social, economic, and institutional structures were described as hindrances of technology adoption by female-headed farmers' (Gebre et al., 2019, Ogada et al., 2014). Contrary to these findings, Bedilu et al. (2022) found that the probability of adopting improved wheat varieties by female headed households is higher by 46% than male-headed households. This higher propensity of adoption was explained by targeting efficiency of vulnerable female – headed households by the Government of Ethiopia (GoE) and Non-Governmental Organizations (NGOs). Due to the long-held patriarchal structure in rural Ethiopia, this study has hypothesized that household heads gender (being a female – headed household) will negatively affect the decision to adopt IBWS and will significantly lower the adoption intensity of IBWP. Moreover, women heavy pre-occupation in drudgeries reproductive chores has markedly contributed to lower productivity and higher technical inefficiency (Tenaye, 2020, Tsegaye, 2020). Therefore, this study assumes that women farmers' be technically inefficient than their men counterparts.

Age: Age of the household in years was found to have a mixed effect on farmers' adoption decision and extent of adoption of agricultural innovations. Longer age bestow farmers' the chance to accumulate necessary skills, knowledge, assets and resources that are required to adopt multiple components of an agricultural technology (Atinafu et al., 2022, Yirga et al., 2013a). On the other hand, age was expected to have an opposite nexus with adoption, as younger farmers' tend to take risks of trying new technologies and become more innovative. Yet, older farmers' who are constrained by labour deficit tend to adopt labour saving technologies earlier than younger farmers (Arslan et al., 2020). Thus, under the current study, age is expected to have negative or positive impact on adoption of IBWS and adoption intensity of the IBWP. Age was also expected to cause a notable technical inefficiency in BWP.

Improved Bread Wheat Seed Use Experience: Studies have indicated that farmers' adoption decision, the extent of their adoption, along with their production and technical efficiency is determined by their experience to a specific commodity or crop technology. This is mainly due to the fact that several years' experience to a technology associated to a specific commodity or crop confer them the chance to weigh the merits and demerits of that specific technology. Thus, experienced farmers' will not take time in evaluating the technology before making its adoption. In addition, better experience to a specific crop enhances production and technical efficiency as it allow farmers' to acquire and accumulate knowledge, skill, attitude, and resources required for the adoption of production and efficiency augmenting technologies (Zoundji et al., 2023, Arslan et al., 2020). Thus, respondents experience in making use of IBWS is expected to have a significant direct impact on adoption decision and extent of adoption.

Grade level of respondents: This variable signals years of formal education by the respondent household head. Educated farmers' are aware of the implications of their technology adoption decision in terms of augmenting their production and raising their profitability. As a result, educated farmers' readily adopt technologies and do so in its entirety (Mihretie et al., 2022, Bedilu et al., 2021). Besides, educated farmers' are capable of reading and comprehending extension manuals and written production recommendations. Educated farmers were also found to have the lowest technical inefficiency score. This is mainly because education improves farmers' ability to allocate scarce resources in to their most efficient way (Zoundji et al., 2023). Moreover, complexity of a technology is an important variable contributing to non – adoption and dis-adoption of technologies. Yet, education assist farmers' to easily understand and operate complex technologies, which encourage them to make use of a technology. Educated households have higher propensity of adopting an entire component of a technology or more of a technology as they do have better understanding of the returns concomitant to new technologies (Huffman, 2020, Ogada et al., 2014). Therefore, it is expected that education has a significant positive nexus with adoption decision, extent of adoption, and TE of respondents of this study.

Family size: It refers to the total number of individuals (adults and children) that could be related or unrelated to the household head and are currently residing in the same dwelling, sharing meals in the previous six months. Family size was found to have a mixed association with adoption of farm technologies, extent of adoption, and levels of production and technical efficiency. Multiple empirical evidences have shown that households with lower family size do have a higher incentive to adopt labour saving technologies (Munguia and Llewellyn, 2020). Paradoxically, Paul et al. (2016) found an inverse relationship between family size and adoption of agro-forestry practices. These authors have explained that households with larger family size do have an obligation to spend more on household consumption and will remain with little to be spent for adoption of agricultural technologies. Due to the labour – intensive nature of the components of agronomic management practices included in the IBWP, this study expects a direct association between adoption and adoption intensity. This variable is also expected to significantly increase the TE of respondents of the study.

Tropical Livestock Unit (TLU): This continuous variable denotes the total number of livestock owned by the respondent household head converted into TLU using the standard conversion factor developed by ILICA (1990). Livestock ownership have multiple benefits for smallholder farmers'. They are used for traction, draught power, source of food, income, and insurance against risks and misfortunes. Crop producers' livestock assets ownership was found to be one of the most important variables that positively enhance farmers' production and TE. It also encourage farmers' decision to adopt and adopt more of a technology (Bedilu et al., 2021). A polar opposite finding was also reported (Mihretie et al., 2022, Ashenafi and Oliyad, 2020). These authors have explained that these negative relationship between livestock number, adoption, and adoption intensity may be due to households' engagement in fattening and husbandry practices than crop production activities. As animals are important labour, income, and organic fertilizer sources in the study areas, it is expected to positively influence adoption, adoption intensity and TE of respondent household heads.

Land Size: In this study, it refers to the total amount of land allocated for bread wheat production and measured using hectares. Findings are not consistent as far as the relationship between land size, adoption, adoption intensity, and technical efficiency is concerned. For instance, it was found that households with higher land size have better adoption status, extent of adoption, and TE. This is mainly due to the fact that households with higher land size have an incentive to try new technologies at least by allocating a portion of their total plot (Paul et al., 2016). Contrarily, Zoundji et al. (2023) found that larger plot size discourages the adoption of organic farming technologies due to a strong demand for labour and the valorization of local resources (animals waste, plant leaf, etc.). While organic farming improves soil fertility and pest control, mobilizing labour and valorization of local resources is operationally difficult on large land size. Due to the low average land holding size in Ethiopia, this study expects a positive association between land size, adoption, adoption intensity, and TE.

Frequency of Average Extension Contact: This refers to the average number of extension contact reported by the respondent household head per year. Agricultural extension and advisory services plays a pivotal role in introducing production augmenting technologies and enhancing farmers' TE (Degla, 2015). Closer supervision and awareness creation about best agricultural innovations and efficiency enhancing practices is ensured when there is more contact between producers and extension workers. More frequent extension contact creates a wider opportunity to discuss production problems and find timely solutions. It also enable to solve problems earlier and before it become very serious or cause to much devastation (Tiruneh et al., 2015, Zoundji et al., 2023). Therefore, this variable is hypothesized to have a significant positive relationship with adoption, adoption intensity, and TE.

Amount of credit: It denotes the total amount of annual credit obtained from formal financial sources and is measured in terms of Ethiopian Birr. Findings have proven that access to sufficient and affordable credit has increased adoption, adoption intensity, and efficiency of farmers'. Sufficient access to credit was found as one of the major motivating factors encouraging the adoption and adoption intensity of agricultural innovations. Credit has improved smallholder farmers' use of technologies that would have been unaffordable without it. Credits extended to poor smallholder farmers' were found to have a significant positive ripple effect, which is attributable to better adoption of technologies and improvement in TE (Martey et al., 2015a, Teferi et al., 2020, Adunga and Fekadu, 2019).

Membership in Seed Multiplication and Marketing Cooperatives: This is a dichotomous variable measuring by assigning a value of 1 if the respondent household is a formally registered member and 0 otherwise. In the current study, membership in IBWS production and marketing cooperative is expected to have a significant direct relationship with adoption, adoption intensity, and TE of respondent households. This is because these cooperatives work in collaboration with national and regional seed enterprises that provides sufficient and timely inputs, technologies, and technical supports. Several studies have reported a significant positive causation between this variable, adoption, adoption intensity, and TE (Altaye and Mohammed, 2013, Anteneh and Asrat, 2020, Benti, 2019, Chandio et al., 2019, Dawit, 2012). These authors have revealed that cooperative membership positively contribute to adoption, adoption intensity, economic, and TE by improving members bargaining power, access to finance, inputs, better product prices, eliminating information asymmetry, and reducing transaction costs.

Tilling Frequency: It denotes the number of ploughing repetition of the land allocated for bread wheat production. It is measured in number (counts). Tilling frequency shows the extent of land preparation required for an optimum seed germination. Recommended tilling frequency for better bread wheat yield response for the study area is three to five times depending on the land type (ATA, 2015, Hunde and Abera, 2019). Mixed farming, extended family pattern, and large family size are important characteristics of the rural community in Ethiopia (Bureau of Finance and Economic Development, 2013a, Dorosh and Mellor, 2013). This is an important characteristics to adopt labour intensive technologies such as tilling frequency. Thus, a positive relationship was expected between adoption and the ploughing repetition of a technology as farmers do have an incentive to adopt technologies even when it is labour intensive.

Hand weeding frequency: It refers to the frequency of mechanically removing weeds competing for minerals, water, sun-light during the specific wheat production season considered in this study. ATA (2015) recommends at least a twice weed removal for optimum production. Due to scarcity of agro-chemicals to remove weeds farmers often rely on mechanical methods. Thus, we expect a positive association between the respondent household head hand weeding frequency and adoption intensity.

Row Spacing: Row spacing here denote the physical distance between rows of the wheat plant and is measured in centimeters. Proper and recommended spacing between rows increases yield as the even distribution of seed reduces competition between plants for nutrient, water, and light. For instance, a row spacing of 30 centimeters between rows was recommended for bread wheat production. However, due to land shortage, farmers often maintain a narrow space between rows. Besides, farmers often employ the traditional broadcasting sowing method that makes it impossible to maintain even spacing between rows (ATA, 2015, Vandercasteelen et al., 2013, Zecevic et al., 2014). Wider spacing between rows and/or plants reduces the cost of wheat production. For instance, a 38 centimeter row spacing instead of 19 centimeters reportedly reduces seed cost, since 50% less seed is required to plant a hectare at a given seeding rate per meter row (Richer and Lindsey, 2016). Thus, this study expects an inverse relationship between the requirements for spacing and adoption. Yet, as row spacing is one important component of the recommended IBWP, a positive relationship is expected between adoption intensity and row spacing.

Seed Rate: This variable is defined as the amount of bread wheat seed applied by the respondent household head in kilograms per hectare. In bread wheat production, the cumulative effects of its yield components including the population of productive tillers, grains per spike, and grain size detected under a particular production environment represent the grain yield (Mubshar et al., 2016). Agronomic trials have shown lower seeding rate ends-up in higher number of kernel spikes, productive tillers and grain size. This is due to the fact that lower seeding rate increase the availability of more free space that allow plants to make use available nutrients without stiff intra-plant competition (Hunde and Abera, 2019, Mehring, 2016, Okusaa, 2017, Tigabu and Asfaw, 2016). However, farmers in developing countries often apply lower seed rate due to lack of access to seed and unaffordable seed prices. Thus, this study hypothesize a mixed effect of seed rate on adoption, adoption intensity and TE.

Fertilizer Rate: NPS and Urea are important factors of production in the study area (Teshome and Abate, 2013). Smallholder farmers in Ethiopia are reported to apply lower amount of fertilizers and agro-chemicals due to expensive fertilizer prices, timely supply shortage, and lack of awareness about the recommended rates. Restricted agro – chemicals import due to the Covid – 19 epidemic during the 2020/2021 production season had also reduced fertilizers supply and nationwide campaign was made to shift to organic farming (Alemu and Abera, 2013, Bizuwork and Yibekal, 2020). Therefore, this study has expected a negative association between adoption status and amount of fertilizer rate. Yet, we expect a positive nexus between adoption intensity and TE.

Table 1. Summary of Variables and their Operation Definition

Variables	Variable type	Definition and operationalization	Expected Sign	
Dependent variable for article 1: Bread Wheat Productivity (Yield Response) and Net Income				
• Bread Wheat Productivity	Continuous	It indicates the total amount of bread wheat produced per hectare (Response) and measured in quintals per hectare ($Qt\ ha^{-1}$). It is a yield response to different levels of seed rate (dose).		
Independent variable				
1. Plot level Seed Rate	Continuous	It indicates the amount of plot-level bread wheat seed rate (dose) applied by smallholder farmers' per hectare for bread wheat production. It is measured using Kilogram.	-	
• Net Income	Continuous	This indicates the net income of smallholder farmers calculated by subtracting the total costs associated to bread wheat production from the total income acquired due to sale of the produced bread wheat. The prevailing market price in Ethiopian Birr for inputs and outputs was used.		
Independent Variables				
1. Production costs	Continuous	This refers to the total amount of costs spend for bread wheat production. Costs for seeds, fertilizers, pesticides, labor (man-day costs), transaction costs (largely transport costs), machinery rent, and land rent were solicited. With the intention of capturing all costs associated with BWP, respondents were asked about other costs they spend for BWP. Costs were measured using the Prevailing market price in terms of Birr.	-	
2. Income (Benefits) obtained	Continuous	This refers to the total income obtained from the sale of the total bread wheat produced and sold under the existing market price for bread wheat	+	
Dependent variables for article 2: Adoption of IBWS and Adoption intensity of IBWP				
			Adoption	Adoption intensity
III. Adoption and Adoption Intensity of IBWP	Dichotomous and continuous	Adoption refers to smallholder farmers' decision whether to make use of (adopt) Improved Bread Wheat Seed (IBWS) or not that assumes a simple yes or no. It is a classic dichotomous variable operationalized by assigning a value of 1 for adopters and 0 for non - adopters. The second dependent variable is the Adoption Intensity of the IBWP, measured using adoption index scores of each respondent and is calculated using equation 1 above.	+	-
Independent Variables				
1. Gender	Dichotomous	It refers to the gender of the respondent household head operationalized by assigning a value of 1 if the respondent is male and 0 otherwise.	+	-
2. Age	Continuous	This refers to the age of the respondent household head in years.	+/-	+/-
3. IBWS use Experience	Continuous	This refers to the average experience of the respondent household head in making use of improved bread wheat seed measured in years.	+	+

4. Educational level	Continuous	This denotes the educational level of the respondent household head.	+	+
5. Family size	Continuous	Family size denotes the total number of family members (adults and children) that could be related or unrelated to the household head and are currently residing in the same dwelling, sharing meals and having done so during the previous six months.	+/-	+/-
6. Tropical Livestock Unit	Continuous	It refers to the total number of livestock owned by the respondent household head.	+	+
7. Land size	Continuous	It indicates the total size of land owned by the respondent household measured in terms of hectare.	+	+
8. Hand weeding frequency	Continuous	It refers to the frequency of mechanically removing weeds by hand during the specific production season of the study	-	-
9. Tilling frequency	Count/continuous	This refers to the ploughing repetition of the land for BWP and is measured in number (count)	-	+
10. Row spacing	Continuous	This variable signifies the spacing between rows of a wheat farm as reported by the respondent household head and is measured in centimeters.	-	+
11. Frequency of extension contact	Continuous	It refers to the frequency of contact of the respondent household head with the extension workers in 2021 ‘*Meher*’ production season.	+	+
12. Amount of credit	Continuous	This refers to the amount of credit used for bread wheat production measured in ETB	+	+
13. Seed rate	Continuous	It denotes the amount of bread wheat seed applied by the respondent household head per hectare. It is measured in kilograms per hectare	-/+	-/+
14. Fertilizer per hectare	Continuous	This is the total amount of NPS and Urea fertilizers applied by the respondent head for bread wheat production during the specific production season (2021 meher). It is measured in kilograms.	-	+

1.9.5. Data Analysis Methods

The study has applied both descriptive and econometric data analysis methods for the quantitative data types. Measures of central tendency (including mean, median, and mode) and measures of central dispersion (such as range, variance, and standard deviations) were used to describe findings of the analysis. Independent sample t-test was employed to see if there are significant differences in the mean values of the different quantitative variables while chi - square test was used to seed if there exist in the proportion of two qualitative variables. The yield effects of plot – level seed rate application was analyzed using the dose – response model. Cragg's Double Hurdle model was employed to analyze the major determinants of the AI of IBWP. Estimation of smallholder bread wheat producers' technical inefficiency and sources of their inefficiency were investigated using a two – stage SFA method. The costs and benefits of seed recycling was analyzed using the CBA method. The adjusted regression treatment effect model was used to analyze the effect of seed recycling on farmers' productivity and TE. Content and thematic analysis methods were employed to analyze the qualitative data. The quantitative data analysis was conducted using STATA Version 17 while ATLAS.ti was used to code and analyze the qualitative data thematically.

1.10. Structure of the Dissertation

The current dissertation is organized based on an article-based dissertation monograph following the Addis Ababa University Guideline. Accordingly, the first chapter is dedicated to the "General Introduction of the Dissertation". This part includes an overall background and justification, statement of the problem, objectives, research questions, significance of the study, scope and limitations of the study along with a concise literature review and conceptual framework. The remaining parts of the dissertation are organized as follows. The second chapter is dedicated to the first article of the dissertation. The third and the fourth chapters are devoted to the second and the third articles of the dissertation respectively. The fifth chapter deals with the overall Synthesis of Conclusion and Recommendation. The contents of each separate article was determined by the author's guideline of the publishers except few modifications in citation and referencing styles.

CHAPTER 2: YIELD AND COST EFFECTS OF PLOT-LEVEL WHEAT SEED RATES AND SEED RECYCLING PRACTICES IN THE EAST GOJAM ZONE, AMHARA REGION, ETHIOPIA: APPLICATION OF THE DOSE–RESPONSE MODEL[1]

Abstract

Previous studies investigated the effects of seed rates and seed recycling practices on the yield and yield-related variables. However, higher yield does not always guarantee cost-efficiency. This study aimed to investigate the yield effects of plot-level seed rate and the cost–benefit analysis of seed recycling practices. This study has introduced the dose–response model to the existing analytical methods used in analyzing the effect of different agrochemicals on crop yield. A multi- stage stratified sampling technique was used to select 450 household heads as sample respondents. A mix of data collection tools were used for gathering data. Descriptive statistics, cost-benefit analysis along with the dose–response model were applied for data analysis. Farmers of the study were found to be dissimilar in terms of their seed rate application. A dose–response analysis indicated that the highest average wheat yield was associated with a seed rate of 50 kg ha^{-1} above what is recommended. The yield effect of seed recycling was also assessed, and a one-time seed recycling has caused a yield decline of 665 kg ha^{-1} compared to the non-recycled seeds. The cost reduced using recycled seed is by far lower than the economic gains associated with using unrecycled and fresh seeds. The cost–benefit analysis made clear that farmers can reduce their seed costs through seed recycling, but their yields and net income can be best improved by using fresh Improved Bread Wheat Seed (IBWS). Thus, farmers must be encouraged to use unrecycled seed by establishing pro-poor agricultural credit schemes geared towards seed procurement and targeted seed price subsidy as key strategies to reduce economically wasteful seed recycling practices.

Keywords: wheat; seed rate; yield effect; dose–response; seed recycling; cost–benefit analysis

[1] This articles is published in Sustainability (MDPI). *Sustainability* **2021**, *13*, 3793. https://doi.org/10.3390/su13073793.

1. Introduction

Wheat productivity is substantially dependent on the use of crop genetics and the application of improved agronomic management practices. Quality seeds are vital in enhancing agricultural productivity and improving the livelihood of smallholder farmers (Mango et al., 2020, Louwaars and De Boef, 2012). Among other best agronomic practices, seed rate significantly determines crop's ability to capture the available resources and hence increase yield. In most cropping systems, seed rate is a factor under farmer's control that requires their prudent decision. However, the optimum seed rate for an optimum Bread Wheat Production (BWP) greatly varies between regions according to climatic conditions, soil types, sowing time, cultivars, spacing, and other agronomic practices (Zecevic et al., 2014, Guth and Smędzik-Ambroży, 2020, Kebede et al., 2017, Mideksa et al., 2018).

The majority of farmers in the developing countries are using either below or above the optimum recommended seed rates causing a wider yield gap between the potential and the actual production. In Ethiopia, despite the need for optimum wheat seed rates disaggregated on spatial, temporal, and varietal levels, seed rate recommendations are still based on blanket recommendations of a "one-size-fits-all" approach. Moreover, the contribution of improved seeds in boosting productivity and enhancing the livelihood of farmers can be realized if seeds are not recycled or are replaced by new seeds based on expected utility. The expected productivity gains concomitant with the use of IBWSs of improved varieties are likely to be lost over time as the genetic merits conferred by breeding will break down and make resource-poor smallholder farmers vulnerable to risks associated with biotic and abiotic stresses. The use of improved IBWSs without a parallel adoption in other agronomic practices, such as seed rates, seed replacement, spacing, and tillage, did not bring a substantial increase in bread wheat productivity (Krishna et al., 2014). Yet, information on the yield effect of different agronomic practices is meager. Especially, there is inadequate information about the yield effect of farmer's plot level bread wheat seed rates and seed recycling practices in the study area. Thus, investigating wheat yield response to different plot level seed rates and seed recycling practices has been the major objective of this study. The output in this study may help farmers to decide whether they can reduce their costs of seed by correcting the seed rate. Moreover, the use of different seed rates and seed recycling practices are often evaluated in terms of one indicator, usually yield gains. However, the use of different seed rates and seed recycling practices should be evaluated from multiple dimensions. This study is thus meant to investigate the yield effects of plot-level seed rates along with the cost–benefit analysis of using recycled and unrecycled seeds. The cost–benefit analysis is expected to help farmers decide if they can reduce their seed cost through seed recycling and if their yields can be improved by using fresh or unrecycled IBWS as compared to recycled seeds.

This research is expected to contribute to the literature in the following three ways. First, it introduces a different analytical approach in its effort to investigate the yield effect of plot-level seed rates. Previous studies measured the yield effect of seed rate simply as the amount of crop yield per hectare in response to a specified seed rate, while others employ linear regression method and average treatment effect models (Zecevic et al., 2014, Lollato et al., 2019, Vandercasteelen et al., 2013). In this study, the dose–response model is applied. It is a common analytical method in medical sciences (Ritz et al., 2015, Van der and C., 2013). To the researcher's knowledge, this paper is the first to use the generalized linear dose–response model to investigate the yield effect of plot-level seed rates in the study area. Second, it adds to the empirical literature on the yield effect of plot-level seed rates (Lollato et al., 2019, Mehring, 2016). Third, this study analyzed the yield effect of seed rates of recycled and unrecycled bread wheat seeds along with the cost–benefit analysis of seed recycling. Therefore, the output in this study may also help farmers to decide whether they can reduce their costs by recycling seeds or not.

2. Research Methods

2.1. Description of the Study Area

East Gojam zone has 17 districts. Its headquarters, Debre Markos, is located 300 and 260 km, far from Addis Ababa (the capital city of the country) and Bahir Dar (the capital city of the region), respectively. It is located at $10^{\circ}19'0.00''$ North and $38^{\circ}00'0.00''$ East. The mixed farming system is the main occupation of farmers in the East Gojam zone. The area is dominated by mixed agricultural systems (MoA (Ministry of Agriculture of the Federal Democratic Republic of Ethiopia), 2015).

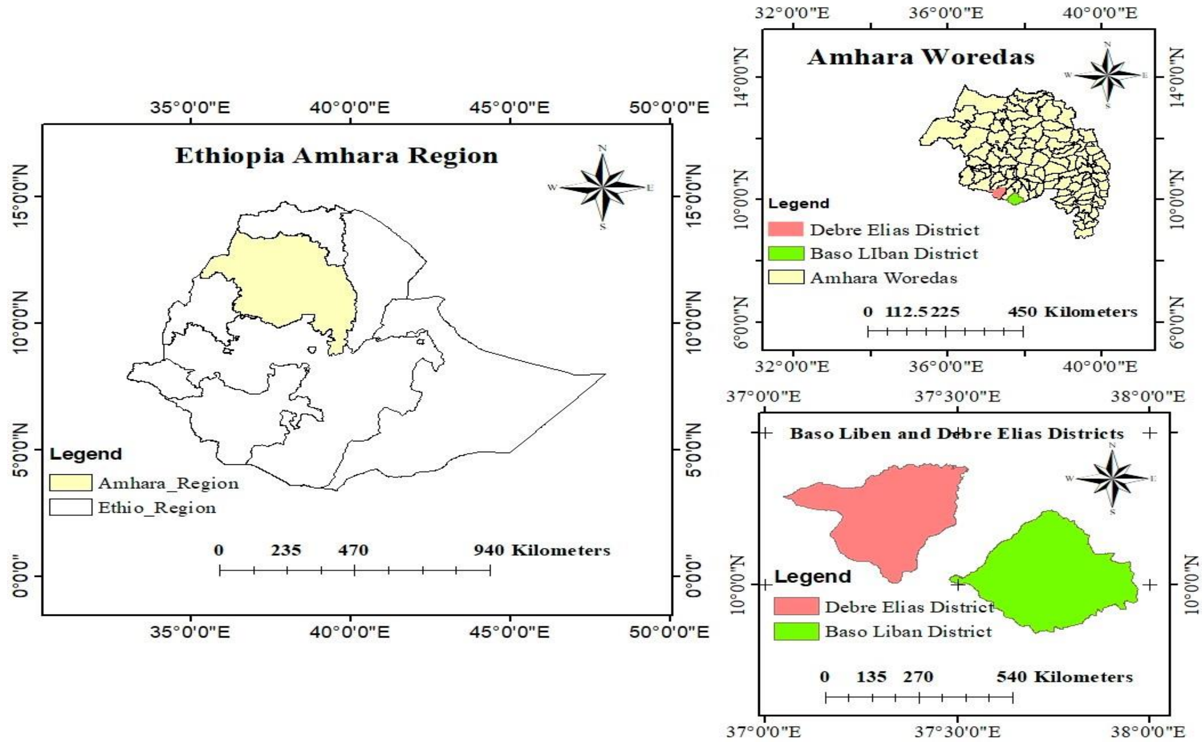

Figure 3: Map of the study area.

2.2. Sampling Technique and Sample Size Determination

Multi-stage purposive and random sampling methods together with probability proportional to size (PPS) were employed in the selection of sample study areas. In the first stage, the East Gojam Zone of the Amhara National Regional State (ANRS) was purposefully considered due to its high potential for wheat production. In the second stage, BasoLiban and Debre Elias districts were considered as specific study areas. The potential for wheat production, availability of sufficient representative sample respondents, and the long year's acquaintance of the study places by the researcher were a few of the reasons to consider these districts. Debre Elias and Baso Liban districts have 15 and 22 kebeles (Kebele is an Amharic term that refers to the lowest administrative region), respectively. Given the financial, time, and other resource constraints, this study has considered a total of 8 rural kebeles. These eight kebeles are thought to be sufficient and representative as there is homogeneity between most of the kebeles in terms of their agronomic practices in wheat production. Then 3 and 5 kebeles were considered as specific study areas by using the PPS sampling technique. A total of 450 household heads, determined by Yamane (1967) sample size determination formula, was considered for the study.

2.3. Data Collection Methods

This study relies both primary and secondary data sources. However, it has heavily relied on primary data sources, including smallholder farmers involved in wheat production, development agents, crop experts, and key informants. Moreover, the information gathered from these primary sources was supported and triangulated from available secondary data sources, including regional and district annual reports, research findings, journals, publications, thesis, dissertations, books, proceedings, and so forth. Both qualitative and quantitative data types were gathered using structured interview schedules, questionnaires, FGDs (Focus Group Discussions), KIIs (Key Informant Interviews), and personal observations.

2.4. Data Analysis Methods

2.4.1. Descriptive Data Analysis Tools

Both measures of central tendency (mean, median, and mode) and measures of central dispersion (range, variance, and standard deviation) were frequently used.

2.4.2. Specification of Dose–Response Model

The Dose–response model is one of the most applied regression models in health and applied agricultural research. In this model, the explanatory variable is often denoted as “dose” or “concentration”. It is also known as “meta – meter” and defined as any pre-specified amount of treatment that could be biological, chemical, or radiation stress stimulating a certain, well-defined response. It is a positive quantity, often assumed to be measured free of errors as in the case of randomly controlled experimental designs (Ritz et al., 2015, Coleman and Marks, 1998). In this study, plot–level bread wheat seed rates applied by sample respondents were considered as dose, while the amount of wheat yield per hectare was considered as response or effect.

The dose-response model has multiple variants. Responses are subject to random variation as they are defined by a given dose. The most common type, which is relevant to the current study, is a continuous response where the dose (seed rate here) has produced a non-negative continuous output. A binary or aggregated binary (binomial) response is also frequently used to describe results, such as dead/alive, immobile/mobile. The response may also be discrete as in the number of events observed in a specific time interval, such as the number of juveniles, offspring, or roots. Dose–response curves may also be used to summarize experiments where the response is an event time that is the time elapsed before some specific event is being observed absent. A statistical dose-response model involves describing the mean response as a function of dose and making assumptions about the distribution of the response. The focus is on modeling mean trends using S-shaped or related biphasic functions that reflect the causal relationship between dose and response. These functions are versatile and biologically plausible for interpreting observed effects. Studies define dose-response models as a collection of statistical models with a common mean structure, encompassing nonlinear regression, generalized linear regression, and parametric survival analysis. The observed response values (denoted as Y) are subject (Van der and C., 2013).

This study undertook a linear dose–response regression between wheat seed rates (dose/concentration) and wheat yield (response/effect). In this study, we denote 'Y' (yield) as an observable response value, corresponding to a dose (seed rate) value $x \geq 0$. The values of y are often positive but may also be zero under conditions where farmers' are unable to harvest due to crop failures induced by natural and artificial catastrophes. Furthermore, we have assumed that observation of Y is subject to sampling variation, necessitating the specification of a statistical model describing the random variation. Specifically, the study has focused on characterizing the mean of Y (Wheat output) in terms of a model function that depends on the dose X. Under the current study, the linear model, which is the simplest form of a dose – response model with the assumption that there is a linear relationship between the dose and the response as specified in the equation below:

$$E\ (\mathrm{Y}) = f(x, \beta_0)$$

$$\mathrm{Y} = \beta_0 + \beta_1 X \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.(1)$$

Where Y, $\beta_0, \beta_1 and\ X$ denotes the response (Wheat output), the intercept, the slope, and the dose (plot level seed rates) respectively. The intercept (β_0) represents the baseline response when the seed rate (dose) is zero, and β_1 (slope) denotes the change in response (wheat output) per unit increase in the seed rate. Thus, the observed response values (bread wheat output here) for a given amount of seed rate (dose) is distributed around f (X, β). The function f is completely known as it reflects the assumed relationship between x and y, except for the values of the model parameters $\beta = (\beta 1, \beta p)$, which was estimated from the data to obtain the best-fitting function. The remaining distributional assumptions on y depends on the type of response. For instance, when the response variables are continuous and binary, the normal and binomial distributions are respectively assumed.

3. Result and Discussion

3.1. Bread Wheat Seed Sources

Several bread wheat varieties have been recommended for highland (Dega) and mid- highland (Weyina-Dega) agro-ecological zones of the country. Ogolcho (ETBW5520), Kubsa, Danda'a, Kakaba, Digalu, Tay, Katar, Abola, Dereselegn, K6290 Bulk, K6295-4A, ET-13 A2, Pavon 76, Dashen, Mitike, Galema (HAR-604), Tusa, Tura, Katar, Shina, Simba, Guna, and Densa have been introduced in both study districts (ATA, 2015). However, almost all farmers have already abandoned using any of these varieties except Ogolcho (ETBW5520). This variety was released in 2012, and it has become an exclusive bread wheat variety being grown in the study areas during the production season considered in this study.

Various agricultural experiments and varietal trials have been carried out by the Ethiopian Agricultural Research Institute, Amhara Region Agricultural Research Institute, Bahir Dar University, and Debre Markos University. Despite these efforts, farmers in the study area are unable to access several alternative wheat varieties during the production season. Farmer's access to seed is quite supply-driven that the major formal source for IBWS (largely the Amhara Seed Enterprise) does not usually supply more than one variety during a specific production season. As a result, farmers are compelled to stick to a single variety supplied to them. Different authors reported a similar trend. For instance, Furtas (2016) found very low spatial diversity of bread wheat varieties where a markedly large section of wheat production land is occupied by a single and/or only a few dominant wheat varieties. Although varietal diversity is low, the use of IBWS has been exceptionally high as compared to findings in several studies (Furtas, 2016, Tiruneh et al., 2015). This may be because farmers are benefited from the spillover effects of research efforts being undertaken by several governmental and NGOs. This may have encouraged farmers to allocate larger plots for wheat production using IBWSs. Given its huge potential for wheat production, farmers of the study area are often preferred targets for seed multiplication for the regional and national seed enterprises. This has allowed farmers to have easy and timely access to IBWSs, which could be one important reason for exceptionally high IBWS use. Moreover, farmers' long years of experience and perceived benefits in using IBWSs could also explain the high rates of IBWS use. The spread effect of agricultural research to large-scale application of farm innovation is witnessed in other studies, too (Bishaw and Atilaw, 2016, Gebre et al., 2019).

Farmers in the study area acquire seeds from four important sources (Appendix Table A3). The Amhara Seed Enterprise has been a dominant seed supplier for almost 73% of the farmers, followed by farmer's cooperatives that supply seed for over 15% of the farmers. Farmers of the study area participate in seed multiplication. Yet, these farmers cannot sell seeds by themselves but through the cooperative to which they belong after getting approval and certification for the seeds. Zonal and district experts working in the seed quality department controls the quality of seeds produced by the farmers, whereas the Ethiopian and the Amhara Seed Enterprises provide the technical support for seed production. Farmer's own saved seeds, along with research and academic institutions have been important seed sources for few sections of the farming community in the study area.

3.2. Productivity Effects of Plot-Level Seed Rates

Boosting wheat yield by reducing competition for water, fertilizers, sun light, and minerals by keeping an appropriate plant density determined by recommended seed rates application is one of the most important agronomic management practices (Mango et al., 2020, Abate et al., 2018). Yet, wheat yield response to seed rate is inconsistent across spatial and temporal bases due to several biotic and abiotic factors. Ceteris paribus, seed rate is an important yield determinant in bread wheat production. A better understanding of the relationship between seed rates and yield in wheat production could have paramount importance in improving seeding rate recommendations according to specific spatial, temporal, and bread wheat variety-related characteristics (Lollato et al., 2019, Mehring, 2016). The application of the best quality seed may lead to lower gains if the recommended seed rates are not applied (Abeyo et al., 2020, Bonny, 2014).

The Ministry of Agriculture generally recommends a seed rate of 80–100 kg of seed per hectare. However, based on location-specific wheat variety trials conducted in the East Gojam zone, a seed rate of 100–150 kg ha^{-1} is recommended for Baso Liban and Debre Elias districts. Nonetheless, farmers in the study area do not stick to the recommendation and use their own seed rates. The yield and yield effects of seed rates of the IBWS of the Ogolcho variety were evaluated when it was introduced in 2012 in the selected farmer training centers (FTCs) in Baso Liban and Debre Elias districts. Since then, the yield effect of farmer's own plot level seed rates has never been empirically assessed. Therefore, exploring the effect of plot level seed rates on wheat yield is an important objective of this study. Respondent farmers are classified into three groups for the study. The first category (below-recommended seed rate group) includes farmers with a seed rate ranging from 50–99 kg ha^{-1} (50 kg ha^{-1} being the lowest observed seed rate). The second group (recommended seed rate users' group) includes respondents with a seed rate ranging between 100 and 150 kg ha^{-1}. The third group ("above recommended") constitutes farmers with a seed rate greater than 150 kg ha^{-1}.

The survey results showed that about 4.9%, 48% and 47.1% of the respondents use seed rates below, above, and within the recommended seed rates, respectively (Table 2). This means that above 95% of the farmers in the study area use seed rates either above the recommendation or within the recommended seed rate range. On average, farmers of the study area have used a seed rate of 194.4 kg ha^{-1}, which is higher than what is recommended. A similar finding was reported by (Zewdie et al., 2014), where they had reported an average seed rate of 264.56 kg ha^{-1}, about 100 kg above what is recommended. Several studies also found the use of higher seed rates. Late seeding dates, planting methods, the need to compensate for possible damages due to ants, rats, and birds, intentions of grain yield maximization, and weed control are reported as some of the reasons for higher seed rates (Abate et al., 2018, Zecevic et al., 2014). These explanations for higher seed could also be adopted as reasons for the higher seed rates witnessed in this study. The Pearson's correlation indicates a negative nexus between seed rate and hand weeding frequency ($r = 0.5248$, $p = 0.05$. This could be interpreted as that farmers reduce the seed rate for making frequent hand weeding easy and convenient. Moreover, farmers in the study area have reportedly used lower seed rates due to perceived high seed prices and insufficient supply of IBWSs. Though it is not witnessed from the findings of this study, studies indicated several reasons that push farmers to use seed rates below what is recommended. For instance, superior agronomic practices, such as row planting and transplanting, reduce the seed rate required in crop production. These practices do not only reduce seed rates but also allow more spacing between seedlings, permit easy weeding, reduce competition between seedlings and allow for better branching out (tillering) of crops Anteneh and Asrat (2020) (Vandercasteelen et al., 2013).

A good section of the respondents (48%) has used a seed rate above the recommendation. The Pearson's correlation indicates a positive nexus between the frequency of seed recycling and the amount of seed rate (r = 0.5534, p = 0.05). This implies that higher seed rates are associated with the frequency of seed recycling. The recycled seeds are cheaper than fresh and unrecycled IBWS that may encourage farmers to purchase and use more amounts of bread wheat seed. Several studies provided explanations as to why farmers use more seed rates. For instance, quite often, late seeding dates cause higher seeding rates because a delay in sowing normally reduces individual plant growth and tiller production (Abate et al., 2018). The result in this study does not portray a significant yield difference between farmers who use recommended and below recommended seed rates. The lowest average wheat productivity was associated with the farmers, who apply seed rates above what is recommended.

Table 2: Distribution of average productivity across varying seed rates

Seed Rate Group	Obs.	Seed Rate (Kg ha^{-1})		Productivity (Qt ha^{-1})	
		Mean (μ)	Std. Dev	Mean (μ)	Std. Dev
Below Recommended	22 (4.9)	67.0455	11.9183	40.3636	3.8365
Recommended	212 (47.1)	133.9623	21.2714	40.3726	4.80499
Above Recommended	216 (48)	266.6667	93.3859	36.7361	6.2424
Total	450 (100)	194.3889	97.0926	38.62667	5.7883

Source: Own Computation (2022)

Respondent household heads were asked about the reasons for application of higher seed rates. Expected better yield gains has been the most frequently reported reason for higher seed rates. The practice of using higher seed rates was reported in other studies as well (Abboye and Teto, 2020, Abate et al., 2018, Okusaa, 2017, Tigabu and Asfaw, 2016). These studies unfold that farmers usually use higher seed rates than what is recommended due to land scarcity, availability of credit markets for agricultural inputs, and access to markets. Though not implied from the current study, these same reasons could also explain the findings here. Similarly, farmers in the LDCs prefer to use higher seed rates than what is recommended as a strategy to control weeds. High seed rate application, however, is not a commendable practice due to the negative consequences on seed quality, such as seed size and weight (Mideksa et al., 2017, Abate et al., 2018).

One cannot have a clear picture of the yield effects of seed rate from the descriptive statistics presented above. The best analytical model to understand the effect of a dose (concentration) on response is the dose–response function based on the generalized linear regression model. This regression model produces such estimates more quickly. However, the use of post estimation command, such as margins plot in STATA, enables to paint a clear picture of the effect of a dose (seed here) on the response (wheat yield per hectare). To do so, the data gathered was arranged in six seed rate groups to include all observations within ± 50 kg ha^{-1} of the recommended seed rate. All farmers that apply a seed rate of 50 kg ha^{-1} or below are categorized as the 1st group, and the seed rate is calibrated as 50 kg ha^{-1} (50 kg ha^{-1} being the lowest seed rate). The seed rates between 50–100 are calibrated as 100, while seed rates between 100–150, between 150–200, between 200 - 250, between 250–300, and between 300 were calibrated as 150, 200, 250 and 300 kg ha^{-1}, respectively. The regression coefficient is calculated using the generalized linear model to investigate the effect of the seed rate applied by farmers on wheat productivity. The result indicated that a 1 kg increase in seed rate is associated with a probability of 0.054 increases in wheat productivity (See Appendix Table A1). To sum up, Figure 2.2 below shows the relationship between plot level seed rate and yield in the study area.

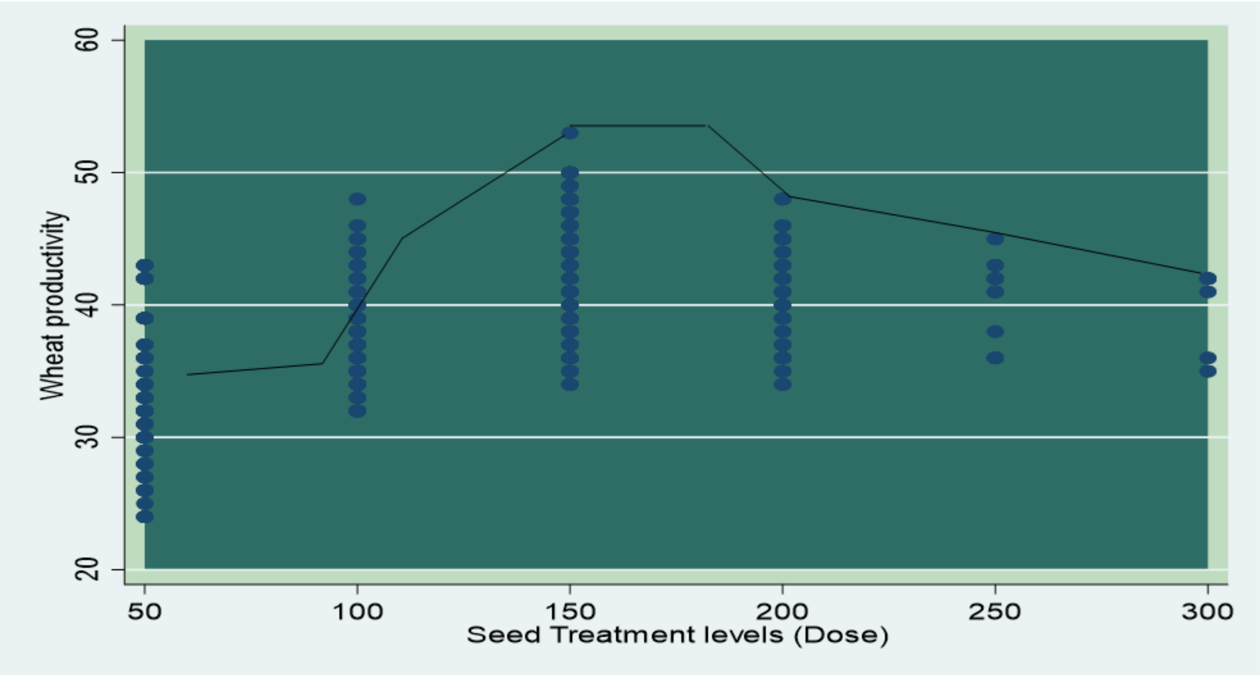

Figure 4: Seed rate–yield response curve.

Further analysis was carried out using predictive margins at the mean to investigate the magnitude of change in wheat productivity when the seed rate applied by the sample respondents increases from 50 kg ha^{-1} (the minimum seed rate reported) to 300 kg ha^{-1} (the maximum seed rate applied). Results of the analysis depicted that seed rates below what is recommended were associated with lower wheat productivity. Interestingly, a seed rate of 200 kg ha^{-1} is associated with the highest average wheat production per hectare (4225 kg ha^{-1}). This means that an extra 50 kg ha^{-1} application beyond the recommended seed rate is associated with higher productivity. This suggests that there might be a need to revise the seed rate recommendation for the study area. As presented in Table 3, an increase in the successive seed rate from 50–200 kg ha^{-1} was associated with an increase in wheat productivity. However, additional seed rates being applied beyond 200 kg ha^{-1} did not show an increasing effect on wheat productivity. Rather, productivity started to decline after the 200 kg ha^{-1}. Though the recommended seed rate in the study area was between 100 and 150 kg ha^{-1}, higher yield gains were reported for seed rates from 150–200 kg ha^{-1}. This is in agreement with other field-level experiments and surveys results by different authors that reported increasing the seed rate of wheat from 100–200 kg ha^{-1} increased the grain yield and straw yields (Anteneh and Asrat, 2020, Mideksa et al., 2017). This study found that about 48% of the respondents reportedly used higher seed rates than what is recommended. Yet, the seed rate is best when it is associated with the maximum grain yield. The economic theory of diminishing return to input was proved from the findings of this study. The wheat yield hardly changes with additional units of seed rates once the maximum yield level was achieved. This could be witnessed from the flatten curve after 200 kg ha^{-1} seed rates in Figure 4 above. Seed rates used above what is required to reach the flat part of the curve is money wasted that could have been used for other development expenditures.

Table 3: Marginal effects of different seed rates on wheat yield.

Seed Rate (Kg Ha^{-1})	Delta Method		t	p>|t|	95% Confidence Interval	
	dydx	Std.Err				
50	34.635	0.37588	92.15	0.000	33.89965	35.37706
100	37.321	0.25025	149.13	0.000	36.82926	37.81289
150	40.004	0.25237	158.52	0.000	39.50783	40.49977
200	42.246	0.75394	56.03	0.000	40.76464	43.72809
250	38.733	0.37375	103.63	0.000	37.99811	39.46745
300	38.480	0.48983	78.56	0.000	37.51762	39.44294

Source: Own Computation (2022)

3.3. Yield and Economic Effects of Seed Recycling

One important finding of this study is the practice of seed recycling. The study respondents were asked whether they use recycle wheat seeds or not and how often they do recycle seeds. Some portion of the farmers (about 27.11%) considered in the study make use of recycled seed beyond what is recommended. Nevertheless, the proportion of farmers' making use of recycled seed is relatively lower as compared to farmers' elsewhere. Studies in Ethiopia and Tanzania indicated that farmers often used obsolete or old varieties whose seeds are recycled. In Ethiopia, about 76% and 10% of the farmers grew modern and obsolete bread wheat varieties, respectively. Several studies also indicated widespread seed recycling practices (Tesfaye et al., 2016, Abboye and Teto, 2020, Bishaw et al., 2011, Clayton et al., 2009).

This study also solicited the reasons for the existing seed recycling practices. Appendix Table A4 summarizes the distribution of farmers in terms of their seed recycling practice and reasons for seed recycling. Expensive prices, problems of timely seed supply, and supply shortage have been the most frequently cited reasons for seed recycling. Furthermore, during the FGD, participants mentioned that they see no noticeable difference in yield and other desirable qualities between non–recycled and recycled seeds if the recycling is made only once or twice. Not all studies indeed show a better yield advantage for IBWS over farmer saved seed. Proper seed production and seed saving practices, maintaining a seed free from contamination and varietal purity affect the yield differences significantly (ATA, 2015, Zecevic et al., 2014). Farmers also indicated that the application of different coping mechanisms in times of seed supply shortage and higher seed prices. One important reported strategy was cleaning and saving seed from the existing production to be used in the coming production. Thus, seed recycling in the study area has been practiced as a seed shortage handling and cost reduction strategy. Farmers complain about the expensive price of IBWS and use it as an excuse for seed recycling. However, from findings of the cost–benefit analysis presented in Appendix Table A2, one can easily learn that these same farmers still incur costs well above the price of the IBWS. This is mainly because the magnitude of recycled seed rate has been so high, which is above equivalent to the costs incurred in using, unrecycled IBWS. Nonetheless, it must be noted that recycled seeds are cheaper and can be easily obtained informally from friends, relatives, neighbors, and consequently, it may encourage farmers to apply higher seed rates.

The cost–benefit analysis was used to assess the economic impact of seed recycling. The prevailing domestic market price was adopted to calculate the costs and benefits of seed recycling. The cost–benefit analysis is concerned with two important issues. One is costs reduced in the production of goods and services. The second is income increased because of the marketing of goods and services. In this study, the cost reduced because of seed recycling practice made at the expense of using fresh and unrecycled IBWS was calculated, followed by the income gained because of using fresh and unrecycled bread wheat seed at the expense of recycled seed. During the 2020/21 cropping season, the unit cost of 100 kg of unrecycled and recycled bread wheat seeds were 2300 and 1800 Ethiopian Birr (ETB), respectively. Farmers that have used unrecycled and fresh IBWSs had applied a mean seed rate of 169.2835 kg ha^{-1} against a mean seed rate of 263.6364 kg ha^{-1} for recycled seeds greater than 5 times (Appendix Table A2). The cost reduction as a result of using recycled bread wheat seed at the expense of unrecycled bread wheat seed could be equated as follows:

$$CR = \frac{A_1 \; X \; B_2}{100} - C_1 \quad \text{(2)}$$

Where CR refers to the cost reduced as a result of seed recycling,

A1 = Mean seed rate of the unrecycled seed (fresh and/or recycled for less than 5 time),

B2 = cost of fresh and/or recycled seeds for less than five time,

C1 = total seed cost of unrecycled seeds.

Unrecycled IBWS users, on average, have used a seed rate of 169.2835 kg ha^{-1} with a total seed cost of 3893.51 ETB. If unrecycled IBWS users have turned into use of the recycled seed, then the total seed cost would have been 3047.10 ETB. Following the formula above, it is clear that farmers can reduce their seed cost per hectare by 846.42 ETB by reverting from the use of unrecycled IBWS to a one-time recycled seed use. Thus, the economic rationale of farmers for seed recycling does hold water in terms of cost reduction. A study by ATA (2015) supports this finding. These authors found that farmers in Canada try to reduce production costs without incurring large decreases in yield from their own saved seed from a current crop to use for next year's planting, and it is common practice with most cereal and pulse crops. There could be several explanations behind costs reduced because of using recycled seed. The first explanation is lower transaction costs. Unrecycled seeds could be purchased from nearby informal sources at local markets. As a result, no extra transportation costs are incurred. In addition to transaction costs, costs pertinent to chemical treatment, labeling, and packaging do not apply to recycled seeds. However, cost reduction alone is not a guarantee to an economically profitable agricultural business. The economic gains because of using the other alternative (unrecycled improved seed here) or the economic loss due to sticking to an old practice (using recycled seed here) are also critical. This calls for the need to calculate the net income gain of a crop enterprise. The next equation in the cost–benefit analysis is to check whether the economic gains from seed recycling are better than unrecycled seed. The income gained (IG) as a result of using unrecycled IBWS at the expense of recycled seed is calculated using the following formula:

$$\boldsymbol{IG = \frac{D_2\ x\ F_1}{D_1}\ x\ F_2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \boldsymbol{(3)}$$

Where IG is income gained, D2 is the mean yield of recycled seed, F1 is mean income from unrecycled seed, D1 is mean yield of unrecycled seed, and F2 is mean income from the recycled seed.

Following the formula above and based on the numerical figures presented in Appendix Table A2, the use of fresh and unrecycled IBWS was associated with a higher yield (4044 kg ha^{-1}) and higher market prices (1950 Ethiopian Birr). Similarly, a one-time seed recycling is associated with a lower yield (3333 kg ha^{-1}) and market prices (1800 Ethiopian Birr). Thus, the average income per hectare given the price of a one-time recycled is 60,823.62 ETB. However, a farmer reverting to use fresh and unrecycled seed receive an annual income of 65,892.26 ETB per hectare. This means that the use of fresh and unrecycled IBWS leads to an economic gain of 5068.635 ETB than a one-time recycled seed. The net income per hectare associated with the use of fresh IBWS and a one-time recycled wheat seed was 74,968.58 ETB and 56,078.16 ETB, respectively. This implies that the use of fresh and unrecycled IBWS ends up in a net income gain of 18,890.42 ETB per hectare than a one-time recycled seed. To sum up, the results of the cost–benefit analysis made clear that farmers can reduce their seed costs through seed recycling, but their yields and net income can be best improved by using unrecycled IBWS.

Several authors highly suggested that farmers should use unrecycled IBWSs as continuous recycling reduces crop yield (Wudineh and Geta, 2016, Abboye and Teto, 2020, Tsegaye, 2012). The finding in this study, too, is quite in agreement with these authors. On average, the mean productivity of unrecycled wheat seed users was the highest (Table 4). Yield superiority of fresh and unrecycled wheat seeds may explain this highest wheat yield per hectare. As it can be learned from the above table, on average, a one-time and a twice seed recycling cause a 665 and 711 kg ha^{-1} wheat yield decline as compared to the unrecycled IBWS. Here it is worthy of mentioning that the average yield difference between farmers, who recycle once and twice, was not conspicuous. This indicates the fact that the magnitude of yield loss because of recycling remains insignificant irrespective of recycling frequency.

It signifies the need to rely heavily on fresh and unrecycled IBWS. Nonetheless, during the FGD, farmers opined that a one-time or twice recycling did not cause noticeable yield reduction. Yet, (Tesfaye et al., 2016, Bonny, 2014) reported that fresh IBWSs increase productivity and farmer's efficiency in comparison to frequently recycled seeds. The productivity and efficiency gains indicate that promoting fresh IBWS has the potential to raise production using the available improved seed technologies at the most efficiency. The finding in this study thus calls for an intensive extension campaign and field-based demonstration to convince farmers of the yield losses because of seed recycling. Such a significant yield difference is not expected between fresh IBWS and a one-time seed recycling for self-pollinated crops. The marked difference in yield could, therefore, be attributed to the quality of the seed as indicated by inappropriate seed rate, seed counterfeiting, and unwise planting method (Bezabeh et al., 2014, Eunice et al., 2016).

Table 4: Distribution of average productivity and seed recycling.

Seed Recycling Status	**Productivity (Qt ha^{-1})**		**Seed Rate (Kg ha^{-1})**	
	Mean (μ)	Std. Dev	Mean (μ)	Std. Dev
Fresh Seed (Never Recycled)	40.4421	4.9718	169.2835	66.96013
Recycled less than 5 times	33.7909	4.6730	263.6364	129.0241
Recycled ≥ 5 times	33.3333	7.3278	245.8333	130.0495
Total	38.6267	5.7883	194.3889	97.09256

Source: Own Computation (2022)

4. Conclusions and Recommendation

4.1. Conclusions

The proportion of farmers that uses a seed rate within the recommended seed rate, above the recommended and below the recommended seed rates were found to be 47.11%, 48%, and 4.89%, respectively. Thus, it can be concluded that a notable section of the farmers do not stick to the recommended seed rate application. One important finding of this study was the practice of seed recycling. In this regard, one can deduce that about 72.89% of the farmers in the study area use fresh seed and/or recycled seeds for less than 5 times. Fresh/unrecycled seed use was associated with mean productivity of 4044 kg ha^{-1}, while seeds that were recycled only up to 5 times and above or equal to 5 times were associated with mean productivity of 3379 and 3333 kg ha^{-1}. This implies that seed recycling, on average, causes 665 kg yields loss per hectare. Keeping other factors constant, the result from the generalized dose - response linear regression indicated that a 1 kg increase in seed rate is associated with a 0.054 unit increase in wheat productivity. From the dose–response relationship, one could learn that the maximum yieldwas associated with a seed rate of 200 kg ha^{-1}, which is higher than the recommended seed rate by 50 kg ha^{-1}. Thus, one can rightly conclude that there exists an opportunity of increasing wheat productivity by adding an extra seed rate of up to 50 kg ha^{-1} exists. However, it also has to be noted that any increase in seed rate beyond the optimum found here has led farmers to diminishing productivity. The average wheat productivity associated with farmers, who applied seed rates as per the recommendation, below the recommendation, and above the recommendation were 4037, 4036 and 3674 kg ha^{-1}, respectively. The use of fresh and unrecycled IBWS ends up in a net income gain of 18,890.42 ETB perhectare than a one-time recycled seed. To sum up, the results of the cost–benefit analysis made clear that farmers can reduce their seed costs through seed recycling, but their yields and net income can be best improved by using unrecycled IBWS.

4.2. Recommendations

The researcher strongly believes that upon the implementation of the suggestions made here, proper seed rate use will be enhanced. Moreover, the researcher is strongly convinced that farmers, extension agents, development practitioners, policymakers, and other stakeholders involved in wheat production can use these recommendations in their efforts to improve wheat productivity. The following are the most important recommendations made based on the findings of the study discussed above.

- Though cost reduction and high seed prices are frequently reported as major pushing factors for seed recycling, the cost–benefit analysis indicated that the use of fresh or unrecycled IBWS leads to better economic gains than recycled seeds. Therefore, this study recommends strategies that will encourage the use of fresh and unrecycled IBWSs. Moreover, targeted agricultural credit schemes and price subsidies geared towards helping poor farmers to make use of fresh or IBWSs are strongly recommended as key strategies to reduce the economically wasteful seed recycling practices. Implementation of these recommendations is expected to bring multiple benefits. First, it will raise farmer's productivity, income, and food security. Second, seed scientists, seed producers, and other individuals and institutions will benefit the most from their research and innovation efforts. This profit could also be reinvested for more research and development efforts. Third, agro-processing could be enhanced that may increase the government revenue and the creation of wider employment opportunities;
- Seed recycling practices have caused yield loss as compared to the non–recycled seeds. Therefore, ensuring the supply of fresh certified and IBWSs is highly recommended. This could be achieved through encouraging seed parastatals, establishing new seed production and marketing cooperatives, and encouraging the existing ones;
- Wheat varietal diversity in the study area is found to be very low. This study, therefore, strongly recommends varietal diversification through the promotion of different varieties in the study areas instead of relying on one variety;
- Grain yield maximization was the most important reason to use seed rates beyond the recommendation. The evidence from the existing seed rate application of the farmers proved that a higher seed rate of up to 50 kg ha^{-1} above the existing recommendation was associated with the highest yield per hectare. Thus, this study strongly suggests that the MoA, agricultural research institutes, and other stakeholders undertake location-specific seed rate trials and validations to keep or modify the existing seed rate application;
- This study has several significant implications for future research efforts that further contribute to the yield effects of plot-level seed rate and seed recycling practices. Thus,

research efforts in the following thematic areas will enrich the existing discussions and knowledge as far as the yield effects of seed rate and seed recycling practices are concerned;

- The use of time-series data will provide clear evidence about the yield effects of plot-level seed rates and seed recycling practices of IBWS on a temporal basis;
- The yield effects of wheat seed rates and seed recycling practices for different wheat varieties in different socio-economic settings, weather conditions, and spatial arrangements should be investigated.

CHAPTER 3: ADOPTION INTENSITY OF IMPROVED BREAD WHEAT PACKAGE AND PRODUCTIVITY CHANGES: APPLICATIONS OF CRAGG'S DOUBLE HURDLE AND REGRESSION ADJUSTMENT MODELS

Abstract

Smallholder farmers can significantly increase their productivity by adopting entire components of the improved bread wheat package. Nevertheless, smallholder farmers' make partial adoption of agricultural technologies. There is limited empirical research on the determinants of adoption intensity and the effect of varying levels of adoption intensity on productivity. To address this gap, we conducted structured interviews, key informant interviews, and focus group discussions with 450 smallholder farmers using multistage stratified sampling. Cragg's Double-Hurdle and the Regression Adjustment Treatment Effect models were used to identify the determinants of adoption intensity and the effect of adoption intensity on productivity, respectively. Our analysis revealed that multiple variables influence the adoption and adoption intensity of the Improved Bread Wheat Package, as indicated by the coefficients in the probit and truncated models of the Double Hurdle model. We found that lack of access to improved fresh seed and insufficient labor were major reasons for non-adoption of the entire package. Additionally, adopters of the entire bread wheat package had 8.24 quintals per hectare lower productivity than the average of 40.21 quintals per hectare, assuming no farmers relied on unimproved bread wheat seeds. Thus, we concluded that adoption intensity of improved bread wheat seed has a significant effect on productivity. We recommend increasing access to improved bread wheat seed through seed aid and credits, encouraging full package adoption, and introducing affordable, laborsaving, and improved machinery. Our study contributes to the understanding of adoption intensity and its effect on productivity in the context of improved bread wheat packages, providing insights for policymakers and development practitioners working to increase smallholder farmers' productivity.

Key Words: Complete adoption, bread wheat package, seed aid, productivity, treatment Effect

1. INTRODUCTION

In the developing countries, agriculture is the most important sector for spurring growth, eradicating poverty, and ensuring food security. Improving crop productivity is not only essential but a necessary condition to break the vicious poverty cycle under which the majority of the population in poor countries have persisted for millennia (Dereje, 2021). The role of wheat production is critical in ensuring global food security because approximately 1.2 billion people are wheat dependent, 2.5 billion wheat consuming poor men, women, and children live on less than 2 USD per day, and it supports the livelihood of approximately 30 million poor wheat producers and their families. Wheat is grown on more than 240 million hectares exceeding other commercial crops (Bekele et al., 2013, CIMMYT, 2012). In Ethiopia, wheat is cultivated on 1,696,907.05 hectares of land, which is 13.38% of the total grain area. Cereal production contributes 87.48% (about 26,778,976.40 tons) of the grain production. Wheat contributes 15.17% (4,642,965.71 tons) to the total cereals production. The national average wheat productivity was 2.76 tons per hectare. The average wheat productivity in Ethiopia in general and in ANRS (Amhara National Regional State) in particular is very low as compared to the global average (CSA, 2018b). Improving wheat productivity, therefore, is essential in the fight against food insecurity and poverty in Ethiopia (Bekele et al., 2013, Dawit, 2012). With the intention of bridging the potential and the observed productivity gaps in wheat, wider diffusion and scaling-up of the Improved Bread Wheat Package (IBWP) has become the major concern of government intervention in the country (Tariku, 2012). Yet, more than 90% of the seed used by the smallholder farmers is supplied by the traditional, local, and informal seed supply system (Abebe and Lijalem, 2011, Bishaw et al., 2012). Besides, the adoption of the whole practices in the IBWP significantly enhances the productivity and food security of smallholder farmers (Ali et al., 2013). Yet, farmers often make partial adoption of the IBWP at the expense of certain components of the package. Thus, there is a need to investigate the determinants that affect the adoption and Adoption Intensity (AI) of the IBWP and this study aimed at addressing this need.

Moreover, the nexus between productivity changes and the adoption of the different levels of the IBWP is not sufficiently addressed by empirical researches. Thus, this study also aimed at investigating the determinants of smallholder farmers AI of IBWP and its nexus with productivity. Besides, most previous empirical studies were flawed and had been dissimilar in the choice of analytical models for adoption. Binomial or dichotomous regression models are commonly employed to elucidate the probability of adoption or non–adoption. However, dichotomous models fail to capture how much of the technology is adopted or rejected. Such understanding of the probability of technology adoption does not provide sufficient information about farmer's behavior as the farmer may allot some percent or 100 percent of their farm for the new technology. Thus, a strict binary model is insufficient for examining the adoption intensity of agricultural technologies (Tobin, 1958, Gujarati and Dawn, 2009). The Tobit model was suggested as a remedy for the failures of the dichotomous model and frequently applied in the analysis of the probability of adoption and adoption intensity of technologies with the assumption that these two decisions are affected by the same set of factors. Yet, the decision to adopt or reject and how much to adopt (adoption intensity) may not be necessarily affected by similar variables. In this study, the adoption decision and how much to adopt are considered as joint decisions and should be addressed together. Furthermore, the productivity change across the different levels of adoption intensity has remained beyond the horizon of empirical investigation. As a result, farmers do not know how much of the IBWP should adopted to hone their productivity. The current study has employed the Regression Adjustment Treatment Effect model to analyze the productivity change across the varying adoption intensity of IBWP. Therefore, this study has a methodological contribution by applying Cragg's Double–Hurdle model along with the Regression Adjustment model, which have been rarely used together.

1.2. Objectives of the study

This study had the following objectives:

1) To analyze the major determinants of smallholder farmers adoption intensity of improved bread wheat package
2) To investigate the productivity changes in bread wheat across the varying levels of improved bread wheat package adoption intensity.

2. RESEARCH METHODS

2.1. Description of the study area

The East Gojam zone in Ethiopia comprises 18 districts and is situated approximately 300 km and 260 km away from the country's capital city of Addis Ababa and the regional capital city of Bahir Dar, respectively. Its coordinates are 10° 19' 60.00" North and 38° 00' 0.00" East. The zone has a total population of 2,358,051, with 1,154,740 males and 1,203,311 females. The primary occupation of farmers in the area is mixed farming, and the zone is dominated by mixed agricultural systems (Bureau of Finance and Economic Development, 2013b). The map of the study areas is presented in Figure 2.1 of the previous chapter.

2.2. Sampling technique and sample size determination

The sampling strategy used in this study involved a combination of multi-stage purposive and random sampling methods, as well as Probability Proportional to Size (PPS) sampling. East Gojam Zone of the Amhara National Regional State was purposefully selected as the first stage, and the specific study areas of Baso Liban and Debre Elias districts were selected in the second stage. These districts were chosen due to their potential for wheat production, availability of representative sample respondents, and the researcher's familiarity with the study areas. From the 37 kebeles in the two districts, eight rural kebeles were selected as a representative sample. PPS sampling was then used to select three kebeles from Debre Elias and five kebeles from Baso Liban as specific study areas. As indicated in Figure 2.1 above, Yelemelmo, Lemechem, Dendegeb, Kork, and Dogemo kebeles were considered from Baso Liban district while Guay, Yekegat, and Debre Elias Zuria kebeles were considered from Debre Elias district. The total sample size of the study was determined to be 450 farmers using a sample size determination formula (Yamane, 1967).

2.3. Data Collection Methods

To gather primary data, this study employed structured interview schedules, Focus Group Discussions (FGDs), Key Informant Interviews (KIIs), and personal observations. These methods were used to collect both qualitative and quantitative data from a sample of smallholder farmers involved in wheat production, development agents, crop experts, and key informants. The data gathered from these primary sources were then supported and triangulated with available secondary data sources including regional and district annual reports, research findings, journals, publications, thesis, dissertations, books, proceedings, and other relevant sources.

2.4. Data Analysis Methods

2.4.1. Specification of the Double - Hurdle Model

This article has two important outcome variables. The first dependent variable is the adoption of Improved Bread Wheat Seed (IBWS) that assumes a simple yes or no (adopter or non-adopter) answer, which is a classic dichotomous variable. The second dependent variable is the Adoption Intensity of the IBWP, measured using adoption index scores. The adoption index for each respondent is calculated using equation 1 presented in the first chapter. The model of this study is based on the micro-level data, where each of the sample respondents (Decision Making Units) must choose whether to adopt or reject the IBWP and then its intensity if adoption takes place. Several studies employ the conventional binary dependent variable models like Logit and Probit models in studying the probability of adopting or rejecting a technology (Finger and El Benni, 2013, Mariano et al., 2012). However, the objective here goes one-step beyond mere understanding of probabilities of adopting or rejecting to understanding how much of the components in the wheat production package are adopted. The Tobit model and Cragg's Double Hurdle model are most commonly used econometric methods under such scenario. According to Tobin (1958) and Medoff (1993), suggest the application of the Tobit model when the research intention is to handle censored dependent variable, where the variable of interest is observed only if it exceeds a certain threshold level. Its estimation is relatively straightforward and most commonly used model. Its assumption is that there is an underlying, continuous variable that is censored or truncated at a specific value. The model estimates the parameters for both the binary decision of whether the variable is observed or not and the continuous values above the threshold.

On the other hand, Cragg's Double Hurdle Model is specifically developed to address situations where the dependent variable has a large number of zero values and two distinct decision processes are involved. It is commonly used in econometrics when analyzing data involving two stages of decision-making, such as purchase decisions or participation in a specific activity. The model estimates separate equations for the probability of observing a zero value (the first hurdle) and the conditional distribution of positive values (the second hurdle). By modeling these two stages separately, the Double Hurdle Model allows for a more flexible and nuanced analysis of the data generating process. The choice between the Tobit Model and Cragg's Double Hurdle Model depends on the specific research question and data characteristics. The Tobit Model may be more appropriate when the focus is on modeling the censoring mechanism and estimating the parameters of the continuous variable above the threshold. On the other hand, if the research question involves understanding the factors influencing zero values and positive values separately, and capturing the two stages of decision-making, then Cragg's Double Hurdle Model may provide more insights (Cragg, 1971, Ogada et al., 2014).

Besides, the choice of a suitable analysis model for this specific research context was decided based on results of a combination of model selection criteria and diagnostic tests. For instance, the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC) are important measures that balance a model goodness of fit along with its complexity (Cragg, 1971, Gujarati and Dawn, 2009, Leathers and Smale, 1991, Tobin, 1958). Under the current study, both the AIC and BIC were found to be the lowest for the DH model than for the Tobit, Probit, and Logit models indicating its goodness of fit. As a result, this study reverts to apply the Double Hurdle model, which is developed by Cragg (1971).

The DH model, which is a parametric generation of the Tobin (1958) model was applied in this study due to the assumption that adoption and adoption intensity of IBWP are influenced by different sets of variables. Thus, the two decisions in this study were the decision to adopt Improved Bread Wheat Seed (IBWS) and the decision how much of the practices in the IBWP to adopt (Adoption Intensity). The first decision variable (Y) takes the value 1 for farmers who have adopted improved bread wheat seed and 0 otherwise. However, the expected utility of adopting a technology is a latent variable. Thus, the first decision (adoption hurdle) equation can be written as:

$$\boldsymbol{\Upsilon_i}^* = \beta_1 X_{1i} + \beta_2 X_{2i} + \ldots + \beta_{11} X_{11i} + \varepsilon_{1i} \ldots\ldots\ldots\ldots\ldots [2]$$

$$\Upsilon_i = \begin{pmatrix} 1 \; if \;\; \Upsilon_i^* > 0 \\ 0 \; Otherwise \end{pmatrix}$$

Where, $\boldsymbol{\Upsilon_i}^*$ is the latent variable for the decision to adopt Improved Bread Wheat Seed (IBWS) by the i^th farmer, β_1 to β_n are the coefficients for the explanatory variables X_{1i} to X_{ni} and ε_{1i} is the error term.

The Double Hurdle model estimates the probability of adoption ($\Upsilon_i = 1$) and the level of adoption intensity (W_i) separately, and then combines them to estimate the overall impact of the explanatory variables on adoption and intensity of adoption of the IBWP. Therefore, the AI (the intensity hurdle) of IBWP is specified in a Tobit like function as specified below:

$$\boldsymbol{W_i}^* = ZX_{1i} + \beta_2 X_{2i} + \ldots + \beta_{11} X_{11i} + \varepsilon_{1i} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$W_i^* = Z_i \beta_i + \mu_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . (4)$$

$$\mathbf{W_i = W_i^* = Z_i\boldsymbol{\beta}_i + \boldsymbol{\mu}_i \; if} \begin{pmatrix} \mathbf{1 \; W_i^* > 0 \; and \; \Upsilon_i^* > 0} \\ \mathbf{0 \; Otherwise} \end{pmatrix}$$

Where $\mathbf{W_i}$ here is the observed responses (Adoption index that refers to the ratio of the total number of actually applied recommendations to the total number of recommendations included in the IBWP), Z_i is a vector of the household characteristics while β_i is a vector of parameters. Farmers decision whether to adopt or reject and their AI can be modeled jointly if they are simultaneously made by farmers while it can also be modeled independently if they are made separately or sequentially if one decision is made first and affects the other one (this is the dominance model) (Finger and El Benni, 2013). If the independence model applies, the error terms are distributed as follows: $\mathcal{E}_i \sim N(0, 1)$ and $U_i \sim N(0, \delta^2)$. If both decisions are made jointly (the Dependent DH), the error term can be defined as $(\mathcal{E}_i \, U_i) \sim BV\,N\,(0, \Upsilon)$ where

$$\Upsilon = \begin{bmatrix} 1 & \rho^{\delta} \\ \rho^{\delta} & \delta^2 \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [5]$$

If the sample household's adoption decision and its intensity tend to have relationships, then the model is said to be a dependent model and such relationship can be expressed as follows:

$$\rho = \frac{Cov\,(\epsilon_i u_i)}{\sqrt{Var(\epsilon_i)}\; Var\,(u_i)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [6]$$

If ρ = 0 and there is dominance (the zeros are only associated with non-participation, not standard corner solutions) then the model decomposes into a Probit for participation and standard OLS for Y. Following (Tobin, 1958) we assume that the error terms and $\boldsymbol{\varepsilon_i}$ and $\mathbf{u_i}$ are independently and normally distributed and thus we have the following expression:

$$\begin{bmatrix} \epsilon_i \\ \mathrm{u}_i \end{bmatrix} (N) \left[\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{bmatrix} 1 & 0 \\ 0 & \delta^2 \end{bmatrix} \right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [7]$$

Finally, the observed variable in a DH model is $W_i = Y_i Wi^*$ and the log-likelihood function for the DH model is:

$$LogL = \sum_0 ln \left[1 - \Phi(\chi_i \alpha)\, \Phi\left(\frac{z_i}{\delta}\right) \right] + \sum_1 ln\, A = \left[\Phi(z_i \alpha) \frac{1}{\delta} \left(\frac{Y_i - \chi_i}{\delta} \right) \right] \ldots\ldots\ldots\ldots [8]$$

Therefore, we employ the Double – Hurdle model to estimate smallholder farmers' adoption decision and their AI. A simple specification test that evaluates for Cragg's DH-model against the Tobit model can be used using the same set of explanatory variables, through a comparison of the log-likelihood function values of the Tobit, Probit and Truncated models estimated. Assuming that the same set of independent variables appears in all the three equations, the following value λ will be distributed as a chi-square random variable with degrees of freedom equal to the number of explanatory variables under the null hypothesis that the Tobit model is the correct (Goodwin et al., 1993, Heckman, 1979).

$$\lambda = -2\, \{ Ƒ_{Tobit} - Ƒ_{Probit} - Ƒ_{Truncated} \} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

Where $Ƒ_i$'s represent the respective estimated log-likelihood function values.

2.4.2. The Average Treatment Effect Estimation

In an experimental impact evaluation approach, the causal effect of technology adoption on smallholder farmers' productivity has been investigated by comparing the mean productivity between adopter and non – adopter groups. This approach, however, assumes a pure random assignment of farmers' to treatment and control groups. It also fully attributes any difference in outcome (productivity under this case) between the groups to the treatment (Improved Bread wheat Seed adoption here) at the complete exclusion of pre-existing differences between adopter and non – adopter groups (Reed et al., 2021, Tesfaye et al., 2016). The other important assumptions in the experimental approach is absence of spillover effects, stable treatment effects, compliance, validity of assumptions, and outcome measures. The no spillover effect assumption refers to the fact that the treatment has no effect on farmers in the control group or farmers' outside the study. Isolating the impact of the treatment (adoption of IBWS) on the treated group (adopters of IBWS) is plausibly possible if the assumption of no spillover effect does hold water (Morgan, 2018). The stable treatment effects assumption implies that the effect of the treatment don't vary on temporal differences that allows for generalization of the treatment effect beyond a specific study period (Morgan, 2018, Reed et al., 2021).

The assumptions of the experimental impact evaluation explained above does not hold water under the current study. First, technology (IBWS) is not randomly assigned, but shaped by farmers' own decision and self-selection. Second, the decision to adopt or reject the technology is determined by a mix of agronomic, socio-economic, institutional, and psychological variables and these factors may directly affect farmers' level of bread wheat productivity. If adoption of IBWS has an effect on farmers productivity, one cannot safely distinguish whether the effect on productivity is caused by the adoption of the IBWS or other covariates considered in the study such as farm experience, gender, amount of credit, frequency of extension contact, and other agronomic factors. Identifying the exact factor contributing to the productivity of the smallholder farmers' demand the application of ATE models. Following Rosenbaum and Rubin (1983), the 'treatment effect' can be defined as the difference between bread wheat productivity farmer *i* receives in the two states of the world:

(i) The farmer that adopts IBWS, $A = 1$, and
(ii) The farmer that does not adopt IBWS, $A = 0$:

$$ATE\ (\lambda_i) = Y_i(1) - Y_i(0) \ldots\ldots (10)$$

The Average Treatment Effect (ATE or $\boldsymbol{\lambda_i}$) is defined as the expectation of the treatment effect across all farmers. A problem arises when using non-experimental data because only one of these states is actually observed; that is, either Yi (1) or Yi (0) is observed for each farmer *i*, but not both. The unobserved productivity is called the counterfactual productivity. Accordingly, it is co nvenient to express the ATE (λ_i) as:

$$E(\lambda_i) = P * \lfloor E(\Upsilon^1)|A = 1 - E(\Upsilon^0 |A = 1)\rfloor + (1 - P * \lfloor E(\Upsilon^1)|A = 0 - E(\Upsilon^0|A = 0)\rfloor \ldots\ldots (11)$$

Where P is the probability of observing a farmer adopting the IBWS. In Equation (11), the ATE for the whole sample is the weighted average of the technology (treatment) effect for IBWS users and non-users. In estimating the ATE, both counterfactual productivity, $E\ (Y^0|A = 1)$ and $E\ (Y^1|A = 0)$, should be constructed. Intending to avoid complications, several studies emphasize on one or the other of the respective counterfactuals. The average IBWS adoption effect on the adopter category or the Average Treatment Effect on the Treated (ATT) is the most important evaluation parameter and is given by:

$$\lambda_i = E\ (\lambda|A = 1) = E\ [\Upsilon\ (1)|A = 1] - E\ [\Upsilon\ (0)|A = 1] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (12)$$

Now, given Equation (12) above, one can directly see the problem of selection bias as the second term on the right hand side is unobservable. If $E[Y\ (0) \mid A = 0] = E[Y\ (0) \mid A = 1]$, non-adopters of IBWS can be used as an adequate comparison group. Yet, this assumption is rarely satisfied as this study rely on non-experimental data. According to Rosenbaum and Rubin (1983), matching is the best way-out for such a problem. The rationale behind the matching exercise is that one infers the behavior of a given technology adopter by matching them with an observationally equivalent technology non - adopters. This would actually assist the researcher to have a similar situation to what really would have been observed in a random experiment. To apply this approach, however, the following two assumptions are expected to hold true.

The condition independence assumption: Given a series of observable covariate Xs, which are not affected by technology adoption, the potential well-being is independent of technology assignment:

$$Y^0, Y^1 Ꝗ T|X, \forall X$$

Where Ꝗ denotes independence. If the assumption is fulfilled, holding the observable covariates constant, the non-adopter's well-being has the same distribution that adopters would have experienced had they not adopted the technology. Accordingly, technology can be deemed as randomly assigned. It follows that the ATT can be expressed as follows:

$$\lambda_{ATT} = E(\lambda|A = 1) = E[\Upsilon(1)|A = 1, X] - E[\Upsilon(0)|A = 1, X \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots .. (13)$$

However, it is quite difficult if there are multiple observable co-variates that affect smallholder farmers' IBWS adoption and productivity. For example, if X contains *s* covariates that are all dichotomous, the adopter must be matched with a non-adopter having identical values for all 2^S variables. This is obviously a problem when *S* is relatively large and/or the sample size is relative ly small. To deal with this dimensionality problem, Rosenbaum and Rubin (1983) suggest using a balancing scores method. The method shows that if potential adoption is independent of technology adoption conditional on covariates *X*, it is also independent of technology adoption conditional on a balancing score. The propensity score, defined as the possibility of farmer adopting technology conditional on covariates *X*, is one possible balancing score:

$$P_i(X) = Prob(A = 1|X) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (14)$$

This conditional probability is the propensity score, which allows one to identify similar farmers. The second assumption relates to the common support or overlap condition. It rules out perfect predictability of *A* given *X*, so that

$$0 < P(A = 1|X < 1 \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . (15)$$

This condition guarantees that farmers with the same *X* values have a positive probability of being both an adopter and a non-adopter. Accordingly, ATE is only defined in the region of this common support. Farmers falling outside this region are not included in the estimation of ATE.

The common support assumption: improves the matching quality by excluding farmers at the tails of the propensity score distribution. It ensures that characteristics observed in the technology adoption group can also be observed among the non-adopters (Bryson et al., 2002). A downside of the common support assumption is that it reduces the sample size. If the proportion of lost farmers is too large, this might raise concerns that the remaining farmers are insufficiently representative of the population, thus casting doubt on the associated ATE estimates. Assuming that both the conditional independence and common support conditions hold, the propensity score-matching estimator for ATT can be expressed as follows:

$$ATT\boldsymbol{\lambda}^{PSM} = E_{p(x|A = 1)}\{E[\Upsilon(1)|A = 1, P[X]\} - E[\Upsilon(0)|A = 0, P(X)]\} \ldots \ldots \ldots \ldots .. (16)$$

Equation (16) reveals that the propensity score matching estimator is simply the mean difference in the economic efficiency of the two groups (IBWS users and non - users) of the study area.

2.4.3. The Regression Adjustment Treatment Effect

Studies in randomized experiments, project and policy interventions, agronomic and clinical trials often use the Average Treatment Effect (ATE) as a metric to compare outcomes between treatment and control groups. The ATE measures the mean outcome difference between decision – making units assigned in the treatment and control arms. Though the origin for the ATE is in a pure experimental science, it has been frequently applied in observational studies. There are different variants of ATE estimators that includes Propensity Score Matching (PSM), Nearest Neighbor Matching (NNM), Augmented Inverse – Probability Weighting (AIPW), Inverse – Probability – Weighted Regression Adjustment (IPWRA), Inverse – Probability Weighted (IPW), and Regression Adjustment (RA) (Li et al., 2016, Becker and Ichino, 2002, Grilli and Rampichini, 2021). The RA estimator is the best option ATE estimator in times when the dependent outcome is continuous (like productivity, wage, birth weight) while the treatment variable is binary (like adoption status expressed as adopter versus non - adopter, survival status expressed as dead versus alive) with a mix of various outcome independent variables. The interest in the current study is to estimate the effect of farmers' adoption status of IBWS on their productivity controlling for the various outcome explanatory variables. Thus, the RA variant of the ATE can best fulfill the interest of this study.

3. RESULT AND DISCUSSION

3.1. Characteristics of Adopters and Non-adopters

Table 5 below summarizes the mean, standard deviation, t-values, and p-values of the continuous variables. Adopters and non-adopters had shown a significantly high difference in the calculated mean values of their adoption index as suggested by a t-value of –30.62 at p = 0.000. Adopters and non – adopters of this study were found to be quite different in terms of the various socio – economic, institutional, and agronomic variables. Adopters were found to be older with more years of experience in bread wheat production. They also own a greater number of livestock and have greater plot and family size than non – adopters. Yet, no significant difference was manifested in the grade level of adopters and non – adopters as can be proved from a calculated t – value of 1.3901 (p = *.9171*). Moreover, these two categories had no any outstanding difference in terms of the amount of credit. Adopters, on average have received only 273.19 Ethiopian birr per year, which do not bring any notable difference with non-adopters. In addition, adopters had better frequency of contact with the extension workers than non-adopters. Additionally, a statistically discernible difference was observed between these two groups in terms of making use of different agronomic practices. For instance, adopters, on average had practiced a hand weeding frequency closer to the recommendation (a twice hand weeding frequency) than non-adopters. Similarly, adopters have been applying bread wheat seed rates, fertilizer, and hand weeding frequencies closer to what is recommended than non-adopters. A quite agreeable finding was also reported by other studies (Abeyo et al., 2020). A χ^2- test has been carried out to check if there exists a significant difference between adopters and non–adopters for all categorical variables considered for the study. Accordingly, an insignificant difference has been witnessed between adopters and non-adopters in terms of gender (χ^2 = .781, p= .377). Similarly, adopters and non-adopters were not significantly different in terms of their membership in seed multiplication and marketing cooperatives and sowing methods (Appendix Table A6).

As can be inferred from Table 5, the adoption index showed a significant difference between adopters and non-adopters with a t-value of -30.62 and p-value of 0.000. This suggests that adopters have a higher level of adoption of the recommended practices than non-adopters do. The study also found that adopters were older and had more years of experience in bread wheat production compared to non-adopters. Adopters also had a greater number of livestock and larger plot and family sizes. However, there was no significant difference in the grade level of adopters and non-adopters, and the amount of credit received. Adopters had better frequency of contact with extension workers than non-adopters, and they made use of different agronomic practices closer to what is recommended, such as hand weeding frequency, bread wheat seed rates, fertilizer, and hand weeding frequencies. This finding is consistent with other studies. The study also conducted a chi-square test to check for significant differences between adopters and non-adopters for all categorical variables considered in the study. There was no significant difference between adopters and non-adopters in terms of gender, membership in seed multiplication and marketing cooperatives, and sowing methods. The results are presented in Appendix Table A6.

Table 5: Descriptive statistics for Improved Bread Wheat Seed adopters and non-adopters

Variables	Adopter		Non-Adopter					
	Mean	Std. Err	Mean	Std. Err	Combined Mean	Mean Dif.	t- value	p value
Adoption Index	.6054	.0112	.000	.000	.5489	-.6054	-17.387	.0000
Productivity	39.578	.2541	29.381	.4559	38.627	-10.197	-12.652	.0000
Age of the respondent	43.103	.5954	36.071	.8671	42.447	-7.032	-3.744	.0002
IBWP use Experience	17.025	.5126	2.214	.4667	15.642	-14.810	-9.2210	.0000
Grade level	1.748	.1316	2	.4132	1.7711	.2525	.5576	.5774
Family size	5.995	.155	4.0714	.185	5.816	-1.924	-3.9380	.0001
Dependency Ratio	.536	.0131	.571	.0167	.5389	.0535	.8550	.3930
Tropical Livestock Unit	6.662	.2367	5.974	.5664	6.662	-.7591	-.9989	.3184
Land covered with IBWS	.7191	.0348	.000	.000	.7191	-.7931	-6.971	.0000
Hand Weeding Frequency	1.5980	.0356	1.905	.0458	1.627	-.3067	2.7405	.0064
Row spacing	18.076	.4449	5.238	.2381	16.8778	-12.8379	-9.1324	.0000
Extension contact frequency	1.623	.0534	.7381	.0905	1.54	-.8845	-4.9439	.0000
Credit Amount	4149.027	237.4739	2592.857	625.8039	4003.784	-1556.17	-1.9119	.9170
Seed rate	180.8211	4.2304	326.1905	16.2763	194.3889	145.3694	10.2551	.0000
Fertilizer Rate	141.6563	4.2780	33.881	2.0878	131.5972	-`07.7753	-8.0650	.0000

Source: Own Computation (2022)

3.2. Adoption of Agronomic Recommendations in Bread Wheat Package

Adoption of improved agricultural technologies has often been viewed as a matter of using one or few components of recommended production packages. However, empirical evidence has shown that the use of improved seeds alone, without a parallel application of recommended fertilizers, agro-chemicals, and fundamental agronomic practices, does not fully exploit the yield potential of improved crop varieties, especially improved wheat varieties (Idrisa et al., 2012, Mideksa et al., 2017). Additionally, farmers may adopt agronomic and other recommendations without actually using improved seeds. To address this issue, the International Maize and Wheat Improvement Center (CIMMYT) developed the Integrated Bread Wheat Productivity (IBWP) package, which includes a set of complementary inputs and agronomic practices aimed at maximizing the yield potential of improved wheat varieties. This package has been widely disseminated to smallholder farmers in different countries.

The current study found that adoption of the IBWP was promisingly high, with only 29.8% of the total respondents failing to adopt it, while 70.2% adopted it. However, adopters were quite heterogeneous in their level of adoption of the different components included in the IBWP. It was evident that wheat growers in the study area did not fully adopt all the recommendations included in the IBWP. This implies that smallholder farmers tend to adopt one or few components of the recommended package without a parallel adoption of all complementary inputs and agronomic practices. The findings of this study suggest that there is a need for targeted extension services that emphasize the importance of adopting all the recommended components of the IBWP. Furthermore, it is important to tailor these recommendations to the specific needs and resource constraints of smallholder farmers in different regions, to ensure that they are able to fully exploit the yield potential of improved wheat varieties.

Poor application of agronomic practices was frequently mentioned as an important factor behind the low wheat yield in Ethiopia (Tiruneh et al., 2015, Mesay et al., 2013). To address this issue, a package of improved bread wheat production recommendations intended to maximize the bread wheat yield potential. Land preparation was one of the essential components included in the IBWP recommendations, with a recommended tilling frequency of 3 to 5 times. However, the use of these recommendations varied significantly between adopters and non-adopters of the study, particularly in terms of land tilling frequency and application of other agronomic practices, as shown in Table 5 above. The mean tilling frequency of non-adopters was significantly lower than that of the adopters.

Row planting is another crucial recommendation in the wheat production package. However, this study found that adopters and non-adopters differed significantly in their choice of sowing methods, with adopters relying heavily on row planting, while non-adopters mostly used broadcasting. Participants in the focus group discussions (FGD) revealed that a lack of sufficient labor and inability to employ hired daily laborers were important factors pushing farmers to stick to the traditional broadcasting method. The discussants also mentioned that this was a major challenge they faced in implementing other recommended agronomic practices, including multiple tilling and weeding practices. These findings suggest that there is a need for targeted extension services to address the labor constraints faced by smallholder farmers in the study area. This could include training on alternative labor-saving techniques such as the use of appropriate machinery, intercropping, and crop rotations. Moreover, there is a need to tailor the recommended agronomic practices to the specific needs and resource constraints of smallholder farmers in different regions to ensure better adoption and implementation. Overall, this study highlights the importance of understanding the underlying reasons for non-adoption of recommended agronomic practices and tailoring extension services to address these challenges effectively.

Agricultural technologies are often interdependent, and the application of one technology may not result in the desired yield increase unless other complementary inputs are also adopted. This is particularly true for improved seeds, which may only increase yields if accompanied by the optimal amount of fertilizer and proper seeding rates applied (Mideksa et al., 2017, Gashaw et al., 2018, Alemu and Abera, 2013). In the study areas, the recommended types of chemical fertilizers were NPS and Urea, with the recommended application rates of 200 and 100 kilograms per hectare, respectively (ATA, 2015). However, as shown in Table 5, there was a clear difference in fertilizer application rates between adopters and non-adopters. On average, respondents applied 132 and 110 kilograms of NPS and Urea per hectare, respectively. Non-adopters applied, on average, 87.12 kilograms less NPS and 84.88 kilograms less Urea than adopters. When asked why they did not adhere to the recommended fertilizer rates, farmers explained that they had followed the recommended rates for more than ten seasons but had experienced diminishing yield gains over time, which prompted them to increase their fertilizer application rates.

A study conducted in Kaffa zone of Southern Ethiopia found that wheat-growing farmers used varying fertilizer rates, but generally below the recommended levels. The difference in fertilizer rates could be attributed to various factors, including capital constraints, insufficient and untimely distribution of fertilizers, and other socio-economic factors affecting the demand and supply of chemical fertilizers. Therefore, the adoption of the IBWP recommendations should be complemented by the parallel adoption of other complementary inputs and agronomic practices, including the optimal application of chemical fertilizers, proper seeding rates, and other recommended agronomic practices.

Effective management practices are essential for achieving maximum wheat yield. Studies have identified various factors, including spacing between rows and plants, crop rotation, tillage practices, and weed control methods, as critical in influencing wheat yield (Tariku, 2012, Kebede et al., 2017). According to ATA (2015) recommendation, a spacing of 30 centimeters between rows is recommended. However, a recent study revealed that the average spacing between rows among farmers was only about 17 centimeters, which is narrower than the recommended spacing. This difference in spacing between adopters and non-adopters was found to be highly significant ($t = -18.863$, $p = 0.0000$). During key informant interviews and focus group discussions, farmers identified lack of appropriate sowing machines, small land sizes, and labor shortages as the primary challenges to maintaining proper spacing between rows. To control weeds, which is also an important component of the wheat production package; farmers reported using a combination of pesticides and hand weeding. Blending these two methods is highly recommended since the disadvantages of one method can be compensated for by the advantages of the other. For instance, weeds that are tolerant to chemicals can easily be avoided through hand weeding (ATA, 2015). Farmers' considered in this study reportedly used both chemicals and hand weeding to control weeds.

3.3. Econometric Results

Results of the Cragg's double hurdle model, which incorporates the probit model in the first tier and truncated normal regression in the second tier, are summarized and presented in Table 6 The Variance Inflation Factor (VIF) was calculated to check if there were problems of multicolinearity among the quantitative variables considered in the study. Serious multicolinearity problem has been observed for two of the variables considered in the study (Improved Bread Wheat Seed Use Experience and Dependency Ratio). To solve the problem, these variables were dropped, and the test was re-conducted again. Finally, we have arrived at a situation where all the VIF were less than 5.16 and the mean VIF turns out to be 2.72, indicating multicolinearity is no longer a problem (Appendix Table A5). Besides, the Wald chi^2 (15) 2175.92 with a p-value (Prob > chi^2) = 0.0000 tells us that the Cragg's DH model is statistically significant as compared to the model with no predictors.

Among the surveyed farmers, the majority of them (70.2%) cultivated bread wheat using IBWS against 29.8% who have used local seeds or seeds recycled more than 5 times. The highest adoption status here could be attributed to improvement in farmer's awareness due to extensive efforts made by development workers and other stakeholders. Though a significantly high segment of the farmers was adopters of IBWS, this study has witnessed a markedly high difference in the adoption index of farmers within the adopter category itself. This implies that adopters make a partial than complete adoption of all the components included in the IBWP. The relatively better adoption of IBWS in the study area could be attributed to the strong farmer-research-extension linkage that stayed for the past several years. Farmers of the study area have a long-held tradition of working together with different governmental and Non-Governmental Organizations (NGOs) including higher learning institutions, research centers, seed enterprises, and the private sectors. The information and experience from these different sources along with the benefits that farmers have enjoyed by working together with these stakeholders could incentivize farmers' adoption of the IBWS. The border effect of agricultural research centers and academic institutions is reported in other studies too. For instance, and (Ragasa et al., 2013) found that long-held customs of working together and proximity between stakeholders involved in crop production ensure sustainable adoption of innovations and reduce technology dis–adoption. The role of research and the seed sector is also well documented by (Bishaw and Atilaw, 2016). Thus, the higher proportion of IBWS users in the study area is not surprising. This finding also signals the need for efficient and sustainable linkage among the different actors involved in technology development, diffusion, and adoption. The next section presents and discuss the results of Cragg's Double Hurdle model to see the relative influence of the socio-demographic, economic, institutional, and plot-level variables on adoption and adoption intensity of IBWP.

3.3.1. Adoption and Adoption Intensity of Improved Bread Wheat Package

Research efforts that deal with mere identification of determinants of adoption of IBWP may not be sufficient to come–up with the best policy actions. It is therefore highly imperative to understand the relative influence of each determinant to allow policymakers and implementers in prioritizing their interventions. Thus, this section deals with the influence of each variable on the probability of farmers' adoption decision and their adoption intensity (Table 6). Gender of the household head (being male) was expected to have a significant effect on the decision to adopt or not and on how much of the recommendations to adopt. Results of the Double Hurdle (DH) model in the first tier turned out in favour of our prior expectation at $P>0.000$. It indicates that the probability that male household heads decision to adopt IBWS is higher by 10.22 units than female household heads. Similarly, the coefficient for gender in the second tier turned out to be highly significant at $p>0.080$. This indicates that male household head's propensity to adopt more or the entire components of the IBWP is higher by 0.025 units than female household heads. In other ways, this can be translated as males tend to adopt more components of the recommendations in the IBWP than their female counterparts do.

There can be several explanations for the weak adoption intensity of female-headed farmers. During the key informants' interview and FGDs, farmers vehemently oppose the idea that there is gender parity in the extension service provision. Therefore, women's weak AI could be explained by lack of inclusive agricultural extension service equally tailored to men and women. This result is consistent with several other studies (Ogada et al., 2014, Gebre et al., 2019). The same authors revealed that the probability of adopting inorganic fertilizer and improved maize variety is higher for male-headed households and this possibly indicates that female – headed households are more resource constrained to adopt and try new technologies. A similar argument and explanation could be adopted in this study too. An opposite finding was reported by Kebede et al. (2017) who claim that the chances of adoption of agricultural technologies is higher for women than men, which suggests success in targeting vulnerable female households in Ethiopia.

The age of the farmer had the same positive and significant effect both on the decision to adopt and how much of the components in the IBWP are adopted. Keeping other factors constant, a one-year increase in the age of the farmer increases the probability of adopting IBWS by 1.214. Similarly, the coefficients in the second tier inform us that older farmers tend to adopt more components of the recommendations in the IBWP. A one-year increase in farmer's age increases AI by .002. A study carried out by Tariku (2012) is in line with the current finding. This author asserts that aged farmers have better chances of accumulating assets and resources than younger farmers that could enable them to be less risk-averse and cope with the risks associated with the use of agricultural technologies. Similarly, Kebede et al. (2017) found that older farmers accumulate more knowledge and are better able to exploit social networks, rendering innovations less risky, capitalize knowledge and information, and reducing information inefficiencies. These explanations could justify the current finding. In addition, a one-year increase farmers experience was associated with a probability of adopting improved bread wheat seed with 2.457 units at p=0.001. Likewise, a one-year increase in making use of IBWP increases farmers AI by 0.014 units. This may be because increased experience in agriculture may bestow farmers with knowledge and information that increase their rationality in making use of farm innovations. The finding in this regard was in agreement with other findings (Altaye and Mohammed, 2013). Paradoxically, Nazziwa-Nviiri et al. (2017) reported quite a different finding. They argued that aged farmers tend to have a shrunken planning horizon that reduces their incentives to invest in the future while younger farmers tend to be more flexible and interested in trying out new things.

The coefficient for education was insignificant in both hurdles. Family size of the household was found to have a significantly high effect on the adoption and AI of IBWP. A one-person increase in the family size increases the probability of the adoption of IBWS by .504 units. Similarly, an additional one-person increase in the family member has increased the AI by 0.3%. This is plausible because the decision to adopt IBWP depends on labor availability, which is largely provided by household members. Moreover, most of the recommendations included in the IBWP such as row planting, hand weeding, repeated tillage, split fertilizer application, and so forth are quite labor-intensive. Thus, farmers with more family members tend to have better adoption propensity than those with fewer family sizes. The other probable reason could be the shortage of land sufficient to satisfy the crop consumption demand of large family size. Therefore, it is logical that households with larger family sizes undertake crop intensification to meet their crop consumption requirements through the adoption of high external inputs such as seed, fertilizer, and other agrochemicals. Other studies also concluded that large family size is normally associated with a higher labor endowment that would enable a household to accomplish various agricultural tasks on a timely basis thus raise productivity. Unlike the findings in this study, (Ghimire and Huang, 2015) found no correlation between adoption and household size. Such a relationship between adoption and family size could be attributed to the fact that larger family size does affect household disposable income and resource allocation decisions. More family size could lead to subsistence needs leaving no or very few resources available for purchasing farm inputs. The paradoxical effect of family size on adoption could have different explanations. The first probable explanation is a difference in the type of crops considered for the study. Some crops such as "*tef*" and wheat tend to be quite labor-intensive as compared to maize. The use of hired labor and membership in labor sharing traditional cooperatives for different farm activities could be the other explanation.

The dependency ratio ended up in thwarting both adoption and AI. A unit change in the dependency ratio of the respondents has reduced the probability of IBWS adoption and the AI by 34.11 and 0.077 units, respectively. This means that higher dependency ratio has forced farmers to go for cheaper and unimproved bread wheat production practices. There could be two plausible explanations for the negative effect of the dependency ratio on adoption and AI. First, the dependency of several family members on one or few members of the family may increase the drudgery and amount of active man-hour spent on non–agricultural activities. This reduces the amount of family labor required to implement the different labor-intensive recommendations included in the wheat production package. Second, farmers with a higher dependency ratio tend to have urgent and high consumption demand that they are compelled to reject technology or make a partial adoption of the technology that could negatively reduce farmers AI. The effect of the dependency ratio witnessed under the current study was supported by earlier studies too (Dawit, 2012, Teshome and Abate, 2013).

Number of animals owned by farmers have shown a significantly high positive impact on both adoption status and AI. A unit change in the TLU has raised farmer's the probability of adoption and AI scores by 0.381 and 0.044 units, respectively. The positive effect of TLU on adoption and AI might be explained by the fact that farmers with better livestock sizes can sell animals and use it for the purchase of farm inputs against those who do not own animals or own a few numbers of animals. In the study area, animals are the most common liquid assets available at farmer’s disposal that serve as insurance against production failure and other production misfortunes. Similar studies made by (Finger and El Benni, 2013, Nazziwa-Nviiri et al., 2017) concluded that livestock assets are important risk-coping mechanisms that encourage the adoption of farm technology. Adoption of recommendations inculcated in wheat production package demands availability of sufficient labor. Another possible explanation for the significant effect of animals on AI would therefore be their role in serving as a source of agricultural draught power. Therefore, it is not surprising that TLU has a significantly high positive effect on the adoption intensity of IBWP. FGD discussants mentioned that livestock ownership has encouraged farmers to adopt wheat and other crop production enhancing technologies. For instance, the need for straw as a livestock feed was one of the most frequently mentioned important reasons to engage in wheat production. Similarly, according to Gashaw et al. (2018), the complementarity of livestock and crop production justifies the direct nexus between TLU and the adoption of crop technologies as crop residues can be used as animal feeds while livestock manure could be used for soil conditioning and management .

Table 6: Coefficients of Cragg's Double Hurdle Model

Estimating Cragg's tobit alternative	Number of Obs = 450
Assumes conditional independence Log pseudolikelihood = 439.5083 Std. err. adjusted for 450 clusters in HHID	Wald chi2(15) = 2175.92 Prob > chi2 = 0.0000

Variables	Coefficient	Robust Std. Err	Z	P>Z	95% Confidence Interval	
Tier 1 (Probit)						
Gender (Male)	10.215	1.039	9.830	0.000	8.178	12.252
Household Head Age Square	-0.013	0.001	-12.440	0.000	-0.015	-0.011
Household Head Grade	0.469	0.126	3.720	0.000	0.222	0.716
Family Size	-1.564	0.293	-5.340	0.000	-2.138	-0.990
Tropical Livestock Unit	0.011	0.074	0.150	0.877	-0.133	0.156
Land Size	108.215	4.990	21.690	0.000	98.434	117.996
Seed Recycling Frequency	6.169	0.637	9.690	0.000	4.921	7.416
Tilling Frequency	0.337	0.395	0.850	0.395	-0.438	1.112
Hand Weeding Frequency	8.278	1.275	6.490	0.000	5.780	10.777
Spacing between Rows	0.700	0.048	14.530	0.000	0.606	0.795
Sowing Method	-2.801	3.514	-0.800	0.425	-9.688	4.086
Frequency of Extension Contact	1.437	0.551	2.610	0.009	0.356	2.517
Amount of Credit	-0.000	0.000	-5.000	0.000	-0.000	-0.000
Seed Rates	0.002	0.004	0.570	0.572	-0.006	0.011
Fertilizer Rate	0.435	0.022	19.610	0.000	0.391	0.478
_cons	-75.125	5.004	-15.010	0.000	-84.932	-65.318
Tier 2 (Truncated Normal)						
Gender of the Household Head	0.025	0.014	1.750	0.080	-0.003	0.053
Household Head Age Square	0.002	0.000	3.560	0.000	0.000	0.000
Household Head Grade Level	0.003	0.002	1.560	0.119	-0.001	0.006
Family Size	0.023	0.004	5.620	0.000	0.015	0.031
Tropical Livestock Unit	-0.001	0.001	-0.750	0.452	-0.002	0.001
Land Size	0.036	0.011	3.350	0.001	0.015	0.057
Seed Recycling Frequency	0.008	0.002	3.330	0.001	0.003	0.013
Tilling Frequency	0.024	0.005	4.580	0.000	0.014	0.034
Hand Weeding Frequency	0.013	0.010	1.250	0.211	-0.007	0.032
Spacing between Rows	0.005	0.001	4.820	0.000	0.003	0.007
Sowing Method	0.097	0.019	5.120	0.000	0.060	0.134
Frequency of Extension Contact	0.006	0.004	1.390	0.165	-0.002	0.014
Amount of Credit	-0.000	0.000	-0.980	0.328	-0.000	0.000
Membership in Seed Multiplication and Marketing Cooperatives	0.061	0.011	5.420	0.000	0.039	0.083
Seed Rate	-0.000	0.000	-2.290	0.022	-0.000	-0.000
Fertilizer Rate	0.000	0.000	2.980	0.003	0.000	0.000
Sigma _cons	0.021	0.042	0.490	0.626	-0.062	0.103

Also, the coefficient in the first and the second hurdles for land were positive and highly significant indicating higher land size enhances the adoption and AI of IBWP practices. A hectare increase in plot size is associated with the probability of increasing adoption and AI of IBWP by 155.49 and 0.095 units, respectively. This may be because greater land size encourages farmers to try technologies on at least some portion of their land. Other studies also found a positive association between plot size and the probability of adoption of various farm inputs. Though it was not inferred from our data, large farm size and land tenure security may bestow farmers the chance to lease out part of their landholding for some cash that could be used to purchase farm innovations (Kebede et al., 2017, Mehmood et al., 2020). Moreover, this study had expected a significant positive impact of credit on adoption and AI. Yet, the coefficient in the first tier is insignificant indicating credit did not help farmers to adopt IBWS. This may be because the amount of credit obtained by farmers is not sufficient enough to adopt all complementary recommendations included in the IBWP. Poor access to credit, lack of sufficient capital, and farmers' poor purchasing power were also reported as major set-back in farm technology adoption (Kebede et al., 2017, Wondimu et al., 2015, Taremwa et al., 2022).

As expected frequency of monthly extension contact appears to have a noticeable effect on the probability of adoption of IBWS. The significant contribution of the frequency of extension personnel contact could happen due to special attention of the extension service to bread wheat production than other crop commodities and technologies that were not introduced so far. Other studies also indicated that lower farmer to extension agent ratio and the last mile penetration of farmers training centers in different kebeles of the country have improved the adoption behavior of farmers in Ethiopia (Tiruneh et al., 2015). Being a member of the seed multiplication and marketing cooperative contributes to higher adoption intensity. Membership in seed multiplication and marketing cooperatives increases the probability of adoption and increase farmers AI. This is because wheat seed multipliers sell the produced wheat to seed enterprises at a price higher than the prevailing market price. This could inspire farmers to dedicate a substantial portion of their land to be covered by IBWP and hence higher AI. Besides, members are often supplied wheat seeds in the right quantity and time by seed enterprises that it is easy for cooperative member farmers to adopt the technology. The special support and advice provided by extension workers and seed enterprises to cooperative members encourage adoption of technologies (Dawit, 2012, Kebede et al., 2017, Ogada et al., 2014, Sisay et al., 2017). In addition, the availability of local inputs supplier cooperatives increases the adoption of improved wheat varieties by 36.77 kg (Manda et al., 2016, Sisay et al., 2017). These authors revealed that seed companies' reluctance to expand their retail networks hinders improved crops adoption. The exceptionally high adoption status and AI of IBWP witnessed in this study area can also be explained by the availability of seed multiplication and marketing cooperatives closer to farmer's residence.

3.4. Productivity Changes along the Adoption Intensity Continuum

This study has found a significant difference in productivity between adopters and non-adopters of IBWS. Adopters had an average productivity of 41.53 ± 4.061 quintal/hectare, while non-adopters had an average productivity of 31.79 ± 2.647 quintal/hectare, indicating that IBWS adoption pushed average productivity by 9.73 quintal/hectare (See Figure 5 below). However, the study also found that the variance in productivity within the adopter category was relatively higher than the non-adopter category. This suggests that the adoption of IBWS alone, without complementary inputs and agronomic practices included in the IBWP (Improved Bread Wheat Production) did not bring substantial productivity improvement.

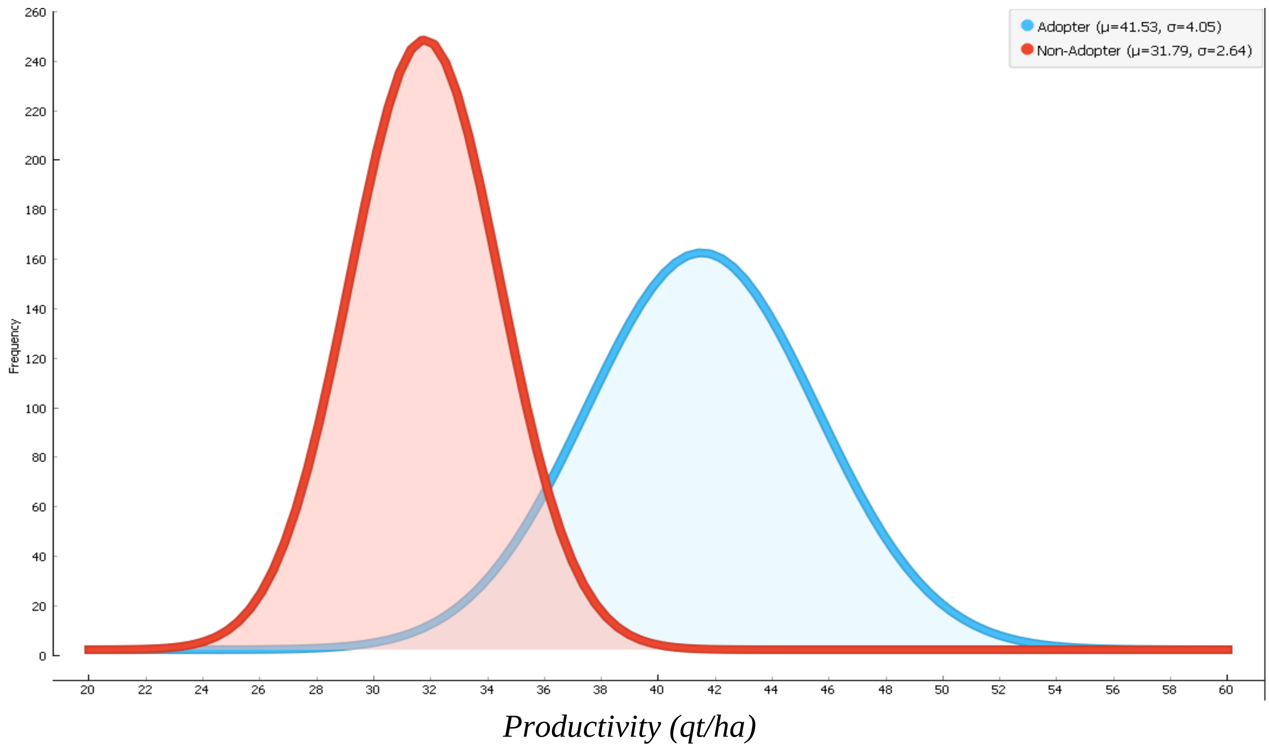

Figure 5: Frequency Distribution of productivity between adopters and non - adopters

To explore the relationship between productivity and adoption of IBWP components, the study divided sample farmers into adoption index continuums, ranging from 0 (unimproved practices) to 1 (the whole package is practiced). The results showed that only 4% of the study respondents had applied the whole package, and their associated productivity was well above 47 quintal/hectare. Additionally, only 19.3% of respondents had an adoption index score greater or equal to 0.8 (80%), while 51.6% of farmers had an adoption index of less than 0.5, indicating that farmers did not make more than 50% of the recommendations included in the IBWP. The study also found that productivity declined with a declining adoption index, indicating the need for extension advisory services to assist farmers in adopting the whole components of the IBWP. The study highlights that the productivity improvement attributable to the adoption of multiple components of a grain production package is well documented (Teklewold et al., 2013, Bezabeh et al., 2014, Kebede et al., 2017, Timu et al., 2014).

3.5. Productivity Effects of Improved Bread Wheat Seed Adoption

3.5.1. Checking the Balance in the Confounders

3.5.1.1. Standardized difference between confounders

The quality of the PSM analysis depends on the extent of the balance in the confounders of the control and treatment groups (Cragg, 1971, Gujarati and Dawn, 2009, Johnson et al., 2003, Morgan, 2018). Before going deep into further analysis, comparison for all confounders between the treated (adopters) and the untreated (non-adopters) was made. With the intention of checking the existence of differences in the confounders, their mean and standard deviation was calculated (See Table 3.1). It is evident from the same table that there is a difference in the confounders for the adopters (treated) and non-adopters (untreated) groups. Yet, because the units of measurement for the confounders is dissimilar, it is difficult to gauge whether if the difference in one variable is more important than the others. One can go for a significance test. However, a significance test is contingent upon sample size, and it may not indicate how big is the difference between adopters and non – adopters. Therefore, we opt for the dissimilarity check based on the standard deviations (standardized differences). The standardized difference in the mean value of the confounders was calculated and presented in Appendix Table A 11.

A simple comparison of the standardized difference between the treated and the untreated groups do not indicate any notable difference in terms gender, grade level, frequency of extension contact, and amount of credit. But, there was a conspicuous standardized difference in other variables between the two groups in terms of age, farm experience, family size, dependency ratio, Tropical Livestock Unit, plot size, seed recycling frequency, sowing method, weeding frequency, spacing between rows, cooperative membership, amount of fertilizer, amount of pesticide, and man-days. The output in the standardized difference between confounders show us the treated and the untreated groups differ by the standard deviations indicated in the Appendix Table A 11. This implies the treated and the untreated tend to be similar in terms of gender than they are in other confounders.

3.5.1.2. Matching confounders using Propensity Scores

The existence of standardized difference between the mean values of the confounders is not sufficient. These calls for matching based on Propensity Score (PS). We have employed the binary logistic regression model in estimating the propensity scores of the variables considered in this study. The distribution of the propensity scores inclined to be higher for the treated than the untreated as indicated in Annex Graph 5 (A). Because the value of the propensity score lies in between 0 and 1, both distributions are skewed. Under such scenario, it is recommended to make use of the log of the odds of the PS (often referred as linear predictor) against the normal PS itself as it bestow the distribution to be more normally distributed as indicated in the Annex Graph 5 (B)(Bryson et al., 2002). The difference between the treated and the untreated ended – up to be statistically significant that make the matching process manageable by creating homogenous classes. Details of the comparison of observed and predicted associations between confounders and the treatment is clearly depicted in Annex Graph 6.

Moreover, assessing the balance attained after the PS matching requires consideration of several other factors that are likely to provide additional insights into the matching quality and reliability of the treatment effect estimates (Gujarati and Dawn, 2009, Johnson et al., 2003, Morgan, 2018). The covariate overlap, statistical significance, the PS distribution, sub-group analysis, and the common support were considered in this study to check the quality of the matching and reliability of the treatment effect estimations. As indicated in Annex Graph 6, a sufficient overlap was observed in the PS between adopters (treated) and non - adopters (non-treated) groups indicating the existence of meaningful comparable units. Besides, from the distribution of the PS, it was observed that the PS for the treated and the untreated groups is similar. This implies the balance in the matching of the two groups. Moreover, it was found that the treated and the untreated groups shared a wider range of the PS indicating the fact that there are units in the data that have a non-zero probability in either of the treatments (adopter or treated versus non – adopters or untreated) as indicated in Annex Graph 7.

3.5.2. Effect of IBWS adoption on Productivity

Based on the information provided, the study employed the Regression adjustment treatment effect model to estimate the average treatment effect of adopting Improved Bread Wheat Seed (IBWS) while controlling for various variables such as gender, age, farm experience, education level, family size, dependency ratio, TLU, land size, amount of capital invested, seed recycling frequency, seed rate, hand weeding frequency, tilling frequency, type of sowing method, row spacing, frequency of extension contact, amount of credit, and membership in seed multiplication and marketing cooperatives.

The study found that the average productivity of farmers relying on local and unimproved bread wheat seed was lower by 8.25 quintal/hectare compared to those who adopted IBWS. However, the study was also interested in knowing the average amount by which adopters' bread wheat productivity increased because of adopting IBWS. The study used the Potential Outcome Mean (POM) to estimate the expected average bread wheat productivity for both non-adopters and adopters. The POM for non-adopters was 40.21 qt/ha, which means that if none of the farmers relied on unimproved/local seeds, the expected average bread wheat productivity would have been 40.21 qt/ha. On the other hand, the POM for non-adoption of IBWS was 31.96 qt/ha, indicating that non-adopters produced 8.25 qt/ha less than adopters. Therefore, the study found that adopting IBWS increased bread wheat productivity by an average of 8.25 quintal/hectare compared to not adopting IBWS. This result suggests that IBWS adoption can significantly increase bread wheat productivity and may be a promising solution for improving agricultural productivity. Several empirical studies are in line with the current finding (Alston and Pardey, 2017, Alemu and Bishaw, 2015, Etwire et al., 2016, Kebede et al., 2017).

Table 7: Estimation of the Effect of Adoption Status on Productivity

Productivity						
POmeans for adopter groups	Coefficient	Robust std.err	z	p>|z|	[95% Conf. Interval]	
Adopters	31.963	.9863	32.41	.0000	30.0301	33.8964
Non-Adopters	40.21	.0000	.0000	.0000	.0000	.0000

4. Conclusion and Policy Implications

4.1. Conclusion

From the probit and truncated model results, it can be concluded that adoption decision and adoption intensity (how much to adopt) are influenced by a mix of variables considered in the study. Older farmers with a greater number of farming experience, higher number of family size and land size, higher frequency of extension contact, membership in seed multiplication and marketing cooperatives had positively contributed to farmers' adoption decision. On the contrary, higher dependency ratio and seed rates had discouraged farmers adoption of IBWS. Albeit, farmers gender, grade level, and amount of credit did not show any marked effect on adoption decision. One can also deduce that a substantial portion of the sample respondents rarely adopt the whole components of the recommendations included in the IBWP and that is associated with their poor productivity. It is also evident from the truncated model that being male, older farmers with more years of farming experience, higher number of Tropical Livestock Unit, land size, family size, and the application of different agronomic practices such as sowing method and row spacing have positively affected how much of the components included in the IBWP should be adopted. This can be interpreted as these variables encourage farmers to adopt all or most of the components included in the calculation of the AI. The variance in the adoption index score within the adopter groups was found higher than the variance within the non – adopters' group. This implies that adopters make partial adoption of the IBWP at the expense of several complementary recommendations of the IBWP. Moreover, one can safely conclude that the adoption of multiple components of the recommendations in the IBWP enhances farmers' bread wheat productivity than the adoption of fewer components of the IBWP. From the POM productivity difference between adopters and non – adopters of the IBWS calculated using the Regression Adjustment it can be inferred that non – adoption of IBWS has a productivity thwarting effect compelling non – adopters to produce 8.25 qt/ha less than adopters.

4.2. Policy Implications

The researcher makes the following recommendations with a strong conviction that upon their implementation, the adoption intensity of IBWP will be considerably improved:

- ✪ Age and experience in making use of improved bread wheat production practices had extremely enhanced the probability of adoption and adoption intensity. Thus, establishing a platform through which farmers will learn from other farmers is strongly recommended to boost both the decision to adopt and how much to adopt. Besides, farmer-to-farmer experience sharing will ease extension agents' work burden in convincing farmers to adopt the IBWP.
- ✪ Higher dependency ratio has significantly reduced farmers' adoption decision and their AI. Thus, it is highly suggested that farmers with a significant proportion of dependent family members should be supported with laborsaving technologies to improve their adoption and AI of the different labor-intensive components of the IBWP. Besides, the design and implementation of alternative social welfare programs and projects that will support farmers with higher dependency ratios are highly recommended.
- ✪ Lack of sufficient labour and inability to employ hired labour were reported as pushing factors to stick to traditional bread wheat production practices such as broadcasting sowing method and minimum tillage. The introduction of laborsaving and improved sowing machineries and their supply with affordable prices is, therefore, strongly recommended.
- ✪ Farmers in the study area were exposed to a single bread wheat variety. This implies the narrow bread wheat variety supply problem. Thus, this study strongly recommends the creation of wider bread wheat varietal options for farmers in the study area.
- ✪ A higher amount of TLU and land size had enhanced the probability of adoption and AI of IBWP. Thus, this study highly recommends expanding farmers' access to diversified asset ownership by implementing additional income-generating alternative livelihood strategies.
- ✪ An entire bread wheat package adoption leads to an 8.25 quintal increment in productivity than non – adoption. Thus, the agricultural extension advisory service should focus its effort on enhancing an entire package adoption than partial adoption.

CHAPTER 4: NEXUS BETWEEN SEED RECYCLING AND TECHNICAL EFFICIENCY OF BREAD WHEAT PRODUCTION IN EAST GOJAM ZONE, ETHIOPIA: THE STOCHASTIC FRONTIER APPROACH[2]

Abstract

In response to declining wheat productivity and production trends, enhancing farm level Technical Efficiency (TE) of Bread Wheat Production should be at the center of the food security strategy in Ethiopia. This calls for the need to improve bread wheat productivity through the introduction of modern technologies and improvement in TE. Yet, there is paucity of empirical studies that investigate agronomic, socio-demographic, economic, and institutional determinants of the TE of BWP in tandem for the study area. Smallholder farmers' practice multiple seed recycling. The effects of seed recycling practices on productivity and TE did not receive sufficient research attention. This study therefore aimed at investigating these determinants with especial emphasis on the nexus between seed recycling, BWP, and TE. Data was gathered from 450 randomly selected sample respondents via structured interviews, focus groups, and interviews with key informants. Data collection took place from December 15, 2021 to January 15, 2022. Bread wheat growing smallholder farmers were the major respondent of the study. Quantitative type of data including the number of inputs used, amount of wheat produced, and socio – demographic, economic, agronomic, and institutional variables were gathered and analyzed. The TE and factors affecting it were examined using a stochastic frontier production analysis with a trans-log functional specification. The coefficients of the stochastic frontier analysis for labour (0.086), capital (0.22), fertilizer (0.042), pesticide (0.014), and machinery (0.005) were positive and significant at $p<0.001$ implying that an optimum increase to these inputs would increase BWP. The coefficient for land was negative and significant suggesting additional land allocation in BWP would likely reduce bread wheat productivity. The coefficient for seed rate was insignificant. The mean TE was found to be 79.99%. The maximum likelihood estimates for the inefficiency parameter portrayed that farmers in the study area operate 20.1% less than their potential. About 9 of the hypothesized variables (69.2%) including age, family size, Tropical Livestock Unit, dependency ratio, hand weeding frequency, row spacing, credit, and membership in seed multiplication and marketing cooperatives had significant impact on TE. Moreover, a typical recycled seed user was 2.34% less than fresh seed users in its TE. This testifies that seed recycling has significantly contributed to farmers' inefficiency. Therefore, the extension advisory service, wheat seed supplier agencies, and producers should closely work together in creating wider access to fresh bread wheat seed supply. There is also strong evidence that few farmers in the study areas are capable of producing bread wheat either on the frontier and/or extremely closer to the frontier that implies their high TE. Therefore, this study highly recommends F2F (Farmer – to – Farmer) extension system that allows farmers to learn from their neighbor farmers. In this regard, FFS (Farmers' Field School), farmers' field days, excursions, and other group extension methods are strongly suggested.

Key Words: Agriculture, Food Security, Translog, Frontier, F2F (Farmer-to-Farmer), Recycled seed user

[2] This is article is published on *F1000Research* 2023, 12:502 (https://doi.org/10.12688/f1000research.128919.1)

1. Introduction

1.1. Background and Justification

Agriculture has continued to be a crucial economic sector in Least Developing Countries (LDCs) for promoting growth, eliminating poverty, and providing food security. In Ethiopia, the agricultural sector accounts for 41% of the country's GDP, 70% of the nation's industrial raw materials, 85% of the nation's food supply, and 80% of all jobs. However, this important sector is generally low-tech, rain-fed, subsistence-based, and very conventional. Crop production plays a key part in both agriculture and the country's overall economic performance. It is the crop production sector's poor performance that has kept the country under vicious poverty cycle for generations (AfDB, 2016, Ayele, 2016, Central Statistical Agency, 2018). Therefore, increasing agricultural yield is not only essential but also a requirement for ending the vicious poverty cycle that has gripped the majority of people in LDCs for millennia (Bishaw and Atilaw, 2016, Kebede et al., 2017, Mideksa et al., 2017).

When it comes to securing global food security, wheat production plays a crucial role. This is because about 1.2 billion people depend on wheat, 2.5 billion wheat consuming poor men, women, and children live on less than 2 USD per day, and 30 million poor wheat farmers and their families depend on it for their subsistence. Next to "tef," wheat is a significant staple crop in Ethiopia. Wheat is a versatile grain that is used to make a variety of foods, including "*Injera*", bread, cake, biscuits, sandwiches, and local beverages like "Areke[3]" and "Tella[4]". Additionally, it is a significant source of animal feed and has been used as a roof covering for house construction in the majority of Ethiopia's rural areas (Omer, 2015). Wheat is a strategic crop for food security. The population explosion has worsened the need for wheat, which is always rising. Wheat has distinctive characteristics due to its well-balanced protein and carbohydrate amounts as well as the presence of gluten, which facilitates bread formation. Besides, it is a beneficial source of

[3] It is a traditional liquor which is prepared by mixing and fermenting powdered malt and grounded buckthorn leaves with water.

[4] It is also a traditional beer brewed by mixing various grains including barley, wheat, sorghum, maize or teff with water and by using grounded shiny-leaf buckthorn leaves for fermentation

carbohydrates due to its high nutritional value, which is indicated by its 63–71% starch and 2%–3% glucose content. Above all, wheat is a significant source of revenue for the agricultural community.

Wheat has been widely grown in Ethiopia because of its many advantages and the country's good climatic circumstances. In Ethiopia, the total cereal production during the 2020/2021 production season was reported to be 302,054,260.6 quintals. Wheat contributes 19.14% (57,801,306.00 quintals) of the total cereal production. In East Gojam Zone, the total cereal production is reported to be 17,095,145.90 quintals and contributes 27.98% (4,743,813.9 quintal) of the total cereal production in the zone. The percentage contribution of wheat to the total cereal production in the East Gojam zone (27.98%) is relatively high as compared to the regional (18.89%) and national (19.14%) averages (CSA, 2021a). The national average wheat productivity was reported to be 30.46 qt ha^{-1} against 28.31 qt ha^{-1} for Amhara region. The average wheat productivity for the East Gojam zone was reported to be 32.12 qt ha^{-1} which is relatively higher than both the national and regional average (CSA, 2021b).This implies the importance of wheat production in the livelihood of the farmers in the study area. Ethiopia remains a net importer of wheat, satisfying around 25 percent of the local demand with wheat imports. A significant share of imported wheat, mainly from the United States, comes to Ethiopia as food aid rather than commercial purchases making the country one of the largest food aid recipients in Africa. Ethiopia grain imports are almost exclusively limited to wheat (USDA, 2021). This proves the importance of wheat as a researchable agricultural commodity in Ethiopia.

Increased input utilization (smaller input for a given level of output) or advancements in technology and the producer's managerial skills in the use of inputs can both boost wheat production and productivity (more output from a given mix of inputs). Efficiency refers to this improvement in the ability of the farmers' or DMUs (Decision – Making Units). It is improving productivity without making use of additional inputs. In countries like Ethiopia where capital is scarce and smallholder farmers lack access to it for the purchase of additional inputs, this is the best alternative for increasing output. Improving wheat production is a function of multiple factors. Studies have shown that plot size, tenure security, access to and effective use of agricultural inputs and innovations, including improved seeds, good agronomic practices, agrochemicals like fertilizer and pesticides, mechanization, and irrigation water significantly affect BWP (Demissie et al., 2015, Dessale, 2019, Kebede et al., 2017, Mehmood et al., 2020, Shikur, 2022).

Despite the favourable conditions for BWP, its productivity has remained very low that has kept the country a net wheat importer. This gap in productivity was associated with climate change induced shocks and stresses, declining soil fertility, poor technology use, lack of proper wheat production policy, poor agronomic practices, and high level of technical inefficiency. The GoE in collaboration with its partners is doing its level best to bridge the potential and observed productivity gaps and the TE of BWP through wider diffusion and scaling-up of IBWS (Alemu and Bishaw, 2015, Ayele, 2016, Dawit, 2012, Shikur, 2022, Tavva et al., 2017). TE in crop production refers to farmer's ability to maximize outputs given a set of inputs and technology. Similarly, the degree of technical inefficiency reflects an individual farmer's failure to attain the highest possible output level given the set of inputs and technology used (Mango et al., 2015). Improving productivity and TE of wheat production is at the center of researchers and policymakers. This is due to the urgent need to improve the food security and livelihood situations of smallholder farmers. There is now a wider recognition that improvement in wheat productivity and TE can be best achieved through the introduction of modern management and agronomic practices along with efficient input use. *Inter alia*, agronomic practices here refers to the different recommended components in BWP package including proper seed recycling, seed replacement, tilling frequency, sowing time and type, crop rotation, use of new crop variety, pest, weed, and disease control, proper packaging (ATA, 2015).

Agricultural production efficiency is measured through the application of parametric and non-parametric approaches. The parametric approach assumes that the maximum output that a farmer can obtain is contingent on both the production function and random external factors such as market failures and other socioeconomic, technological, institutional, plot level, and other factors. The parametric economic efficiency approaches is mainly an econometric modeling derived from a broad set of models referred as stochastic frontier models. On the contrary, the non-parametric models assume that the deviation of an observation from the theoretical maximum is attributed solely to the inefficiency of the farm and are mostly based on mathematical programming methods known as Data Envelopment Approach (DEA) (Coelli et al., 2005, Aye and Mungatana, 2011).

1.2. Statement of the problem

Rural poverty in LDCs is largely explained by the theory of economic equilibrium of traditional agriculture. There are two critical conditions underlying this type of equilibrium. First, the state of the art remains constant. This implies the fact that smallholder farmers heavily rely on the same old, traditional farm technologies, and ways of doing agriculture due to supply-induced problems. Second, the state of preference and motives for holding and acquiring sources of income remains constant due to demand-induced problems. Finally, both states (supply and demand) remain constant long enough for marginal preferences and motives for acquiring agricultural factors as sources of income to arrive at an equilibrium with the marginal productivity of these sources viewed as an investment in permanent income streams and with new savings approaching zero. The long – held stagnation of agriculture characterized by both low demand and supply for farm innovations and improved agronomic practices have kept the LDCs at vicious poverty cycle (Abro et al., 2019, Schultz, 1966). Moreover, the agriculture sector in LDCs is constrained by population growth unparalleled to the resources available. As a result, it has now become apparent that achieving and sustaining the needed increase in agricultural production is almost impossible based on frontier model of agriculture as the opportunities for area expansion is limited. This indicates the fact that the solution for agricultural production would depend on production and policy measures that promote efficiency enhancement through intensification (Alemu and Abera, 2013, Tavva et al., 2017, Schultz, 1966).

The agricultural extension system of the country has been heavily preoccupied with the diffusion of improved bread wheat production package for several decades passed. Yet, the country has not been able to produce enough wheat grain commensurate to its ever-growing population and has remained a net wheat importer. In the absence of perceptible food imports, such imbalance between the slightly growing wheat production and the ever-growing population would mean that the gap had been filled by food aid and/or the wheat poverty level had increased over the past periods (USDA, 2021). This dependence may even get worse in the future than today, unless the country take measures that will curb its rapidly growing dependence on wheat imports. East Gojam zone was known to be the “bread basket” of the country in general and the Amhara region in particular. However, in recent times, some Woredas of the region that had been surplus grain producing areas are becoming dependent on social welfare programs like the rural PSNP (Productive Safety Net Program). Research findings have indicated that several structural, institutional and socioeconomic factors are responsible for such poor performance and declining wheat production (Gashaw et al., 2018, Mahmood et al., 2018).

Generating and disseminating adaptable technologies and helping farmers adopt the technologies could be crucial. Yet, the fruits from such efforts cannot be realized if farmers are inefficient. Reducing inefficiency of farmers do not only increase the gains from technology adoption but it also increase yield response of local inputs. Especially in a situation where the capacities of generating and disseminating locally-adapted modern technologies is limited, attempting to attain the maximum possible output with the existing local inputs (increasing efficiency) can have substantial contribution to the growth of agricultural outputs. In Ethiopia and particularly in the study areas, the relevance of improving TE of smallholder farmers' wheat production is not as such for commercial competitiveness but should be viewed from the contribution of improving inefficiency in reducing poverty and improving food security (Dorosh and Mellor, 2013, Dessale, 2019) .

However, available literature with regard to TE tend to be quite generic. As a result, farmers in Ethiopia do not know the exact amount of inputs (land, labour, oxen power, fertilizer, seed, capital, etc) that go into the production of a particular commodity or crop in which case a generic TE analysis may not be sound. Besides, such generic analysis has the potential to hide crop, variety, spatial, and temporal specific and relevant information for policy uptake. This means that if care is taken in generating empirical evidences, doing crop – specific efficiency analysis may bring policy relevant information. This study therefore aimed at generating policy relevant information for bread wheat production (BWP) through TE analysis by estimating farmers' level of technical inefficiency and its determinants. Moreover, about 90% of the farmers in Ethiopia rely on multiple times recycled seeds for bread wheat production. However, bread wheat seed recycling beyond five production seasons was considered as unproductive and unwise practice as continuous recycling of the same seed causes deterioration in seed quality. Yet, farmers in the developing world and Ethiopia are continuously using the same seed over several production seasons (Aravindakshan et al., 2015, Chandio et al., 2019). However, to the knowledge of the researchers, the effect of seed recycling on the TE of bread wheat productivity has never been empirically investigated. As a result, farmers are continuously making use of recycled seeds without knowing the implications of seed recycling on their TE. This study therefore has dealt with the nexus between seed recycling practices and TE of smallholder bread wheat producers'. It has also aimed at investigating the sources and determinants of farmers' technical inefficiency.

The measurement of TE in BWP is vital, as it gives a practical evidence to make wise decision in the use of scarce resources, revise recommendations contributing to inefficiencies, and reformulate crop production policies. Besides, there is dynamism is rural and social development that there is a need to update the already available data and information based on the current efficiency and productivity of smallholder farmers. Thus, the principal objective of this study was to investigate the level of TE of smallholder bread wheat producers in the study area. This research also recognizes that mere understanding of smallholder bread wheat growers' inefficiency is useless without having a clear picture of the sources of the inefficiency and the contribution of these inefficiency sources on the extent/level of inefficiency. Henceforth, this study also aimed at investigating the various plot-level agronomic practices, socio-demographic, economic, and institutional factors that were hypothesized to have an impact on bread wheat productivity and TE.

1.3. Objectives of the study

Given the above background and research problems, this study was conducted with the following general and specific objectives.

1.3.1. General objective

The general objective this study is to analyze the nexus between Seed Recycling, Productivity, and TE of BWP in the East Gojam Zone of Ethiopia.

1.3.2. Specific Objectives

The following were the specific objectives of this study

1 To investigate the agronomic, socio-demographic, economic, and institutional determinants of the TE of BWP of the East Gojam Zone of Ethiopia in tandem.

2 To compare and contrast productivity and TE differences between Recycled and fresh bread wheat seed users in the study area.

III. RESEARCH METHODS

3.1. Ethical statement

The proposal for this study was first reviewed and approved by the academic commission (AC) of the Center for Rural Development Studies during the 2020 academic year, which is before the approval of the standard operation procedure (SoP) of the Addis Ababa University. The authors received retrospective institutional review board (IRB) approval for this study where the ethical review board of the Center for Rural Development Studies of the AAU reviewed the contents of the proposal, the associated research tools, and informed consents of the respondents retrospectively. As a result, the University found the proposal to be qualified for ethical clearance and issued an IRB certificate dated on February 18, 2023 with an IRB number 002/02/2023 indicating that the proposal fulfills the standard requirements described in the SoP of the Addis Ababa University, College of Development Studies.

The trained enumerators of the study have properly read the consent form for the participants. The consent form clearly contains the objectives of the study and their participation is on voluntary basis that they are free to disengage if they are not comfortable. Participants were told that there is no direct benefit to be provided for them as a compensation for the data that they are going to give for the study. They were also told that the data collected might be published to inform policy makers and the research community and will not be used for any other purpose. Besides, they were informed that the analysis of the study do not identify participant individuals and be anonymized by assigning a unique identification number. Yet, a significant number of participants have refused to put their signature on the consent form. This is because of the long held tradition and culture of the participant farmers' do not allow them to put their signature on studies like this. Besides, substantial portions of the participants were incapable of reading and writing to sign on the written consent. Traditionally, farmers of the study area are skeptical in providing written consent. After assessing this situation and the minimal risk that the study may cause to human subjects, the ethical review board has confirmed the documentation of written consent can be waived. Thus, the data collection took place only when respondents of the study gave their consent at the beginning of each interview. As a result, this study has relied on verbal consent of the participants.

The common difficulty in collecting data from poor farmers' in the rural setting is that farmers may feel that they may not be targeted for aid, credit schemes, welfare packages, and other development interventions based on the data they unfold to outside researchers. Fearing such vulnerability to exclusions, they often under report their annual production, plot size, number of animals, inputs used, and assets owned. On the contrary, farmers may also exaggerate certain variable values such as their age, family size, and number dependent family members hoping that they may be entitled for aid and other welfare benefit packages. Yet, the authors make sure that such participants' expectation did not harm the quality of the data by employing different methods. First, the local government registers most of the variables that could be under reported or exaggerated. Thus, we have triangulated the reported values with what is locally registered. Second, we have recruited enumerators (development agents) working with the local community who have long years acquaintance of the villages and the community members that participants do not often hide information. The other challenge when collecting data using FGDs is that participants farmers' may not feel comfortable to share their experience with development agents who often support them by providing inputs and agricultural advisory services. With the intention of avoiding this potential problem, the facilitation and transcription of the FGDs were made by the authors themselves than the local development agents.

3.2. Context: Setting and salient contextual factors

This study was conducted among smallholder bread wheat growers in selected districts of the East Gojam zone of Ethiopia. There are two major crop-growing seasons in the study areas. The major crop growing season is called '*Meher'* in Amharic extends from May to September. The second and the shorter crop growing season is called '*Belge'* extends from February to April. Smallholder farmers of the study areas culturally and historically grow bread wheat during the main season for several reasons. Lack of access to irrigation for all season production and the availability of sufficient rainfall during the main rainy season are the major reasons to heavily rely on '*Meher'* wheat production. Agronomic recommendations such as crop rotation also can be cited as important reason to grow bread wheat during the main season only. Thus, we have considered smallholder farmers who grow bread wheat during the main production season. The list of bread wheat growers during the 2021/2022 major production season was obtained from the farmers' training centers' (FTCs) of the selected villages. These farmers grow bread wheat using different varieties that were introduced at different points in time. However, this study has considered a bread wheat variety largely grown by the dominant section of the farmers. Respondents were further stratified into fresh and recycled bread wheat seed users based on their experience in seed recycling. Besides, the data was gathered during the weekends and holidays during which farmers were not busy to provide information required for the study. Production inputs and agronomic practices applied by the respondents are important variables of this study. Thus, we intentionally undertook the data collection effective from December 15, 2021 to January 15, 2022 during which wheat has been harvested.

3.3. Description of the study area

This study took place in the East Gojam Zone of Ethiopia. East Gojam zone has a total of 18 Woredas and its headquarters, Debre Markos, is located 300 and 260 km far from Addis Ababa (the capital city of the country) and Bahir Dar (the capital city of the region), respectively. It is located at 10° 19' 60.00" North, and 38° 00' 0.00" East. The total population size of the East Gojam zone is estimated to be 2,358,051, out of which 1,154,740 and 1,203,311 were reported to be male and female respectively. Mixed farming system is the main occupation of farmers in the East Gojam zone. The area is dominated by mixed agricultural systems (Bureau of Finance and Economic Development, 2013b). Out of the 18 Woredas located in the East Gojam Zone, this study has especially considered Baso Liban and Debre Elias districts presented in Figure 2.1.

Baso Liban is situated at the southernmost point of East Gojam zone. This Woreda is bordered by a bend of the Abay River in the South, by Gozamen Woreda on the Northwest, by Aneded Woreda on the Northeast, and the Chamwaga River on the Western part. Baso Liban is geographically located at 10^0 09' 60.00'' North and 37^0 34' 59.99" East at 1, 945 meters above sea level. It has an estimated total population of 153, 247, of whom 77, 463 were males and 75,784 were females with a population density of 114.4 people per square kilometer. Debre Elias Woreda where this study was conducted is located in Amhara region. It is bordered by the Abay River on the South and West that separates it from the Oromia region, by West Gojam zone on the Northwest, by Machakel on the North, and by Guzamen on the East. Debre Elias has a total population of 82,150, of whom 41,109 are men and 41,041 are women. Geographically, it is located at a longitude and latitude of 10.22 North and 37.47 East, respectively with an altitude of 1995.00 meters above sea level.

3.4. Sampling techniques and procedures

3.4.1. Sample Size Determination

This study has followed a multi – stage systematic random sampling technique in the selection of sample districts and respondents. The study districts and kebeles were selected purposively. The potential for wheat production, absence of sufficient prior studies, availability of sufficient representative sample respondents who make use of similar bread wheat variety and the long year's acquaintance of the study places by the researcher were the reasons to consider these Woredas. Debre Elias and Baso Liban districts have 15 and 22 kebeles, respectively. The researcher has decided to consider eight kebeles (around 22% of the total kebeles) from both of the districts with strong conviction that these kebeles are sufficient and representative due to their homogeneity in agro-ecology, agronomic practices, and potential for BWP. As indicated in Figure 2.1, Yelemelmo, Lemechem, Dendegeb, Kork, and Dogemo kebeles were considered from Baso Liban district while Guay, Yekegat, and Debre Elias Zuria kebeles were considered from Debre Elias district. The number of kebeles from each Woreda was determined using the probability proportional to size (PPS) formula specified below:

$$\boldsymbol{ni} = \boldsymbol{n}({}^{\boldsymbol{Ni}}/_{\boldsymbol{N}}), \textbf{ and } \boldsymbol{n} = \sum \boldsymbol{ni}$$

Where n_i is the number of kebeles from each Woreda, n is total sample size of the study kebeles which is the sum of the sample size of the kebeles from the two Woredas (eight in this case), Ni is the total number of kebeles in each Woreda and N is the total number of kebeles in both Woredas (37 in this case). The specific sample kebeles were selected in collaboration with the development agents (DAs) based on their BWP potential and availability of farmers who make use of similar improved bread wheat production (IBWP) variety. Yamane's sample size determination formula is often used in studies where the study population is finite and known. Henceforth, the total sample size of this study was also determined by using (Yamane, 1967) sample size determination formula, which as specified below

$$n = \frac{N}{1 + N(e^2)} = \frac{206{,}115}{1 + 206{,}115(0.05)^2} = 399$$

Where n is the desired sample size; N is total number of population and, e = the level of precision or the quality of being careful and accurate which is equal to 0.05. Generally, the sample size for this study was 399 along with a 15% contingency, which adds up to 459 total households. The analysis of the study has considered only 450 respondents as three of the respondents have refused to provide information while 6 of the questionnaires collected were incomplete for analysis. As the study deals with the nexus between seed recycling and TE, the respondents were further disaggregated into fresh (unrecycled) and recycles bread wheat seeds. Farmers who produce bread wheat using wheat seed above 5 times were labeled as recycled seed users while those who produce bread wheat using wheat seed unrecycled or recycled below or five times were considered as fresh/unrecycled seed users. It was found that about 247 (54.9%) of the respondents were recycled seed users.

Table 8: Distribution of sample respondents by Woreda and Kebele

Districts	Kebeles	Total HHs	Number of HHs from each kebele
Debre Elias	Gway	816	44
	Yekegat	1065	57
	Debre Elias Zuria	1124	61
	Sub - total	3005	162
Baso Liban	Gibtsawit	890	48
	Dogem	1301	70
	Dendageb	1150	62
	Lemechem	953	51
	Korke	1048	57
	Sub - total	5342	288
	Grand - total	8347	450

Source: Own Computation (2022)

3.4.2. Sampling procedures and participants selection

The main intention of this study was to investigate the major determinants of smallholder farmers TE in bread wheat production. Thus, we have first obtained a list of smallholder farmer bread wheat growers in the selected sites from the FTCs. From the list of bread wheat growing, it was found that 83.5% of the smallholder farmers grow bread wheat using a bread wheat variety called 'Ogolecho'. Since agronomic practices, input use, and productivity is likely to vary by the nature of bread wheat variety, we have included farmers that make use of the same variety. Thus, farmers who make use of varieties other than 'Ogolecho' were excluded from the study. Besides, as the study deals with the implications of seed recycling on smallholder farmers TE, the respondents were further disaggregated into fresh (unrecycled) and recycled bread wheat seed users. Farmers who produce bread wheat using seeds reused more than five times were labeled as recycled seed users while those who produce bread wheat using fresh/unrecycled seed or recycled below or five times were considered as fresh/unrecycled seed users. It was found that about 247 (54.9%) of the respondents were recycled seed users while 203 (45.1%) were found to be fresh seed users. Figure 6 depicts the sampling procedures. These sample respondents were used for the face – to – face household interview using a structured interview schedule. Thus, bread wheat growing households were the unit of analysis under the current research.

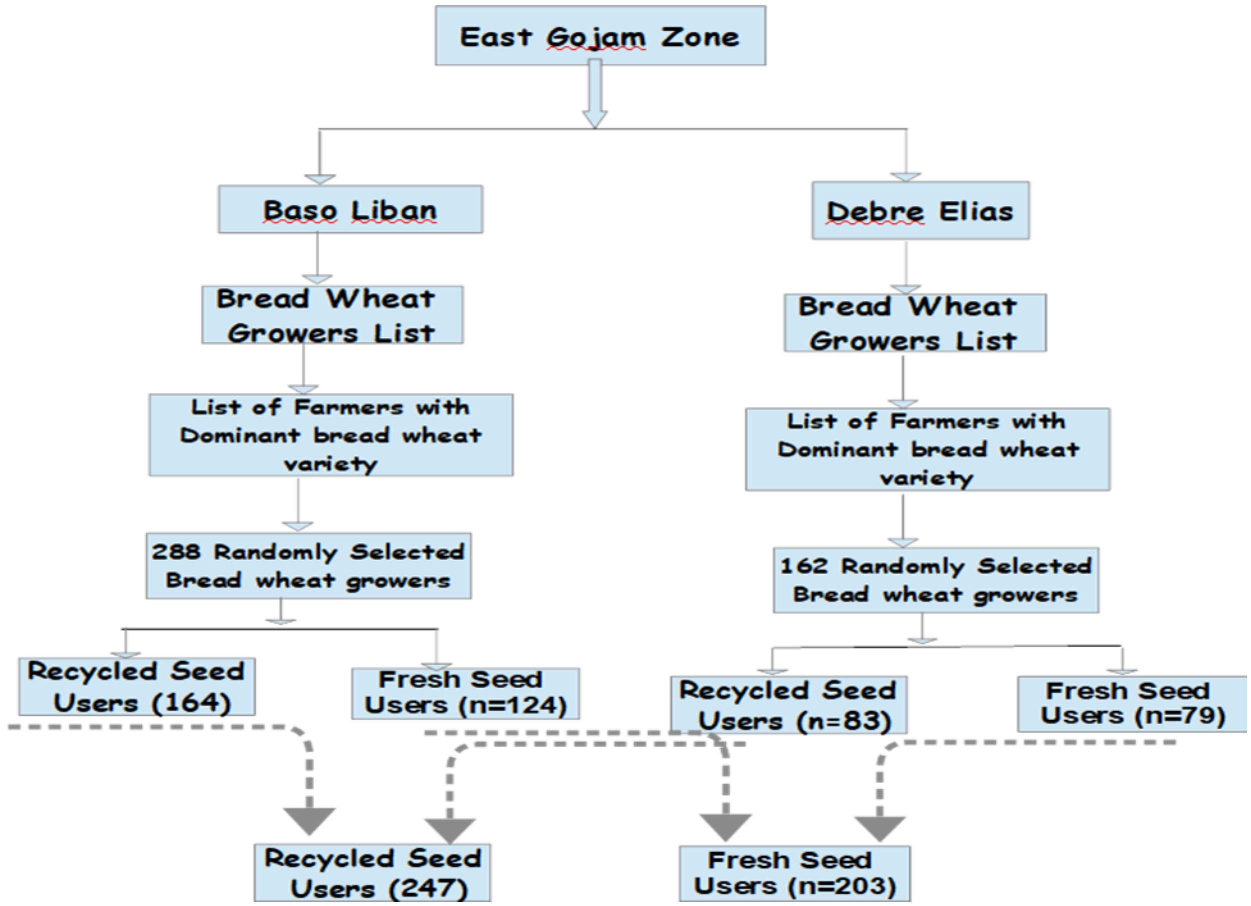

Figure 6: Sampling procedures

We believe that key informant pluralism or diversity from different background or sector has allowed us to capture varying perspectives about the determinants of smallholder farmers TE and problems of seed recycling. As a result, we have included key informants from different walk of life and responsibilities in relation to bread wheat production. Doing so has helped us to avoid a one – sided or biased information that may result by interviewing people from a particular division. We have first prepared a long list of potential key informants from stakeholders or actors involved in the value chain of bread wheat production. Then, we have narrowed down the list into the most relevant and knowledgeable informants. Hence, the sample respondents for the key informant interviews (KIIs) were purposively selected based on their experience and knowledge to the subject under consideration. Development workers, agronomists, seed experts, researchers, district bureau heads, seed suppliers, agro-dealers, and seed multiplication and marketing cooperative members who do have ample information due to their position and expertise were selected as key informants. These informants were considered as they are the most important actors across the value chain of bread wheat production. They are involved either in the inputs supply, business development support provision, organize the transport and marketing of agricultural inputs and products. The authors believe that inclusion of these individuals, as key informants may assist to capture information that may be obscured during the quantitative data collection. These key informants were knowledgeable people who can talk on behalf of the farming community about the subject matter. These key informants were physically visited at their offices for the interview. These informants were busy experts and office position holders. Thus, we received appointments before the visit for the interview was made. The profile of the KII participants is provided in the supplementary table 1 (https://doi.org/10.17605/OSF.IO/8K6RJ).

Efforts were made to compose the FGD discussants from the homogenous groups that have some natural characteristics in common such as gender, residential locations, and seed recycling practices so that to ensure participants feel comfortable speaking in the group. We have followed two approaches in composing the focus discussion groups. First, we made sure that there is sufficient homogeneity between groups so that to have comparable data among the groups. This approach has encouraged sense of uniformity and conformity among FGD participants and assisted participants to reach on some consensus on issues raised. Second, we make sure that there is sufficient diversity within the groups. This has helped us to bring together participants that assume different roles, varying experiences and dissimilar backgrounds that may end – up in unexpected views and results. The selection the FGDs participants has involved organizing group of community members based on important criteria relevant to the objectives of the study and their consent to take part in the discussions. The first criteria in grouping discussants was bread wheat seed recycling practice. In this regard, we had two group of FGD discussants that include fresh and recycled bread wheat seed users. The second group of the FGD discussants were composed of female and male-headed households. The third group was composed of smallholder farmers who are member of improved bread wheat seed multiplication and marketing cooperatives.

3.5. Data collection procedures

3.5.1. Data types and sources

This study has employed both quantitative and qualitative data types. Quantitative type of data including the number of inputs used in bread wheat production along with different agronomic practices such as amount of fertilizer, man - days, seeds, plot size, amount of capital invested, amount of pesticide applied, weeding frequency, seed recycling frequency, and spacing between rows were gathered. The study has also considered different socio – economic and institutional quantitative variables such as gender, age, grade level, family size, dependency ratio, tropical livestock unit (TLU), land size, frequency of extension contact, amount of credit, and membership in seed multiplication and marketing cooperatives, respectively. The qualitative type of data included smallholder farmers' knowledge and perception towards seed recycling, reasons for seed recycling, perception about the impact of seed recycling, barriers affecting seed replacement, and major challenges affecting technical efficiency and bread wheat productivity. These study variables were selected after extensive review of relevant literature, pre – data collection discussions made with experts and elders in the study districts, and long years acquaintance and experience of the researchers about the issue under consideration. These data were gathered both from primary and secondary data sources. Smallholder farmers, district development workers, agronomists, and subject matter specialists were the primary data source of this study. In addition, secondary data sources such as published research findings, journals, articles, statistical reports, official websites, government reports, dissertations, and thesis were consulted to triangulate and support the information obtained primary data sources. A systematic desk review was conducted to gather relevant information related to the objective of the study. The authors have heavily relied on important secondary data sources related to the technical efficiency of improved bread wheat production and its determinants including PubMed, Semantic Scholar, and Google Scholar platforms. Two typical search phrases, separated by the operator "OR," were used: "technical efficiency" AND "bread wheat production in Ethiopia" or "technical efficiency" AND "determinants in Ethiopia." We have applied this with the expectation that it increases the likelihood that all studies conducted in Ethiopia would be found. For the systematic review, the authors have applied various articles inclusion and exclusion criteria including the following.

a) Articles concentrating primarily on technical efficiency or technical efficiency of bread wheat production were considered while articles related to other wheat or crop varieties were excluded from the review.
b) Articles evaluating the seed recycling practices of smallholder farmers and/or determinants of the TE of smallholder farmers were included.
c) The authors have focused on publications based on qualitative and quantitative empirical investigations.
d) The authors also focused on articles where the country of data collection is in Ethiopia and/or in the Sub – Saharan Africa.
e) The systematic desk review have emphasized articles published in scholarly journals and non-published documents such as government policies and strategies, agronomic training manuals, annual reports, and location specific agronomic recommendations.

The evidences obtained from these secondary sources were then checked against the findings of the current study. The authors have critically triangulate the data and findings between the current study and the secondary empirical evidences. We have further assessed the reasons and explanations for convergence, divergence, and complementarity of the data and findings between this study and the secondary data sources. Explanations were sought whenever we found strong degree of deviation between this study and the secondary sources. In general, the areas of divergence and convergence were further discussed.

3.5.2. Data collection methods

For a thorough understanding of the research problem, the study has used data collection methods employed in a mixed research design, which blends qualitative and quantitative research data. A mixed research design was used in order to compare the various viewpoints obtained from quantitative and qualitative data, as well as to demonstrate potential data convergence and divergence by combining the two database. We have applied convergent parallel mixed methods to gather quantitative and qualitative data, analyze each kind individually, and then compare the findings to see whether they support or refute one another. The main premise behind our preference for this approach is that both qualitative and quantitative data offer distinct forms of information. Authors apply this approach for the purpose of triangulation and validation of findings from each method. As a result, the data for this study were collected using three important quantitative and qualitative data collection methods described below.

3.5.3. Tools translation and piloting

The tools used for both the quantitative and qualitative data were created in the English language based on extensive relevant literature reviews and discussions held with subject matter specialists. These tools were then translated into Amharic language using a group translation approach. The tools were given to two different certified and hired translators who independently translate the tools (meaning they do not review each other's translation). After the two translators complete the translation, a third translator has reviewed and reconciled the translation differences and produced a final translation. All the tools translated by all of the translators were submitted to the authors of this research and checked for their originality, meaning, and consistency. All of the tools used in this study incorporates informed consents that specifies the objectives of the study and seeks the consent of all of the respondents. The data collection was carried out under a complete private setting and keeps the principles of data confidentiality, privacy, and informed consent. Eight hired and trained enumerators were used for data collection. The corresponding author provided the training. The training encompasses line – by – line discussion of each questions, research ethics, and interviewing methods. Before starting the main survey, each enumerator was allowed to collect data from four randomly selected farmers that were expected to have similar characteristics with the sample respondents of the study. A debriefing session was then held after this field level pilot test and some modifications were made on the tools based on findings from the debriefing session. Finally, the hired enumerators were deployed to collect data under strict supervision of the corresponding author.

3.5.4. Quantitative data collection method

A structured questionnaire based interview was largely used as quantitative data collection method. The questionnaire used for the structured interview included questions with close ended response options only. The questions included in the structured interview were crafted in such a way that it enable us to capture the objectives of the study. Enumerators of the study were given the list of respondents identified using the procedures indicated above. Then they systematically select target respondents from the list at a regular interval to conduct a face – to – face interview using the structured questionnaire. The enumerators visit the selected household at his/her residential place for the interview. Enumerators of the study were trained to make several contact attempts for respondents who cannot be found at his/her residence for the interview. Yet, the maximum contact attempt was only three that all of the sample respondents were contacted for the interview during the first visit of the interviewers. The questions as well as their order was already scheduled that enumerators ask the questions accordingly and without change in the wordings of the questionnaire. The interview was conducting using the structured questionnaire detailed above that was translated into the local language (Amharic). The structured questionnaire in both English and Amharic along with the consent statement is available as extended data for this study (https://doi.org/10.17605/OSF.IO/8K6RJ).

3.5.5. Qualitative data collection methods

This study has employed key informants' interview (KIIs) and focus group discussions (FGDs) to gather qualitative data required to capture the objectives of the study. KIIs were carried out to get an in-depth understanding of the different issues pertinent to seed recycling, technical efficiency, and challenges related to bread wheat production. The KIIs were conducted with respondents such as development agents, subject matter specialists, researchers, and improved bread wheat seed suppliers who are believed to have ample information about the issues under consideration of this study due to their position, expertise, and leadership. A total of 14 key informants composed of four women and 10 men were approached for a face – to – face interview using the KII checklist. The interview was conducted at the office of each key informant. Appointments were taken through phone calls before visiting the key informant at his/her office so that they could have sufficient time to provide detail information. The data collectors approached and introduced themselves for the key informants and read the consent statement. After reading the consent statement, enumerators put a tick mark next to the option 'yes' to indicate that the respondent has verbally provided his/her consent to continue the interview. No key informant has declined to take part in the interview and his/her responses are recorded. The author himself was a note taker while a trained enumerator pose the questions from the KII checklist and facilitate the interviews. The data collection was conducted using a local language. The authors later transcribed the information obtained from the key informants. For the sake of confidentiality and privacy, pseudo names were used to identify the name of the KIIs participants. The maximum amount of time to finish the KIIs was 31 minutes. FGDs were conducted to examine the existence of consensus among the different group of discussants on certain common agricultural practices such as seed recycling, planting methods, spacing, and other agronomic practices. Besides, these qualitative data collection methods were employed with the intention of triangulating the data obtained from the quantitative survey. Issues raised for the FGDs were reasons or pushing and pulling forces for seed recycling, farmers' perception on the consequences of seed recycling, knowledge and awareness of factors hampering or promoting their technical efficiency in bread wheat production.

As indicated in supplementary table 2 deposited at OSF (Open Science Framework) repository (https://doi.org/10.17605/OSF.IO/8K6RJ), six FGDs (three in each district) were conducted. All FGDs were properly recorded, transcribed, and translated into English by the corresponding author of this study. The highest group size for the FGDs was nine and 49 discussants have participated in all of the FGDs. The FGDs were conducted at the FTCs assembly halls of each village. The date and the time for the FGDs was fixed to be on Sundays at 10:00 PM in consultation with the participants. Discussants prefer Sunday as it is observed as Sabbath by the community that they don't engage in other activities. The assembly halls where the FGDs took place were large enough with sufficient ventilation and lighting. It has allowed us to keep more than two meters distance between discussants so as to avoid risks of the COVID-19 spread. We also distributed face masks to participants to contain the spread of the virus. The group sitting was arranged in a circular setting so that all participants have a balanced eye contact with each other and can listen to what each other speaks. FGDs were set up where each discussant of the FGDs were encouraged to feel free to speak on the issues raised by the facilitator. As a standard ethical procedure, we never keep personal identifying information such as names either in the notes or in the report. Rather we have used pseudo names so that the study does not lose its human sense. Female facilitators and note takers were assigned in the female – headed group of FGD discussants so that participants may openly discuss questions posed to them. The data collection took place starting from September 15, 2022 to October 19, 2022. The longest discussion time was 72 minutes while the shortest was 61 minutes. This could imply that there is a relatively uniform level of discussion across the FGDs.

3.5.6. Definition, Operationalization, and Hypothesis of the Study

The variables for the SFP and the technical inefficiency models were chosen based on extensive literature review and discussions with subject matter specialists and farmers who do have sufficient information and expertise on cereal crop production with special emphasis on bread wheat production. Therefore, this study has considered 7 variables for the SFP model and 12 variables for the inefficiency model. However, three variables including tilling frequency, seed rate, and seed recycling frequency were removed from the inefficiency model due to the observed multicolinearity problem. Table 9 below deals with the variables, their type, definitions and operationalization along with the expected relationship between the dependent and explanatory variables of this study.

Table 9: Variables, Definition, operationalization, and Hypothesis of the Study

No.	Variables	Variable type	Operationalization & Measurement	Hypothesis
A.	**Production Function**	**Continuous**	This refers to the amount of bread wheat produced per hectare measured in terms of quintal ($qt\ ha^{-1}$). For the sake of uniformity quintal was later changed into kilograms	
1.	Labour	Continuous	It refers to the total amount of labour employed & measured in terms of man-days ha^{-1}. It includes both hired and family labour used for BWP during the 2021 major production season ("*Meher*").	+
2.	Capital	Continuous	This refers to the amount of capital invested for BWP during the 2021 major production season ("*Meher*") & is measured in Ethiopian Birr. However, capital invested for land and machinery rent, seeds, fertilizer, hired labour, and pesticide were excluded to avoid double counting.	+
3.	Land	Continuous	This is the amount of land used for BWP measured in terms of hectare	+
4.	Seed	Continuous	This denotes the amount of seed used per hectare and measured in kilograms	-/+
5.	Fertilizer	Continuous	This denotes the amount of different types of fertilizers used per hectare in kilograms	-/+
6.	Pesticide	Continuous	This refers to the amount of chemical applied per hectare and measured in liters.	-/+
7.	Machinery	Continuous	This signifies the cost of a machinery measured in terms of rents paid in Birr	+
B.	**Inefficiency model**	Continuous	This signifies the calculated value of technical inefficiency	
1.	Gender	Binary	A value of 0 is assigned for female and 1 for male	-/+
2.	Age	Continuous	This is the age of the respondent in years	-
3.	Grade	Continuous	This denotes the respondents' education level measured in years of schooling.	-
4.	Family size	Discrete	This signifies the number of family members in the households	-
5.	Dependency Ratio	Continuous	This is the ratio of the sum of family members less than 15 years, greater than 65 years, weak and disabled family members to total family size.	+
6.	Tropical Livestock Unit	Continuous	Number of animals owned multiplied by the Standard Conversion Unit developed by ILCA (1990)	-
7.	Land size	Continuous	This is the amount of total land owned by the respondent and is measured in terms of hectare	-
8.	Weeding frequency	Discrete	This denotes the frequency of hand weeding and is measured in number	-
9.	Row spacing	Continuous	It signifies the spacing between rows in BWP and is measured in centimeters.	-
10.	Extension contact	Discrete	It denotes the number of extension contacts per month	-
11.	Credit	Continuous	It refers to the amount of credit obtained per year and is measured in Ethiopian birr.	-
12.	Cooperative Membership	Dummy	It refers to respondent membership in seed multiplication and marketing cooperatives and is measured by assigning a value of 1 if a farmer is member and 0 otherwise	-

3.5.7. Conceptual Framework of the Study

The overall activities of this study has been guided by the conceptual framework diagrammatically represented in Figure 7 below. The conceptual framework provides a visual representation of the exogenous variables considered to have significant nexus with the dependent variables of the study. It paints a clear picture on the concepts to be explored, the dependent and independent variables along with the expected nexus between them. It was designed in a way that it help the researchers to capture the research objectives and answer the research questions. It is designed based on the institutional analysis and development approach of the new institutional economics that assumes a set of exogenous variables that influence production practices and behavior of producers that leads to certain outcomes, which then feedback to modify the explanatory variables and the situation of producers influenced by these factors.

The conceptual framework provides a vivid picture about two important issues pertinent to the objectives and research questions of the study. The first issue is related to the input-output relationship in BWP. Seven inputs including allocation of labour (person-days), land size, application of fertilizer, use of pesticide and machinery, amount of capital invested, and seed rate were considered to have a highly significant impact on BWP, which in turn affects the TE of farmers. Second, this study has hypothesized that BWP in the study area suffers from serious problems of technical inefficiency. Thus, this study has estimated the TE of bread wheat producers and the factors responsible to the existing inefficiency. The socio-economic, demographic, institutional, and agronomic practices that are expected to influence farmer’s technical inefficiency are thus indicated in the conceptual framework depicted in Figure 7 below.

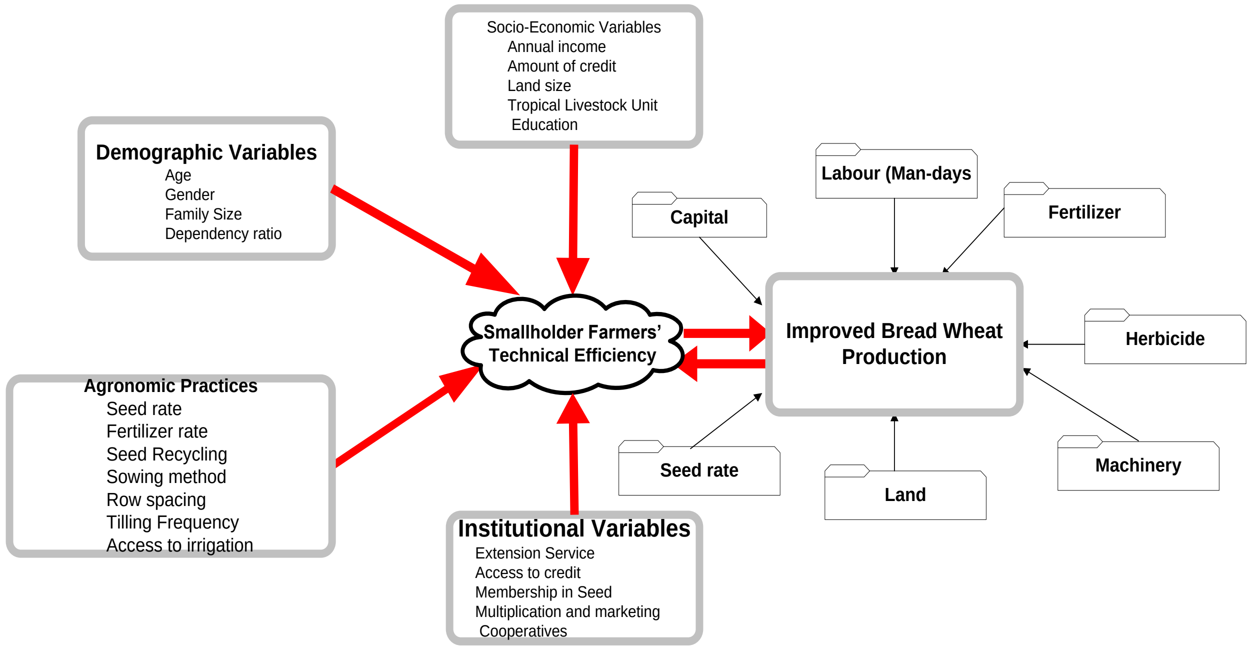

Figure 7: Conceptual Framework on the nexus between TE and Bread Wheat Output

Source: Own Construction (2022)

3.6. Data Analysis Methods

The data collected for this study were analyzed using both descriptive and econometrics models. One stage SFA with the translog functional form was used in identifying the factors significantly contributing to BWP and in estimating the contribution of the hypothesized parameters on the technical inefficiency. The analysis was made using the STATA Software, Version 17 (https://www.stata.com/). R software (https://posit.co/download/rstudio-desktop/) which is an open source and freely accessible software is also capable of the same analysis used in this study. The sub-headings below are a summary of the data analysis methods employed in this study.

3.6.1. Descriptive and Inferential Statistics

This study has frequently employed a number of descriptive statistics. It has used both measures of central tendency (mean, median, and mode) and measures of central dispersion (range, variance and standard deviation). Inferential statistics such as t-test and χ^2 tests were frequently employed to check if there exists a difference in the different continuous and categorical variables considered in the study between farmers who recycled bread wheat seed and those who do not recycle (use fresh) seed, respectively.

3.6.2. Econometric Model Specifications

3.6.2.1. Technical Inefficiency Model of the SFA

The SFA, a parametric technique, and the Data Envelopment Analysis (DEA), a non-parametric approach, are the two most crucial methods for estimating the level of efficiency/inefficiency in production economics. The DEA is preferred because it accommodates multiple inputs and outputs in TE analysis. Nonetheless, DEA disregards the potential effects of random shock, such as measurement error and other sorts of data noise. The SFA, on the other hand, does not accommodate multiple inputs and outputs and is more susceptible to misspecification problems. The SFA, however, boosted its application in the examination of TE of agricultural production since it included stochastic components in the model (Coelli et al., 1998, Jondrow et al., 1982, Kidane, 2020). Thus, this study has opted for the SFA than the DEA.

Agricultural production in developing countries is contingent upon factors that are beyond the control of the Decision Making Units (DMUs). External factors such as crop pests, disease infestation, drought, flood, frost/hail, and other exogenous factors, which are beyond the control of the smallholder farmers, do have significant effect on smallholder farmers' crop production. Therefore, studies are expected to capture the effects of such uncontrolled variables and technical errors that may arise due to measurement and observation during data collection. Bread wheat production (BWP) in the study areas is reported to be hampered by the climatic variabilities that are least controlled by smallholder farmers' (Abid and Abdul, 2014, Beshir, 2014, Chiona et al., 2014, Dessale, 2019, Kidane, 2020, Rahman et al., 2012, Wudineh and Geta, 2016). In addition, sample respondents of this study were non-commercial and subsistence smallholder bread wheat growers' who largely depend on family labour to operate their farm, and do not have a tradition of keeping accurate records. Above all, the data for this study were collected using local units of measurement that their conversion into standard units of measurement may be erroneous. Thus, the data for certain variables like production, plot size, and amount of inputs used are likely to be susceptible to measurement and conversion errors.

Given the situations above, this study therefore adopts the SFA (Stochastic Frontier Analysis) model as it enable the researcher to accommodate the effects of these uncontrolled variables and technical errors. The SFA was first proposed by Aigner et al. (1977) and Meeusen and J. van Den Broeck. (1977), and later modified by Jondrow et al. (1982). The SFA model has also been used to model the technical efficiency effects of other observable explanatory variables (Battese and Coelli, 1995). This approach splits the error-term (deviations) into two parts to capture purely random factors and are beyond the control of the DMUs. The first component is the technical inefficiency of the DMUs. The second component is the random shocks that among others include climatic variabilities, errors in measurement during data collection, and omitted variables. Therefore, the general stochastic frontier econometric model for this study is specified as below:

$$\boldsymbol{\ln \gamma_i = \beta_0 + \sum \beta_i \ln X_{ij} + \epsilon i} \text{ .... } \textbf{[1]}$$

Where ln - refers to the natural logarithm, i - refers to the ith farmer in the sample (i = 1, 2, ...N), γ_i – refers to bread wheat yield (output) of the ith farmer, X_{ij} – refers to the farm inputs used by the ith farmer, β_0 – refers to the constant term, β_i - represents the regression coefficient, while ϵi denotes the residual random error term which is composed of the following two elements.

$$\boldsymbol{\epsilon i = V_i - U_i} \text{ .... } \textbf{[2]}$$

V_i is a symmetric component that captures/accommodates the random error associated with random factors which are beyond the control of the DMUs such as weather variabilities like drought, frost/hail, flood, omitted variables, measurement errors, and other exogenous shocks. U_i is the one-sided component that capture deviations associated with factors under the control of the DMU (i.e., inefficiency). The model is such that the possible production $\boldsymbol{Y}_i$, is bounded above by the stochastic quantity, $\boldsymbol{f(x_i, \beta)}$* $\mathbf{exp}(\boldsymbol{V_i})$; hence the term stochastic frontier. The random errors (V_i), where i = 1, 2…N were assumed to be independently and identically distributed as N (0, σ_v^2) random variable independent of the $\boldsymbol{U_i}'$s which were assumed to be non-negative truncations of the N (0, σ_u^2) distribution (i.e. half normal distribution) or have exponential distribution.

As far as TE is concerned, the variance parameters, σ_v^2 & σ_u^2 are of critical importance in this model. They are expressed as follows:

$$\boldsymbol{\sigma^2 = \sigma_v^2 + \sigma_u^2} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . [\mathbf{3}]$$

$$\boldsymbol{\gamma} = \frac{\boldsymbol{\sigma_v}^2}{\boldsymbol{\sigma_u}^2} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . [\mathbf{4}]$$

Where σ^2 = overall wheat output deviations, Υ is the ratio of farmers' wheat output deviations due to technical inefficiency to the overall deviations. It ranges from 0 to 1, when Υ=0 indicates that all output deviations are due to factors outside the farmers control ($\boldsymbol{\sigma_u}^2$ = 0, thus $\boldsymbol{\sigma^2}$ = $\boldsymbol{\sigma_v}^2$), when Υ = 1 indicates that all deviations are due to technical inefficiency ($\boldsymbol{\sigma_v}^2$ = 0, thus $\boldsymbol{\sigma^2}$= $\boldsymbol{\sigma_v}^2$).

The technical efficiency of an individual farmer considered in this study can be defined as the ratio of observed or realized (actual wheat output) to the stochastic frontier output (potential output). The stochastic frontier output is the maximum output possible given the technology available and inputs used, it is given by:

$$\boldsymbol{q_i^* = exp(x_i\beta + V_i)} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots [\mathbf{5}]$$

Where U_i = 0 because production is technically efficient on the stochastic frontier.

$$\boldsymbol{TE_i} = \frac{\boldsymbol{Actual\ Output}}{\boldsymbol{Potential\ Output}} = \frac{\boldsymbol{q_i}}{\boldsymbol{q_i^*}} = \frac{\boldsymbol{exp(x_i\beta + V_i - U_i)}}{\boldsymbol{exp(x_i\beta + V_i)}} = \boldsymbol{exp(-U_i)} \ldots \ldots \ldots \ldots \ldots \ldots . [\mathbf{6}]$$

Where $\boldsymbol{TE_i}$ is technical efficiency, the inefficiency term $\boldsymbol{U_i}$ is always between 0 and 1, When $\boldsymbol{U_i}$ is equal to zero, then production is on the frontier, $\boldsymbol{q_i^* = exp(x_i\beta + V_i)}$ and $\boldsymbol{TE_i}$ =1, therefore a farmer is technically efficient. When $\boldsymbol{U_i}$ is greater than zero ($\boldsymbol{U_i}$>0) the farmer is technically inefficient ($\boldsymbol{TE_i < 1}$) since the production may become below the frontier.

Factors affecting $\boldsymbol{TE_i}$ was previously estimated by using a two-stage process. In the first stage, the level of efficiency/inefficiency was measured using a normal production function. In the second stage, a probit/logit model was used to investigate the factors that determine levels of technical efficiency. However, since 2000, STATA, Limped, and Frontier computing packages which apply the Maximum Likelihood Estimate (MLE) are available which has enabled researchers to jointly estimate the Stochastic Frontier and the inefficiency model (Mango et al., 2015, Rahman et al., 2012, Sultan and Ahmed, 2014). Therefore, bread wheat producers TE and its determinants were estimated together using a single stage SFA under the current study.

3.6.2.2. Empirical Model Specification of the Production Function

The SFM can take either the Cobb-Douglas (CD) production function or the Translog production function. The CD production function imposes restrictions on the farm's technology by assuming constant production elasticities and setting the elasticity of input substitution to unity (Coelli et al., 1998, Kibaara and Kavoi, 2012). In addition, it assumes a fixed return to scale and a linear relationship between the output and inputs used in production. The Translog production function, however, assumes existence of nonlinear relationship between the output and inputs, and production elasticities are not constant. Researchers prefer the translog functional form due to its flexibility and does not impose assumptions about constant elasticity of production nor elasticities of substitutions between inputs (Beshir, 2014, Kibaara and Kavoi, 2012). Thus, this study too opt for the stochastic frontier production function using the flexible translog specification and is specified as follows:

$\mathbf{ln}\, \boldsymbol{q_i} = \boldsymbol{\beta_0} + \boldsymbol{\beta_1} \mathbf{ln}(\boldsymbol{X_{1i}}) + \boldsymbol{\beta_2} \mathbf{ln}(\boldsymbol{X_{2i}}) + \ldots\ldots\ldots\ldots\ \boldsymbol{\beta_7} \mathbf{ln}(\boldsymbol{X_{7i}}) + (\boldsymbol{\varepsilon_1}) \ldots\ldots\ldots\ldots [\mathbf{7}]$**,** Where

- ✓ q_i = wheat output per hectare of the ith respondent
- ✓ ln = the natural logarithm
- ✓ β_0= Constant term
- ✓ β_i = regression coefficient of the ith variable
- ✓ X_{1i}= amount of labour (man-days ha^{-1}) by the ith respondent
- ✓ X_{2i}= amount of capital invested for wheat production per hectare by the ith respondent
- ✓ X_{3i}= amount of total fertilizer applied (kg/ha) by the ith respondent

- ✓ X_{4i}= amount of land allotted for BWP (ha) by the ith respondent
- ✓ X_{5i}= amount of seed rate used (kg ha^{-1}) by the ith respondent
- ✓ X_{6i}= amount pesticide applied (L ha^{-1}) by the ith respondent
- ✓ X_{7i}= Machine rent (Ethiopian Birr) by the ith respondent
- ✓ ε_1 = is an error term and defined as $V_i - U_i$
- ✓ V_i = random effects (measurement errors, omitted explanatory variables) assumed to be independent ofU_i, identically and normally distributed with zero mean and constant variance$\boldsymbol{\sigma_v}^2$.
- ✓ U_{is} = Non-negative random error variables which are assumed to account for technical inefficiency among bread wheat producers of the study areas.

U_{is} are the technical inefficiency effects which are assumed to be independent of V_i such that U_i is the non-negative truncation (at zero) of the normal distribution with mean U_i and Variance (δ^2). The inefficiency model for this particular study is specified as follows:

$$\mathbf{U_i = \sigma_0 + \sigma_1 lnX_1 + \sigma_2 lnX_2 + \ldots\ldots\ldots\ldots \sigma_{13} lnX_{13} + \varepsilon_1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots [\mathbf{8}]$$

Where U_i denotes the technical inefficiency of the ith farmer, while X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, X_9, X_{10}, X_{11}, X_{12}, X_{13} and X_{13} denotes gender, age, Grade level, Family Size, Dependency Ratio, Tropical Livestock Unit (TLU), Land Size, hand weeding frequency, row spacing, frequency of extension contact, amount of credit, and membership in seed multiplication and marketing cooperatives, respectively.

3.6.2.3. Generalized Likelihood Ratio (LR) Test

This study has employed the generalized LR test to select the appropriate functional form that best fits to the data, the appropriate distributional assumptions of the technical inefficiency term and the existence or non-existence of inefficiency on the model and others. One hypothesis has been tested with regard to the model specification using the generalized LR test, which is defined as follows:

$$LR = \boldsymbol{\lambda} = \boldsymbol{-2ln}\left[\frac{\boldsymbol{L\,(H_0)}}{\boldsymbol{L\,(H_1)}}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . [\mathbf{9}]$$

$$\boldsymbol{\lambda = -2\{lnLH_0 - \ln L(H_1)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{[10]}$$

Where, λ is the likelihood ratio (LR), L (H_0) = the log likelihood value of the null-hypothesis; L (H_1) = the log likelihood value of the alternative hypothesis; and ln is the natural logarithm. This has a chi-square distribution with degree of freedom equal to the difference between the numbers of estimated parameters under H_1 and H_0. Yet, where the test involves a $\boldsymbol{\gamma}$, then the mixed chi-square distribution was used. The H_0 is rejected when the estimated chi-square is greater than the critical value.

IV. RESULTS AND DISCUSSION

4.1. Results

4.1.1. Descriptive statistics of the socio-demographic variables

The findings presented here were based on the data collected from fourteen KIIs, four FGDs, and 450 structured interviews. The profile of the KIIs and FGDs participants are summarized and presented in the supplementary materials of this study. Smallholder farmers' wheat production and their TE is not solely contingent upon the quantity, quality, availability, and affordability of farm inputs. As a result, this study has hypothesized that there are multiple agronomic practices, plot level variables, demographic, socio-economic, and institutional factors affecting smallholder farmers wheat productivity and their TE. Thus, it is essential to present findings of the descriptive analysis prior to presenting results of the SFM as it provides a vivid picture of the study area and sample farmers who grow bread wheat using recycled and fresh seeds. The descriptive statistics for all the variables considered in this study are presented in Table 10 below and it includes the mean values, the mean difference, the standard error, t-value, and p values. From this same table, one can witness the significant difference was observed between fresh and recycled seed users in terms of the different variables considered in the study. For instance, a significant age difference was observed between recycled (μ=38.98) and fresh seed (μ=46.08) users. The mean age of the farmers' in the study area was 42.18 years. On average fresh seed users were 7 years older than recycled seed users and the age difference between these two groups was significant at p=0.000. This is very close to the average age reported in other studies (Atilaw et al., 2016). There are ample evidences that support this finding. For instance, (Gebrie and Mada, 2018) have reported that aged households tend to have more years' experience that motivate them to take risks and engage in making use of recent innovations and practices. Other studies also revealed that age and experience have positively contribute to adoption of farm technologies. This is mainly due to the fact that old and experienced farmers have got sufficient time to weigh the merits of agricultural technologies than youngsters with no or few years' experience (Dessale, 2019).

Table 10: Results of descriptive statistics by seed recycling status

Variables	Mean (μ) Values					
	Recycled Seed Users (n= 247)	Fresh Seed Users (n=203)	Difference	Std.Err	t - values	p - values
Age (Years)	38.976	46.084	-7.108	.929	-7.65	.000
Grade levels (Year of Schooling)	1.899	1.616	.283	.265	1.05	.285
Family size	5.158	7.005	-1.847	.276	-6.7	.000
Dependency Ratio	0.623	.436	.186	.022	8.3	.000
Tropical Livestock Unit	4.537	9.713	-5.176	.409	-12.65	.000
Land Size	0.586	.861	-.275	.068	-4.05	.000
Frequency of Extension Contact	1.373	1.744	-.371	.106	-3.5	.001
Wheat Productivity	36.858	40.779	-3.92	.517	-7.6	.000
Credit amount	3825.510	4220.699	-395.19	477.402	-.85	.408
Seed Recycling frequency	6.450	2.616	3.833	.339	11.3	.000
Weeding frequency	1.425	1.872	-.447	.063	-7.15	.000
Row Spacing	14.433	19.852	-5.419	.858	-6.3	.000
Seed rate	214.778	169.582	45.196	8.957	5.05	.000
Fertilizer Per hectare	112.595	154.718	-42.123	8.12	-5.2	.000
Pesticide per hectare	0.406	.741	-.335	.045	-7.5	.000
TE Score	0.789	.813	-.024	.004	-6.65	.000
Categorical Variables	Number	Number	Total	Pearson's χ^2	P - values	
Gender	223	185	408			
Female	24	18	42	0.100	0.75	
Membership in Seed Multiplication & marketing Cooperatives						
No	90	186	276	143.101	0.000	
Yes	157	17	174			

Source: Own Computation (2022)

Education level of rural households enhances agricultural productivity and efficiency as it improves farmers knowledge and managerial skills, quality of labour, and the tendency to adopt new technologies (Kidane, 2020). Making use of fresh (unrecycled) wheat seed use was an important recommendation in IBWP. Yet, no significance difference was observed in terms of education between farmers who have used recycled and fresh seeds in BWP. In most developing countries, agriculture is operated by family labour. Thus, higher family size is expected to improve farmer's productivity and TE. The Ethiopian Demographic Health Survey has reported that the average household size of Ethiopia is 4.6 members (EDHS, 2016). The GDL (Global Data Lab) has estimated the national and sub-national average family size of Ethiopia from 1997 to 2019. The estimated national average household number for the year 2019 was 5.76 persons against 4.88 for Amhara region (www.globaldatalab.org). The average family size for this study was 5.99 persons which is closer to the national average but higher than the average family size of the region. The t-test has indicated a significantly high difference among fresh (μ=7.01) and recycled bread wheat seed users (μ=5.16). The need for more family member and least penetration of family planning awareness services might have contributed to the relatively higher number of household members in the study area. Moreover, the average dependency ratio in the study area turned out to be 0.54. A markedly high difference was noted between fresh (μ = 0.44) and recycled bread wheat seed users (μ = 0.62) at p=0.000. This implies that recycled bread wheat seed users have several dependent family members including children below 15 years old and old aged people above 64 years along with other disable/unhealthy family members.

Empirical evidences has indicated that animals' ownership enhances adoption of farm technologies that augment agricultural production. For instance, Assefa (2016) has shown that higher number of TLU has increased wheat productivity. In this study, it was found that fresh bread wheat seed users had significantly high number of TLU (μ =9.71) than recycled bread wheat seed users (μ = 4.54). The mean land size for the overall sample respondents was 0.71 hectare. However, farmers who make use of fresh bread wheat seed (μ = 0.861 ha) had significantly higher plot size than those who make use recycled bread wheat seed (μ =0.586 ha). The average wheat productivity for all sample respondents was 38.63 Qt ha^{-1}. This is higher than the 30.46 qt ha^{-1} national average and the 28.31 qt ha^{-1} regional average (CSA, 2021b). Yet, the two groups considered in this study were found to be significantly different in terms of their wheat productivity. Fresh seed users on average were able to produce 3.92 additional quintal of wheat per hectare against recycled seed users. Similarly, fresh bread wheat seed users were significantly better than recycled bread wheat seed users in terms of their annual income. Besides, there was no any noticeable difference in the amount of credit between these two groups. Meanwhile, smallholder farmers on average have received a credit amount of 4004 Ethiopian birrs, which was woefully inadequate to support wheat production and other urgent cash demands. Similarly, no any notable difference was seen between fresh and recycled bread wheat seed users in terms of gender. A significantly high proportion of fresh seed users had been member of seed multiplication and marketing cooperatives than recycled seed users.

4.1.2. Descriptive Statistics on Agronomic Practices

The productivity and technical efficiency of BWP depends on the extent to which farmers able to practice agronomic recommendations such as spacing, sowing methods, fertilizer application, cluster farming, seed rate, planting time, and tillage frequency (Aravindakshan et al., 2015, ATA, 2015, Manjunatha et al., 2013, Moti et al., 2020). Recycled and fresh wheat seed users considered in this study were found to be unique in terms of different agronomic practices. Spacing is an important agronomic practice in crop production. For instance, studies have indicated that keeping an optimum spacing between rows and seeds has increased crop production and farmers TE. Row planting and keeping optimum spacing involved cultivation of crops in lines which ease farmers mobility during different farm operations (e.g. weeding, fertilizer application/dressing, and harvesting), improve sunlight and soil nutrient use efficiency, and ultimately lead farmers towards higher grain yield (Aravindakshan et al., 2015). Respondents of this study widely vary in terms of spacing between rows. Fresh bread wheat seed users on average keep a row spacing (μ = 19.85) closer to the scientific recommendation of 20 – 25 centimeters. On average, fresh bread wheat seed users keep 5.42 centimeters more spacing between rows than recycled seed users.

Similarly, ATA (2015) has recommended at least a twice hand weeding frequency in BWP. However, farmers in the study place, on average, have practiced below the recommendation. Yet, fewer hand weeding frequency should not be taken as malpractice and has to be cautiously interpreted. For instance, during the KIIs, the researcher has learnt that farmers don't undertake multiple hand weeding due to the fact that they spray pesticide which hamper weed infestation and re-infestation. This qualitative information is in polar opposite to findings from the quantitative survey. Bread wheat producers who have used fresh/unrecycled seeds practice multiple weeding and at the same time apply pesticides. This discrepancy, however could have certain explanations. First, this could be because pesticides were sprayed after the weeds are well matured to be killed or to stop their propagation. Second, farmers may not use the right amount of pesticide and/or did not apply the right ratio of water & chemicals. Third, combining the chemical and mechanical weed control methods is recommended to have full control of the weed that may have encouraged farmers to make use of both weed control techniques. Moreover, chemical weed control requires spraying pre and post emergence pesticide. Nevertheless, the key informant interviews have indicated that farmers spray either only the pre-emergence or the post emergence pesticide.

Seed rate is another important agronomic practice in wheat production. Plenty of agronomic studies and trials have proven that seed rates below and above scientific recommendations have lessened productivity and TE of crop production (Abdulai et al., 2018, Abeyo et al., 2020, Tariku, 2012). The recommended seed rate for BWP in the East Gojam Zone is 150 kg ha^{-1} (ATA, 2015). Yet, farmers' in the study area did not stick to this recommendation. Irrespective of their seed recycling practice, respondents of this study, on average, have used a seed rate well beyond the scientific recommendation (μ=194.39 kg ha^{-1}). However, it is worth noting that wheat producers with recycled seeds (μ=214.778 kg ha^{-1}) apply a significantly higher amount of seed rates than fresh seed users (μ=154.718 kg ha^{-1}). It has now become clear that feeding the ever-growing population of the world through conservation agriculture and without application of chemical fertilizers is quite difficult. Thus, application of different types of fertilizers based on scientific suggestions has become a viable option (Nazziwa-Nviiri et al., 2017, Desta and Almayehu, 2020). Sample respondents of this study had been applying two types of fertilizer including the new blended fertilizer (NPS_B) and Urea (NH_2CONH_2). The amount of recommendation for the NPS_B and Urea fertilizers per hectare was 150 and 200 kgs ha^{-1}, respectively. Nevertheless, farmers in the study area have applied well below the recommendations for both types of fertilizers.

4.2. Results of Hypothesis Tests

The GLR test has been conducted using the formula specified in equation 11 in order to select the model that best fits the data of this study. The test rejected the H_0 (null hypothesis) that asserts the translog stochastic frontier production function can be reduced to a CD production function at 5% level of significance. This favors the application of the Translog functional form at the expense of the CD. Thus, earlier studies based on the CD model (Chiona et al., 2014, Dessale, 2019, Kidane, 2020, Mesay et al., 2013, Wudineh and Endrias, 2016) may be misleading and hence can't be replicated here. The second hypothesis test was conducted to check the existence of inefficiency parameters. The null hypothesis was that technical inefficiency effects are not in the model (H_0: $\gamma = \delta 0 = \delta_1 = \delta_2 = ... = \delta_{13} = 0$ (all wheat producer farmers considered in this study were efficient) was tested against the alternative hypothesis that inefficiency factors were in the model (H_1: $\gamma > 0$ and $\delta i \neq 0$ for i= 0, 1, 2, . . . ,13). The likelihood ratio test also rejected the null hypothesis H_0 at 5% level of significance. Thus, it can be concluded that there exist technical inefficiencies in BWP which in turn implies that the traditional production functions that do not account for technical inefficiencies are inadequate for modelling BWP in the study areas. The estimated parameter for γ was higher than 1, implying that the variation in BWP was mainly attributed to variations inefficiency (Appendix Table A7). The GLR statistics value confirmed that the $\boldsymbol{\sigma_u}^{\mathbf{2}}$ was strongly biased towards $\boldsymbol{\sigma_v}^{\mathbf{2}}$. The third hypothesis was carried out to check the H_0 (null hypothesis) that the distribution of inefficiency can be reduced from truncated normal to half normal distribution $\mu=0$. The result has turned out in rejection of the null hypothesis. This means that the distribution of the inefficiency term is truncated at 0 normal distribution which is significant at 5% (Appendix Table A7).

Before going to analyze the determinants of farmers' TE in BWP, there is a need to check the assumption that the amount of bread wheat output is explained by variations in farmers TE. The estimated value of gamma (γ) indicates the total variation in output that can be explained by variations in farmers' TE. According to Kumbhakar and Lovell (2003), the estimated value of Lambda (λ) presented in Table 11 below can be used to calculate the value of gamma (γ) as specified below:

$$\gamma = \frac{\lambda^2}{1+\ \lambda^2} = \frac{(1.09)^2}{1+\ (1.09)^2} = 0.545$$

This estimated value of gamma here implies that 54.5% of the total variation in the amount of bread wheat output was due to variations in TE between producing units. Besides, using the findings presented in Table 4.4 below, the value of sigma square (σ^2) which indicates the model goodness of fit can be calculated as follows

$$\sigma^2 = \sigma_v^2 + \sigma_u^2 = (0.043)^2 + (0.045)^2 = 0.04$$

According to Battese and Coelli (1995), the lowest sigma square value (σ^2) which is significant at 1% is a clear indication for the goodness of fit and the validity of the specified assumption about the composite error terms distribution.

4.3. Estimates of the Stochastic Frontier Production Function

This study has employed the maximum likelihood estimates (MLE) of the TL functional form to investigate the major determinants of BWP difference among farmers. About seven variables were considered in the estimation of the frontier production function. The coefficients for the factors used in BWP were estimated under the full frontier production function (Maximum Likelihood Estimation). Each coefficient represents individual elasticities. These individual elasticities adds-up to 1.49 indicating that farmers in the study area are facing increasing returns to scale. This portrays the potential to further increase the extent of BWP. This also means that there exist a wide opportunity to increase bread wheat production with an increasing rate of return. The result of the MLE gave the value of the parameter estimations of the frontier model along with the value of log-likelihood function for the stochastic production function. Table 11 below is a summary of the MLE of the parameter of TL functional form of the stochastic frontier model.

Table 11: Maximum likelihood estimates of the Translog Stochastic production frontier

lnOutput	Coef.	St.Err.	Z-value	p-value	[95% CI]	
Frontier						
Lnlabour	0.086***	0.006	14.210	0.000	0.075	0.098
lncapitalin	0.220***	0.005	48.730	0.000	0.211	0.228
lnfertilizer	0.042***	0.004	10.270	0.000	0.034	0.050
lnland	-0.031***	0.004	-8.870	0.000	-0.038	-0.024
lnseedrate	-0.007NS	0.005	-1.420	0.155	-0.018	0.003

lnpesticide	0.014^{***}	0.005	2.720	0.007	0.004	0.024
lnmarent	0.005^{***}	0.001	6.260	0.000	0.004	0.007
Constant	1.193^{***}	0.057	20.750	0.000	1.080	1.305
Mu						
_cons	-1.673	13.656	-0.120	0.902	-28.439	25.093
Usigma						
_cons	-6.220	10.053	-0.620	0.536	-25.923	13.482
Vsigma						
_cons	-6.276	0.067	-93.500	0.000	-6.408	-6.144
sigma_u	0.045	0.224	0.200	0.842	0.000	846.535
sigma_v	0.043	0.001	29.800	0.000	0.041	0.046
lambda	1.090	0.224	4.590	0.000	0.589	1.468
Number of obs. = 450 Prob>Chi2 = 0.000 LR test of sigma_u=0: chibar2(01) = 0.000						
Wald chi2(7) = 4130.30 Log likelihood = 772.7384 Return to scale = 1.491						

The study has hypothesized seven factors of production determines the BWP function. All of the hypothesized variables except seed rate had a significant effect in explaining the variation in BWP among respondent household heads. The coefficient for labour measured in terms of man-days spent for BWP turned out to be significant and positive at $p<0.01$. This coefficient for labour implies that a 1% increase in man-days leads to a 0.086% increase in bread wheat productivity. This finding is backed by earlier studies that have revealed an increase in crop productivity is the result of intensive labour use for different farm operations and agronomic practices that augment production (Chiona et al., 2014, Dessale, 2019, Shamsudeen; et al., 2018, Wudineh and Endrias, 2016). Thus, the better wheat productivity in this study can also be attributed to the fact that farmers in the study area have allocated sufficient man-days for the various labour intensive agronomic practices such as maximum tilling frequency, row planting, weeding, and timely harvesting practices that enhance their productivity.

Similarly, the coefficient for capital invested measured in terms of Ethiopian birr was significantly positive at $p<0.01$. As expected, this coefficient indicates that an additional 1% rise in capital invested leads to a 0.22% increase in bread wheat productivity. This finding is backed by earlier studies. For instance, better annual income is reported to increase framer's propensity to be productive as it enables them to have access to production supplementing inputs and technologies. The positive impacts of income on production enhancing agricultural innovation is frequently reported (Mideksa et al., 2017, Tavva et al., 2017, Yirga et al., 2013b). The effect of capital investment was higher than any other variable considered in the production function of this study. The extremely significant effect of capital on BWP could have several explanations. First, it may serve farmers as an incentive to purchase production improving and efficiency augmenting technologies. Key informants of this study including seed suppliers and DAs have revealed that better-off farmers adopt technologies earlier than poor farmers. This could be because better-off farmers are well above the poverty line that they took the risk of trying a new innovation. Conversely, farmers who are already below the poverty line or closer to it could not have the appetite for production enhancing innovations for two obvious reasons. First, farmers who are already below the poverty line could not afford the purchase of production enhancing technologies as they don't have sufficient capital for investment. Studies have also shown that poor farmers do not invest even on the cheapest farm innovations as they do have urgent consumption demand (Alemu and Bishaw, 2015, Dawit, 2012, Dorosh and Mellor, 2013, Mehamood et al., 2020). Second, farmers closer to the poverty line do not have the incentive to try new innovations as risks of innovation failure puts them below the poverty line. This could be another explanation for the highly significant impact of capital investment in BWP. Besides, the agronomic practices in BWP are quite labour demanding. Higher income is likely to encourage farmers to make use of hired labour and machinery rent which in turn would improve production and efficiency of the farmers. This could be another explanation for a highly significant nexus between BWP and high capital investment.

Chemical fertilizer application was another important hypothesized determinant expected to have a considerable impact on bread wheat productivity in the study area. The coefficient for chemical fertilizer was positive and significant at $p < .05$ indicating that a 1% rise in chemical fertilizer application has contributed to a 0.042% increment in the amount of BWP per hectare. Several studies have revealed that the low wheat yield in Ethiopia is attributable to low fertilizer use, continuous nutrient uptake by crops leading to serious depletion of soil fertility, and deficient application of organic matter. Besides, Ethiopia's sole dependence on narrow imported fertilizer products (largely urea and di ammonium phosphate (DAP)) is blamed to cause a considerable productivity loss. These two imported fertilizer products are rich sources of nitrogen (N) and phosphorus (P). But most Ethiopian soils lack other macro nutrients (Bizuwork and Yibekal, 2020, EthioSIS (Ethiopian Soil Information System), 2014, Kidane, 2015). The introduction of the blended NPS_B fertilizer in addition to the existing types of fertilizer could explain the positive impact of fertilizer in wheat productivity of the study area. Despite the observed positive nexus between wheat productivity and fertilizer application, it is worth noting that farmers in the study area have applied fertilizer rates well below the recommendation. This could be due to the blanket fertilizer rate recommendation that did not take spatial differences into consideration. This might call for study area specific fertilizer rates related agronomic trials. Thus, future research should focus on this critical issue. Similarly, (EthioSIS (Ethiopian Soil Information System), 2014) argue for a soil test based application of plant nutrient rather than the blanket recommendation of urea and DAP, and especially those containing sulfur, boron, and other nutrients is recommended in averting problems caused due to nutrient deficient soil.

The coefficient for land is interestingly significant and negative at $p<0.01$. This implies that an extra one-hectare land addition to the current wheat production leads to a 0.03% productivity loss. This finding is diametrically opposite to the findings reported in multiple empirical investigations (Ayele, 2016, Chandio et al., 2019, Dessale, 2019, Abid et al., 2019, Mango et al., 2015, Omer, 2015). Unlike the finding under the current study, these authors found a significant positive association between land and crop productivity. Higher land size enable owners to benefit from economies of scale. The production theory of diminishing marginal utility states that an increase in input can increase the production of crop and other commodities up to certain optimum levels. Any additional input use after this optimum level has lead to a flat production. Further input addition after the plain/flat production curve causes a decrease in production (Colman and Young, 1989). This theory could be a plausible explanation for the current finding. Besides, Abdulai et al. (2018) has indicated that a major reason for the non-attainment of achievable yields is low fertility of the soils which is partly due to low use of fertilizers. But low fertilizer use was not observed in this study. The declining soil fertility and land fragmentation could explain the negative relationship between total wheat productivity and land size.

The coefficient for seed rate was not significant at the conventional probability levels indicating that seed rate did not contribute to total wheat productivity. As indicated in Appendix Table A8, farmers in the study place have used an average seed rate of 194.39 kg ha^{-1} which is higher than the recommendation by 44.39 kg ha^{-1}. During the FGD, participants have raised that recycled seeds are used from reserves saved during the previous production, can be borrowed from relatives and friends, and are cheaper in the market. They have also confirmed that the productivity of recycled seed is believed to be inferior to the fresh seeds, unless compensated by applying extra seed rates. This farmers attitude of increasing productivity by making use of extra seed rates is against the recommendation and the established scientific theory of Diminishing Marginal Productivity (DMP). The relatively cheaper market price for recycled seeds might have encouraged farmers to apply more amount of seed rate per hectare. Besides, according to Tavva et al. (2017), higher seed rates application imply a risk aversion behavior of farmers to ensure good plant stand and survival. This explanation can be adopted in this study too. Contrary to the current study, seed rate has shown the highest input effect on production and estimated elasticities. The positive contribution of seed rates on production and TE was attributed to the quality and quantity of the seeds (Mehmood et al., 2020, Mideksa et al., 2017, Tenaye, 2020). The insignificant contribution of seed rate in this study may therefore be explained by the inferior quality of the seeds and the seed recycling practices in the surveyed areas. Weeds remain a major challenge to increasing crop output as they compete with the crop plants for light, nutrients, and water. Such growth retarding weeds could not cause a significant harm if proper weeding frequency is followed (Kibaara and Kavoi, 2012). Thus, the application of pesticide was expected to increase total crops productivity. As expected, the coefficient for pesticide was positive and significant at p=0.007 indicating BWP is highly dictated by weed management.

Machine rent was expected to have a significant positive impact on total factor productivity. As expected, a 1% change in machinery rent has led to a 0.005% change in bread wheat productivity. There are studies that support the current finding. Higher productivity, which requires greater power and mechanization, is one of the most important technologies that can increase production when resources are limited (Mohammad et al., 2012). This implies that mechanization leads to production improvement under sufficient supply of land, labour, and other resources. This may be a plausible explanation for the significant contribution of machinery on BWP under the current study. In addition, key informants of this study have repeatedly mentioned that the state sponsored harvester and threshing machineries has helped farmers for timely harvest and substantially reduce post-harvest losses. It is also worthy to note that out of the seven variables expected to improve bread wheat productivity, machinery rent has the least contribution. This could be due to the fact that these machineries (especially combine harvesters) were brought to the study areas from other regions on rental basis with expensive prices which is likely to increase the operation cost of BWP.

4.4. Implications of bread wheat seed recycling on technical efficiency (TE)

In Ethiopia, making use of freshly purchased improved seeds and improved seeds recycled for a maximum of five seasons are considered as improved seed use (Abeyo et al., 2020). Therefore, fresh seed use in this study refers to the use of freshly purchased seed and seeds recycled for a maximum of five seasons. This study has expected that multiple bread wheat seed recycling has a significant negative impact on the productivity and TE of smallholder farmers. Studies have shown that bread wheat seed recycling to a maximum of five production seasons can be considered as improved practice and don't cause significant productivity loss. But, multiple seed recycling is reported to be a common practice in wheat growing areas of Ethiopia. For instance, about 84% of the farmers depend on recycled seeds while only 14% used new seeds. This practice produce seeds that have low germination percentage and is contaminated with weeds. The problem of recycled seed is serious in Ethiopia, where pathogens of the wheat rusts evolve quite rapidly, rendering farmers' varieties less resistant to disease. To avoid yield losses from disease, farmers should replace their wheat varieties frequently and regularly (Abeyo et al., 2020, Yirga et al., 2013b). Given these existing literatures, this study had the following hypotheses as far as the nexus between TE and bread wheat seed recycling is concerned:

H_0: diff = 0. This hypothesis assumes that there is no difference in mean TE between wheat producing farmers with fresh and recycled seed use

H_{a1}: diff ! = 0. This is an alternative hypothesis with an assumption that the difference in mean TE between fresh and recycled bread wheat seed users is different from zero.

H_{a2} = diff < 0. This is a second alternative hypothesis that expects the difference in the mean TE between recycled and fresh seed users is less than zero.

H_{a3} = diff > 0. This is the third alternative hypothesis that expects the mean TE difference between recycled and fresh bread wheat seed users is greater than zero.

This study has found that about 247 (54.89%) of the respondents make use recycled seeds for more than five production seasons while about 203 (45.11%) make use of either freshly purchased seed or recycled seeds below five times. The average TE of fresh and recycled seed users were 0.8123 (81.23%) and 0.7789 (78.89%), respectively. This can be interpreted as a typical fresh seed user and recycled seed user are operating 0.1877 (18.77%) and 0.211 (21.11%) less than his/her maximum TE and this difference is highly significant at p=.0000 (See details in Table 12). Figure 9 presented below paints a clear picture about the relationship between seed recycling and TE scores. It offers a strong evidence that the variance in distribution of the TE scores between recycled and fresh seed users. A substantial proportion of fresh seed users had a mean TE score of greater or equal to 0.8165 while none of recycled seed users hit a TE score of this magnitude.

This study has also examined the marginal effect of seed recycling on the overall TE of BWP. As presented in the Table 12 below, a unit increase in seed recycling frequency is associated with a .001 decline in TE. Based on the ordinary least square (OLS) estimation of the Generalized Linear Model, the marginal effects of successive seed recycling up to four, eight, twelve, sixteen, and twenty times on the TE of BWP were predicted, respectively. Farmers who make use of fresh seeds (fresh or seeds recycled less than five times had a mean TE of 80%. Further seed recycling up to eight, 12, and 16 times has caused a 0.003, 0.007, and 0.01 loss in TE, respectively. Generally, it can be concluded that seed recycling and TE have a significant inverse relationship. This finding is backed by other empirical investigations (Abeyo et al., 2020, Alemu and Bishaw, 2015, Atilaw et al., 2016, Bishaw et al., 2012, Mideksa et al., 2017).

Thus, from these findings, it is clear that the null hypothesis (H_0: diff=0) that expects no TE difference and the fourth alternative hypothesis that expects a positive TE difference (H_{a3}: diff > 0) are rejected in favor of the 2nd (H_{a1}: diff ! = 0) and the 3rd H_{a2}: diff < 0) alternative hypotheses. This means that the assumption that seed recycling does not cause inefficiency in BWP does not hold water. In general, it can be deduced that seed recycling has caused considerable TE loss as compared to fresh seed. Recycled seeds are reported to be highly vulnerable to the most important wheat rusts, a group of diseases caused by fungal pathogens (*Puccinia* spp.), are stem rust (also called black rust), stripe rust (also called yellow rust) and leaf rust (also called brown rust). Stem and stripe rusts are the major biotic constraints to wheat production in Ethiopia, with frequently recurring epidemics. Studies revealed that recycled seeds are susceptible to weeds and pathogens (Moti et al., 2020, Tolemariam et al., 2018). The biotic constraints and diseases may add financial and management burdens on farmers that might explain farmers technical inefficiency in this study.

Table 12: Marginal effect of different levels of seed recycling frequency on TE

Adjusted predictions

Model VCE: OLS

Expression: Linear prediction, predict()

1._at: Seed recycling Frequency = 4

2._at: Seed recycling Frequency = 8

3._at: Seed recycling Frequency = 12

4._at: Seed recycling Frequency = 16

5._at: Seed recycling Frequency = 20

TE Score	**Coef.**	**Std. Err**	**t-value**	**p-value**
Seed recycling frequency	-.001	000	-2.02**	.000
Constant	.804	.003	297.19***	.000
Mean dependent var =.79963	SD dependent var = 0.037423			
R-squared =0.736	# of obs = 450			
F-test =4.084	Prob > F 0.044			
Akaike crit. (AIC)=-1679.537	Bayesian crit. (BIC) -1671.318			

		Delta-method				
	Margin	std.err	t	P>t	[95% Conf Interval]	
_at						
1	0.800	0.002	447.440	0.000	0.797	0.804
2	0.797	0.002	351.570	0.000	0.792	0.801
3	0.793	0.004	218.950	0.000	0.786	0.800
4	0.790	0.005	151.510	0.000	0.779	0.800
5	0.786	0.007	114.360	0.000	0.773	0.800

Variables that uniquely identify margins: Seed recycling frequency

4.5. Discussions

4.5.1. Determinants of TE

This study has considered about 12 different socio-demographic, economic, institutional, and agronomic determinants hypothesized to influence TE of BWP. Among these variables, gender, grade level, plot size, and frequency of extension contact of the respondents did not have a notable contribution to BWP technical inefficiency. Figure 8 below illustrates the nexus between TE scores and the different quantitative variables hypothesized to influence the TE in bread wheat production. The coefficient for gender (being female) is negative but insignificant indicating technical inefficiency is not caused by gender differences. However, ample studies unfold that female headed households generally have less access to and control over different factors of production including land, credit, farm inputs, extension services, and irrigation water which contributes to their inefficiency in farm operations (Gebre et al., 2019, Kibaara and Kavoi, 2012). A plausible explanation for the current insignificant impact of gender on technical inefficiency may be the traditional support system by which the community assist farm operation of widowed and divorced women. Moreover, participants of the female FGD have explained that helpless, single or unmarried, widowed, divorced, and women with disability are beneficiary of social welfare programs like the Productive Safety Net Program (PSNP) and other non-governmental organization (NGO) sponsored supports. These social welfare programs support women by providing farm inputs and emergency assistances in times of shocks and stresses that might have helped them to enhance their production and improve their TE. These same FGD participants have explained that there are women Village Economic and Social Associations (VESAs) that provide credit, saving, training, farm inputs, marketing services, labour, and social supports in times of misfortunes including crop production failures, livestock and human death. It was frequently mentioned that these VESAs have helped women to have access to and control over financial services which is not open to male headed households. The insignificant effect of gender on farmers technical inefficiency thus could be attributed to these support mechanisms. A study made by Anbes, (2020) backs the finding we found here.

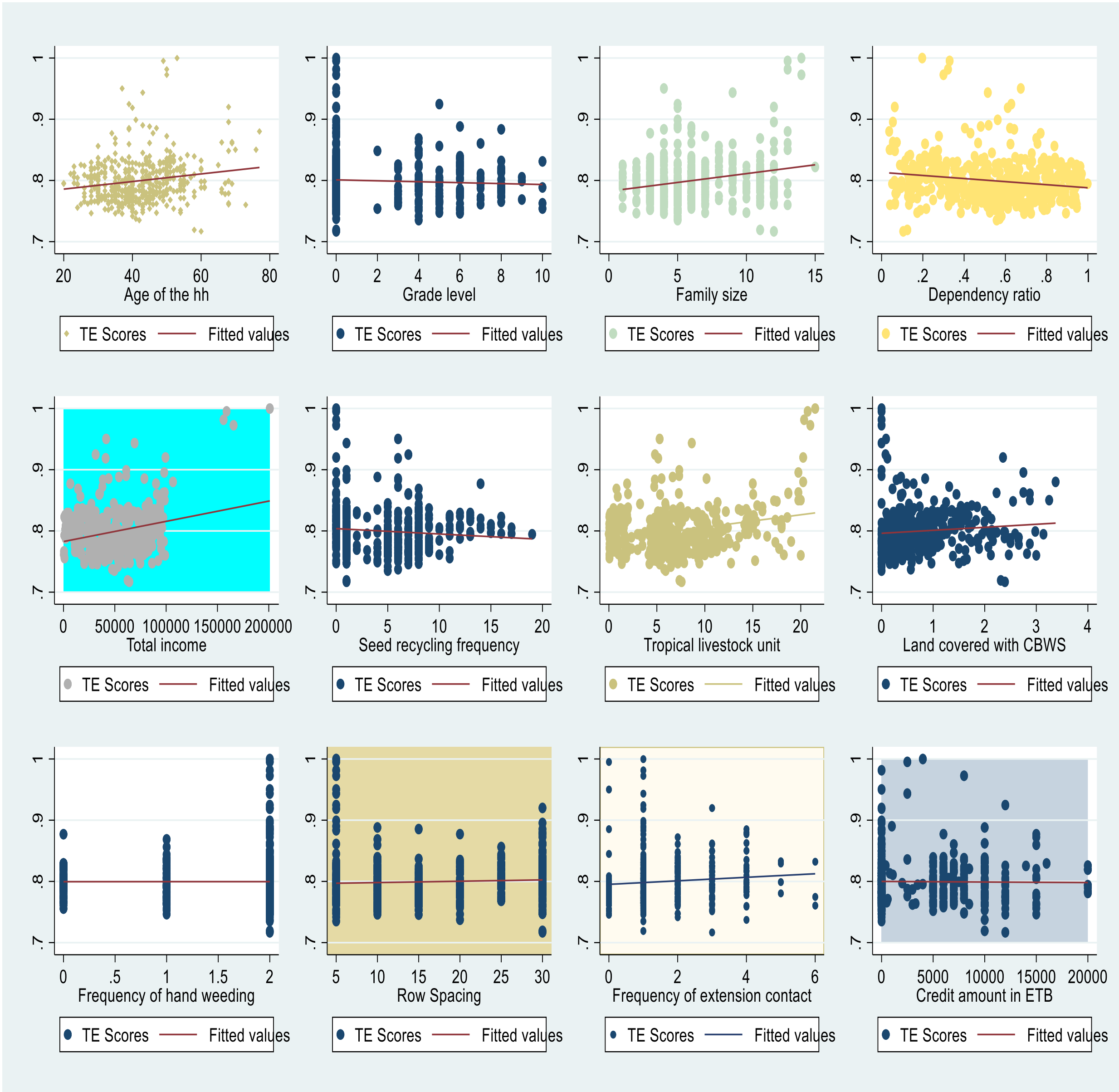

Figure 8: Combined Graph between TE Score and Hypothesized Variables

The age of the farmer was hypothesized to have a statistically significant positive effect on the TE of BWP. Age is considered a proxy indicator of farmers' experience in making use of improved practices and farm inputs. The coefficient for this variable is highly statistically significant with a negative sign at p<.01, which indicates that the age of the farmer is inversely related to inefficiency. This implies that younger farmers tend to be more inefficient than older ones. From Table 13 presented below, it is clear that a one-year increase in farmers' age reduces technical inefficiency by 0.13%. This could be due to the fact that longer years and experience in agriculture have helped older farmers to weigh the merits and demerits of efficiency-enhancing practices and inputs which in turn motivate them for further adoption and improvement in production efficiency. In addition, longer years may bestow farmers the chance for better asset ownership and socio-economic status that embolden them to take risks in trying efficiency and production augmenting inputs and practices. Thus, the age of farmers can be considered a vital socio-personal variable in improving the efficiency of BWP. A similar finding was reported by other studies (Wudineh and Endrias, 2016, Chiona et al., 2014, Ayele, 2016). However, few other studies are against this finding. For instance, it was found that older farmers are likely to be more conservative and hesitant to adopt new innovations and evade frequent experimentation with the new technologies that reduce their TE (Mesay et al., 2013). This study has also mentioned that farmers managerial ability decreases with age that reduce their productivity and TE.

Table 13: Maximum likelihood estimates of the determinants of technical inefficiency.

Variables	**Coef.**	**Std.Err**	**Z-value**
Gender (Female)	0.015^{NS}	2.982	0.010
Age	-0.125**	0.734	-0.170
Grade	0.089^{NS}	0.273	0.330
Family size	-0.502**	0.690	-0.730
Dependency Ratio	0.019**	32.844	0.000
Number of animals (TLU)	- 0.095*	1.037	- 0.090
Land size	0.014^{NS}	5.077	0.000
Hand weeding frequency	-0.075**	2.401	-0.030
Row spacing	-0.031***	0.169	-0.180
Extension contact	-0.026^{NS}	1.147	-0.020
Credit amount	-0.002**	0.001	-1.990
Cooperative Membership (Yes)	-0.060**	2.616	-0.020
Constant	0.511***	48.329	0.010
Number of obs = 450	Log likelihood = -146.4552	Wald chi2(7) =20.67	
Prob > chi2 = 0.0043	Mean TE Score = .7996	SD Dependent var. = .037482	

*** p<.01, ** p<.05, * p<.1 ^{NS} Not significant Source: Own Computation (2022)

Education level of the respondent was expected to have a significant direct relationship with the farmers' TE. Yet, the inefficiency coefficient found in this study is negative and insignificant. This means that farmers' level of education measured in years of schooling attended don't affect their level of TE. This is diametrically opposite to several established facts that have proven the highly significant positive impact of education on improving TE of farmers (Mesay et al., 2013, Tavva et al., 2017, Wudineh and Endrias, 2016). These studies unfold that education improves the ability of the household to make informed and timely decision about production inputs. Educated farmers more often have better access to agricultural information and higher tendency to adopt improved inputs (like fertilizers and crop varieties) more optimally and efficiently. However, the discrepancy about the impact of education could have several explanations. The first explanation may be the difference in the level of education attained by farmers. The mean grade level attained by farmers of this study area is less than two years. The average years of schooling reported by the studies mentioned are higher than two years. Thus, few years of schooling in the study area could plausibly explain the insignificant contribution of education on farmers TE. Second, the difference in the scale of farm operation could be another explanation. For instance, the positive efficiency impact of education is observed in large and medium farms than small farms (Rahman et al., 2012). However, this is against the established facts by the proponents of the small farm approach. For instance, studies have proved that land productivity of small farms was at least twice that of the largest ones. Small farms enable to make use of family labour intensively and also help in avoiding supervision constraints of managing a large hired labour force in big farms. Hence, small farms maximize return to land which is the scarce resource for them and for nation (Schultz. T.W, 1964).

Larger family size has been associated with better productivity and TE. Studies unfold that households with larger family sizes have better advantage by being able to use labour resources to accomplish different labour demanding farm operations at the right time (Tariku, 2012, Yohannis et al., 2020). Yet, higher household size has also been linked to less productivity and technical efficiency, when the actual family members are sick, unproductive, old, and disabled (Solomon, 2014). These findings sheds light on the need to consider family size and dependency ratio separately. In this study dependency ratio refers to the number of dependent household members (which includes children less or equal to 14 years, elderly people greater or equal to 64 years, along with sick and people with disability) divided by the number of productive household members (which include working age people from 15 to 64 years). The same definition was used in several studies (Harasty and Ostermeier, 2020). Given these evidences, this study therefore has hypothesized that family size has a highly significant contribution to TE while dependency ratio ends-up in curtailing farmers TE. The findings for both of these variables was congruent with prior expectations. From the coefficient presented in Table 13 above, it can be inferred that a 100% increase in family size reduces technical inefficiency by 50.2% at $p<.05$. On the contrary, a 100% increase in dependency ratio has increased farmers technical inefficiency by 1.9% at $p<0.05$. From these findings, it is also clear that the TE gains from an increase in family size can be cancelled by the efficiency loss as a result of higher dependency ratio. This finding is in agreement with the study made at Wolmera district of West Gojam in Ethiopia (Solomon, 2014) .

Studies have shown that bigger land size makes production operations difficult and costly to fulfill the production input requirements. Moreover, big farm owners with limited family and hired labour, draught power, and no access to labour saving technologies tend to poorly manage their plots (Dessale, 2019, Sultan and Ahmed, 2014). As a result, land size allocated for BWP was expected to have an inverse relationship with farmers TE. The coefficient for land size, however did not show any noticeable impact on farmers TE and was not in line with a priori expectation of the study. This means that the amount of land allocated for BWP did not affect farmers TE. Several findings are against what has been observed in this study area. For instance, a significant and positive impact of plot size on wheat producers' inefficiency was reported in another study (Dessale, 2019) . The same author has argued that the significantly high positive impact of plot size on technical inefficiency is due to the inherent nature of big plot sizes that hamper farmers ability to carry out important agronomic practices that must be done on time given the limited resources available at farmers disposal. On the contrary, farmers with larger area of cultivable land have the capacity to use compatible technologies that could increase their efficiency and enjoy the benefits of the economies of scale. The negative but insignificant coefficient for land size in this study could also be due to land fragmentation and declining soil fertility (Ayele, 2016).

Quite often, livestock and crop production tend to be complementary. Animal wastes can be used as a soil conditioner while crop residues and remnants serve as livestock feed. Animals can be good source of cash and draught power, which in turn enhance productivity and efficiency.

Furthermore, animals can be used as a hedge and shock absorber to artificial and natural shocks and stresses (Ayele, 2016). Thus, the number of animals owned expressed in TLU was hypothesized to have a highly significant positive impact on the TE of farmers. The parameter estimate was significant and negative indicating technical inefficiency decrease with increasing TLU at $p<0.1$. The parameter estimate has indicated that a 1% increase in TLU decrease farmers probability of being inefficient by 0.095%. This is in line with the prior expectation of the study.

Hand weeding frequency was expected to enhance production and TE of farmers in the study area. The coefficient for this variable is highly significant and negative implying a unit increase in weeding frequency reduces the probability of being technically inefficient by 0.05 at $p<0.01$. Farmers in the study area make use of both mechanical and chemical weed control methods that may have assisted them to enhance their production and TE. Earlier studies have also stated weed control as quintessential practice for efficient and profitable BWP. Weeds have direct and indirect impact on BWP. Directly weeds compete with the wheat crop for space, water, light, and nutrients while they harbor insects and disease-causing organisms indirectly (Wondimu et al., 2015).

Our prior assumption on the negative relationship concerning the spacing between rows and technical inefficieny does holds water. A unit increase in the spacing between rows has reduced technical inefficiency by 0.005 at $p=0.001$. Given this finding, encouraging farmers to stick to keeping the optimum row spacing leads to reduction in technical inefficiency and improve BWP. This study found that row planting and cluster farming is widely practiced in the study area. This is because the extension advisory service has been actively pushing farmers to move from the conventional broadcasting wheat sowing method on fragmented plots to row planting and cluster farming. This finding is quite inline with other findings (ATA, 2015, Wondimu et al., 2015).

The frequency of extension contact was hypothesized to have a significant positive impact in improving farmers TE in BWP. Unlike the prior expectation, the coefficient for extension contact turned out to be insignificant. Given the strategic importance of bread wheat and the political commitment of the government, this finding should be cautiously interpreted. The indirect nexus between frequency of extension contact and households TE may be explained by the highest emphasis and political commitment paid to irrigation based wheat production at the expense of rain-fed production. Key informant DAs have indicated that they have been intensively working on bread wheat advisory service for more than 30 years now. As a result, they have shifted their attention to introduction of economically superior and industrial crops than conventional crops production. Thus, the insignificant contribution of the frequency of extension contact could also be explained by the focus shift to other commodities. Of course, the theory of diffusion of innovations proposed by Rogers (2003) could be the best explanation for this indirect causal relationship between frequency of extension contact and TE. This theory asserts that extension may have significant impact in earlier stage of technology introduction when farmers lack sufficient information and skill. But at later stages, there could be information equilibria between the farmer and extension worker. Thus, this assessment has focused on later stage during which information, improved practices, and inputs for BWP has already been fully diffused and no new ways of BWP is generated. This late assessment may belittle the impact of the extension service at earlier time of improved bread wheat production technology introduction and could explain the trivial contribution of the extension service. However, several findings reported the highly significant positive contribution of agricultural extension service in enhancing producers TE (Assefa et al., 2014, Tiruneh et al., 2015). Lack of extension service pluralism was also found to hamper smallholder farmers’ production efficiency (Kassa and Alemu, 2016). According to these authors, the majority of farmers in Ethiopia are not exposed to multiple agricultural technology and information sources. It is only the state-led agricultural extension system that often provides them with agricultural advisory services and innovation that could reduce diversity information.

The coefficient for the amount of credit has turned out contrary to a priori expectation of this study. The amount of credit did not show any marked effect on the TE of BWP. This is due to the fact that the majority of the farmers in the study area don’t have access to formal financial institutions. Participants of the FGDs have frequently and unanimously explained that access to credit and financial services is very limited. These FGD participants further mentioned that it is only Amhara Credit and Saving Institution (ACSI) that provide credit service for the community. This is due to expensive collateral requirements, unaffordable interest rates, lack of appropriate risk mitigation products, and supply driven nature of the financial services that don’t match smallholder farmers felt needs. The insufficient credit supply that has retarded agricultural production was reported in several studies (Abate et al., 2014, Abdulai et al., 2018, Chandio et al., 2019, Shikur, 2022). These facts on credit could explain the unmarked contribution of credit on the TE of BWP in this study area. Therefore, in order to increase the TE in BWP, farmers must be provided with sufficient amount of credit and easy access on favorable terms through formal institutions.

The coefficient for respondents membership in IBWS production and marketing cooperative has turnedout in favour the assumption. It indicates that the probability of being inefficient is reduced by 0.003 for members than non-members at $p<0.05$. The Sieve diagram presented in Annex Graph 2 also offers a strong evidence about the variance in distribution of the TE scores between recycled and fresh seed users. A substantial proportion of fresh seed users had a mean TE score of greater or equal to 0.8165 while none of recycled seed users hit a TE score of this magnitude. There are evidences that agree with the current finding (Altaye and Mohammed, 2013, Guth and Katarzyna, 2022). These same authors reported that producers membership in cooperatives boost productivity and enhance TE due to the fact that their membership bestow them the prospect of a reduced transaction cost both for inputs and their produce in times of unfavorable market prices and supply shortages. The study area is known for its wheat production suitability. Thus, the Ethiopian Seed Enterprise (ESE) and the Amhara Seed Enterprise (ASE) establish wheat seed multiplication and marketing cooperatives that has enhanced members efficiency and productivity

Our finding has indicated that row planting and cluster farming is widely practiced in the study area. This is because the extension advisory service has been actively pushing farmers to move from the conventional broadcasting wheat sowing method on fragmented plots to row planting and cluster farming. However, earlier studies unfold that it is not only the sowing method that counts most in improving productivity and TE. The spacing between seeds and rows have also considerable impact on crop productivity and production efficiency (ATA, 2015, Wondimu, 2015). Given these findings, this study has assumed that the spacing between rows has a highly significant positive impact on the TE of BWP. This assumption holds water under the current study. A unit increase in the spacing between rows has reduced technical inefficiency by 0.005 at $p=0.001$. Given this finding, encouraging farmers to stick to keeping the optimum row spacing has led to reduction in technical inefficiency and improve BWP.

Evidences from extensive literature review indicates that crop productivity and efficiency are enhanced when credit and other financial services are tailored to the needs of smallholder farmers (Abate et al., 2014, Chandio et al., 2019, Martey et al., 2015b, Shikur, 2022). These empirical evidences further argue that farmer's decision to invest and produce crops and other agricultural commodities is substantially influenced by access to a mix of financial instruments. Given these evidences, amount of credit was expected to produce a highly significant impact on the TE of BWP. Nevertheless, the coefficient for the amount of credit has turned out contrary to a priori expectation of this study. The amount of credit did not show any marked effect on the TE of BWP. This is due to the fact that the majority of the farmers in the study area don't have access to formal financial institutions. This study has conducted FGDs with recycled and fresh seed users to understand the major challenges in BWP. Participants of the FGDs have frequently and unanimously explained that access to credit and financial services is very limited. These FGD participants further mentioned that it is only ACSI (Amhara Credit and Saving Institution) that provide credit service for the community. These participants have complained about the highest interest rate and the targeting criteria to access credit. It was mentioned that all farmers are not entitled to access credit. Land certificate, membership in the PSNP (Productive Safety Net Program), assets ownership, and repayment ability are considered as major targeting criteria. It was also explained that farmers get access to credit from their own RuSACCOs (Rural Saving and Credit Cooperative). The interest rate from the RuSACCOs is mentioned to be fair as compared to other sources. Nevertheless, RuSACCOs do not have the financial capacity to meet the financial requirements of all members. Thus, they give insufficient amount of credit to be repaid only within one year. Similarly, some credit arrangements reportedly discourage farmers from adoption of new agricultural technology, purchasing main farm inputs, or making other decisions that can increase their productivity and efficiency.

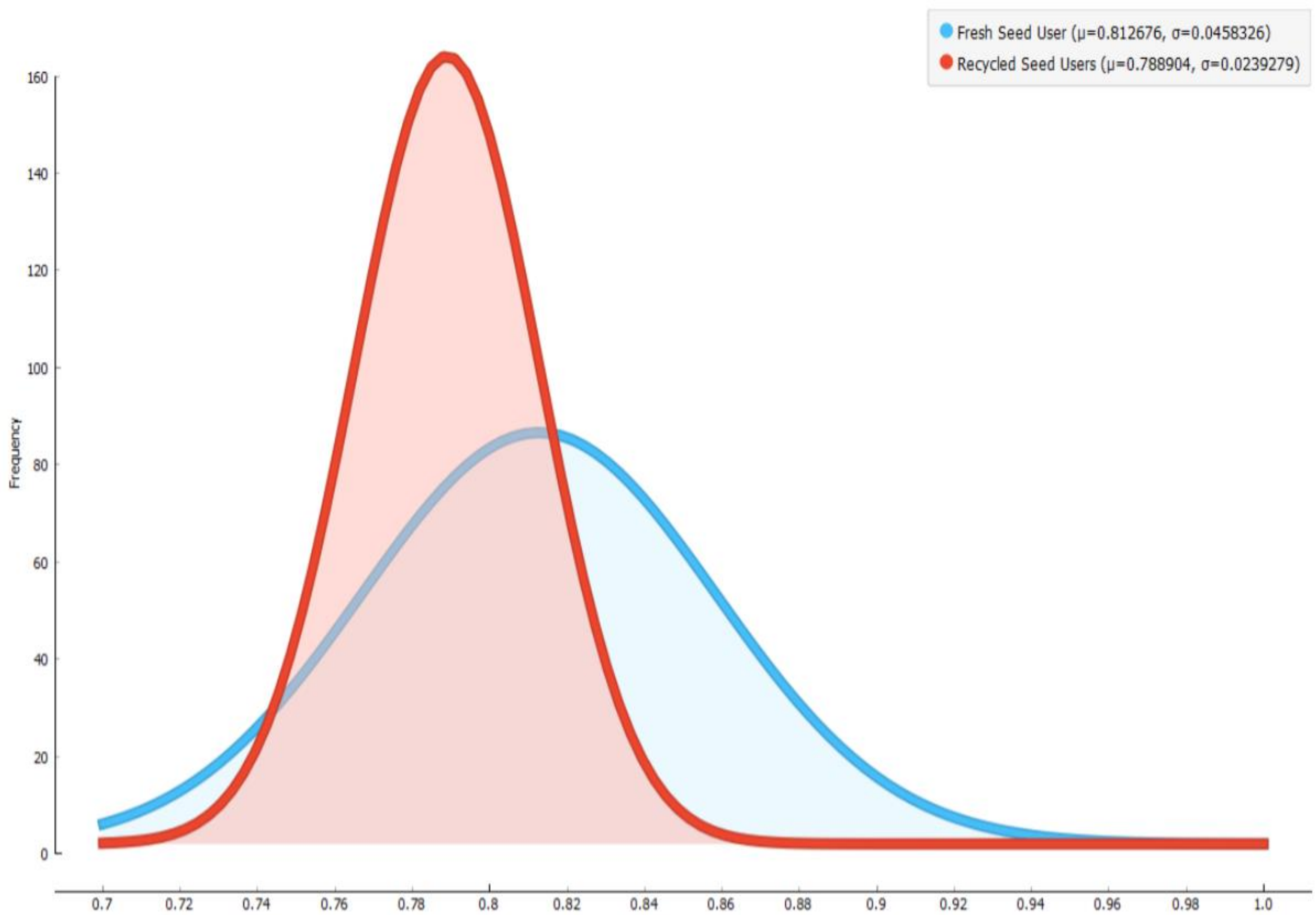

Figure 9: Distribution of TE Scores based on Seed Recycling Frequencies

4.5.2. Nexus between Productivity and Seed Recycling Frequency

This study had two important hypotheses about the relationship between seed recycling practice and bread wheat productivity. The first hypothesis was about the nexus between seed recycling and fresh seed use. In this regard, the following were the null (H_0) and alternative (H_a) hypotheses of the study:

1) H_0: diff = 0. This is a null hypothesis that asserts there is no difference in mean productivity between wheat producing farmers with fresh and recycled seed
2) H_{a1}: diff ! = 0. This is an alternative hypothesis which asserts that the difference in mean productivity between fresh and recycled bread wheat seed users is different from zero.

3) H_{a2}: diff < 0. This is a second alternative hypothesis that expects the mean productivity difference between recycled and fresh seed users is less than zero.
4) H_{a3}: diff > 0. This is the third alternative hypothesis that asserts the mean productivity difference between recycled and fresh bread wheat seed users is greater than zero.

Given the above expositions, this study has conducted a Student t-test with the intention of checking two issues. The first issue is related to scrutinizing whether there exist a difference in bread wheat productivity between fresh and recycled seed users while the second issue is checking if this difference is significant or not. The average bread wheat productivity for the study area was found to be 38.627 qt ha^{-1} (3.8627-ton ha^{-1}). This is higher than the national average (μ=2.1-ton ha^{-1}). Yet, it is by far lower than the maximum potential productivity (μ = 5.3 ton ha^{-1}) obtained at FTCs demonstration sites and model farmers (Abeyo et al., 2020). Despite the observed high difference in productivity between the national average (μ=2.1-ton ha^{-1}) and the current finding (μ=38.627 qt ha^{-1}), other studies have found similar bread wheat productivity values. For instance, (Solomon, 2014) reported an average wheat productivity of 37.63 qt which is quite closer to the current finding. Productivity comparisons was made between recycled (μ = 36.858 qt ha^{-1}) and fresh (μ = 40.778 qt ha^{-1}) seed users. This implies that bread wheat seed recycling on average has caused a 3.92 qt ha^{-1} productivity loss. Thus, the null hypothesis (H_0) that assumes no difference in terms of mean productivity between the two groups is rejected in favour of the second (H_{a1}) and the third (H_{a2}) alternative hypotheses at p<0.0000. The fourth alternative hypothesis (H_{a3}) that assumes a positive productivity difference between recycled and fresh bread wheat seed users is also rejected.

With the intention of capturing the real impact of seed recycling on bread wheat productivity, the study has employed an OLS Delta method. The results that indicate the marginal effect of different levels of seed recycling on bread wheat productivity is summarized and presented in Table 4.7 below. It is clear from this table that there is a 90.1% probability of production decline as a result of a unit increase in seed recycling at p=0.0000. The average wheat productivity obtained from bread wheat seeds recycled for less than five times was 39.275 qt ha^{-1}. However, the average wheat productivity obtained with further seed recycling beyond 5 to 8 times was 35.672 qt ha^{-1}. A glance look at Annex Graph 2 provides a vivid picture on the highly significant inverse nexus between seed recycling and bread wheat productivity. From a closer look at Table 14 below, it can be concluded that the productivity lose gets worse with increasing levels of seed recycling. Besides, as can be proved from the box plot presented in Annex Graph 3, while the mean bread wheat productivity is higher for fresh seed users than recycled seed users, the variance in mean productivity is greater for recycled seed users (36.86 ± 5.9) than fresh seed users (40.78±4.9). This means that there is huge difference in productivity among farmers with recycled seed users while there is a relatively uniform productivity among fresh seed users. This is a vivid illustration of the fact that variation in recycling leads to variation in productivity.

Table 14: Marginal Effect of Different levels of Seed Recycling Frequency on Productivity

Adjusted predictions
Model VCE: OLS
Expression: Linear prediction, predict ()
1._at: Seed recycling Frequency = 4
2._at: Seed recycling Frequency = 8
3._at: Seed recycling Frequency = 12
4._at: Seed recycling Frequency = 16
5._at: Seed recycling Frequency = 20

Productivity	Coef.	Std. Err	t-value	p-value
Seed recycling frequency	-.901	.052	-17.21	.0000
Constant	42.879	.326	131.72	.0000
Mean dependent var = 38.627	SD dependent var = 5.788			
R-squared =0.398	# of obs = 450			
F-test =296.228	Prob > F 0.000			
Akaike crit. (AIC)= 2631.893	Bayesian crit. (BIC) 2640.111			

	Margin	Delta-method std.err	t	P>t	[95% Conf Interval]	
_at						
1	39.275	0.215	182.450	0.000	38.852	39.698
2	35.672	0.273	130.780	0.000	35.136	36.208
3	32.068	0.436	73.540	0.000	31.211	32.925
4	28.464	0.627	45.370	0.000	27.231	29.697
5	24.860	0.827	30.040	0.000	23.234	26.486

Variables that uniquely identify margins: Seed recycling frequency *** *p<.01*, ** *p<.05*, * *p<.1*

This study has conducted two separate FGDs with fresh and recycled bread wheat seed users to learn about farmers' awareness about the impact of seed recycling along with their perception and motives behind seed recycling. The finding from this qualitative survey was congruent with the quantitative analysis presented above. Participants of the FGDs in both categories have frequently explained that there is no noticeable productivity and efficiency difference between recycled seed from 5 to 9 times. However, they have mentioned that recycling beyond 9 to 10 times often shows negative impact on productivity and TE. Yet, discussant have unanimously agreed that EGSs (Early Generation Seeds) makes significant productivity and efficiency difference in BWP. FGD participants have also complained that there is market absence for early generation and improved seeds. If access to the improved and EGSs is available, then it was either expensive or after the farmers have planted their wheat plots with recycled or local bread seeds. Other studies have found that supply deficiency, lack of access to recently released varieties, inability to identify fresh and recycled seed, lack of varieties superior to those already available, relative slowness with which information about newly released varieties reach to farmers were mentioned as major reasons for multiple seed recycling. Besides, the slow varietal turnover because of poorly developed seed industry and ineffective extension services reportedly hampered the rate at which fresh and new varieties are made available to the farmers (Alemu and Bishaw, 2015, Assefa et al., 2014, Bishaw et al., 2012, Moti et al., 2020). Farmers who have participated in the FGDs and Key informant DAs have also reported that farmers lack the skill and knowledge required to identify recycled and fresh seeds. These respondents mentioned that farmers usually misidentify fresh seeds but in fact are recycled or unimproved. A study by (Moti et al., 2020) has also reported farmers misidentification of different wheat varieties, and misidentification fresh and recycled seeds. These researchers further have mentioned that misidentification may result in production inefficiencies. For instance, farmers may apply fertilizer to what they think are improved varieties but are in fact unimproved; or alternatively, may fail to apply fertilizer and other agronomic practices to what they think are local varieties but are in fact improved.

Table 15: Difference in Productivity and TE between Recycled and Fresh Bread Wheat Seed Users

Variables	Groups	Mean	Std.Err	Std.Dev	95% Conf. Interval		t-test	p-value
Productivity	Recycled Seed (n=247)	36.858	.37420	5.881	36.121	37.595	-7.72	.0000
	Fresh Seed (n=203)	40.778	.34295	4.886	40.102	41.455		
	Combined (n=450)	38.627	.27286	5.788	38.090	39.163		
	Difference	-3.920	.5076		-4.918	-2.922		
TE Score	Recycled seed (n=247)	.7889	.0015	.02398	.7859	.7919	-6.66	.0000
	Fresh seed (n=203)	.8127	.0032	.04595	.8063	.8190		
	Combined (n=450)	.7996	.0018	.0375	.7962	.8031		
	Difference	-.0238	.0036		-.0308	-.0168		

Source: Own Computation (2022)

5. Conclusions and Implications for Policy

5.1. Conclusions

The elasticities from the MLE under the full frontier production function adds – up to 1.49. Thus, one can conclude that farmers in the study area are facing increasing returns to scale and there is a room to increase bread wheat production beyond its current level of production. In addition, the coefficients of the stochastic frontier production function for labour (0.086), capital (0.22), fertilizer (0.042), pesticide (0.014), and machinery (0.005) were positive and significant at $p<0.001$ implying that an optimum increase to these inputs would increase BWP. In other words, from these coefficients in the stochastic frontier production function it can be deduced that amount of labour employed (man – days), capital invested, fertilizer, pesticide, and machinery rent had significantly high contribution to the existing level of bread wheat production. However, the coefficient for land was negative and significant suggesting additional land allocation for BWP would likely reduce bread wheat productivity.

The mean TE was found to be 79.99%. The maximum likelihood estimates for the inefficiency parameter portrayed that farmers in the study area operates 20.1% less than their potential. It is therefore evident from this finding that there is an opportunity to increase the existing BWP without extra inputs allocation and through improving farmers TE or reducing their level of technical inefficiency. From the MLE, there is also strong evidence that few farmers in the study areas are capable of producing bread wheat either on the frontier and/or extremely closer to the frontier that implies their high TE. From the inefficiency analysis one can easily infer that longer years, higher number of animal ownership (TLU), credit amount, and membership in seed multiplication and marketing cooperatives have helped farmers to significantly reduce their technical inefficiency. Similarly, agronomic related parameters such as hand weeding frequency and row spacing had significantly enhanced farmers technical inefficiency. However, dependency ratio has significantly curtailed farmers level of technical efficiency. Also, from analysis of the nexus between seed recycling and TE, a typical recycled seed user was 2.34% less than fresh seed users in its TE. This testifies that seed recycling has significantly contributed to farmers' inefficiency. Generally, it can be concluded that seed recycling and TE have a significant inverse relationship. Bread wheat seed recycling up to five times is considered as improved practices. However, a substantial TE difference was observed even among farmers who had recycled seed less than five times. Thus, one can conclude that the recycled seeds do have higher chance of contamination with impure and genetically inferior seeds that contribute to lower productivity and technical efficiency.

5.2. Implications for Policy

From results of this particular study, the following policy recommendations are made:

- There are strong evidence that few farmers in the study areas are capable of producing bread wheat either on the frontier and/or extremely closer to the frontier that implies their high TE. Therefore, this study highly recommends a F2F extension system that allow farmers to learn from the most efficient farmers operating at the frontier or closer to it on how to increase their productivity and enhance their level of technical efficiency. In this regard, Farmers' Field School (FFS), farmers' field days, excursions, and other group extension methods are strongly suggested. This could also be a financially viable informal technology diffusion and training modality for the existing extension system. Implementation of these group extension methods will also have a complementary effect on the face – to – face (individual) extension methods.

- The number of person-days allocated and the amount of capital invested had significantly high positive contribution for wheat production. Therefore, improving labour use efficiency through training and increasing farmers' access to financial sources and services is strongly recommended.

- Respondents' annual income from various sources and credit have helped farmers to substantially reduce their production inefficiency. This study therefore calls for an urgent policy design and implementation geared towards improving farmers' financial access. Encouraging RuSACCOs' to develop and implement alternative credit and saving products and services is strongly suggested to increase farmers' access to capital.

- Dependency ratio has a considerably high contribution to farmers' technical inefficiency. It is therefore quintessential to introduce labor saving technologies that would ease the work burden of families of with the highest dependency ratio induced by availability of family members with disability, old age, sick, and unproductive children.

- Farmers continue bread wheat seed recycling that substantially curtail their productivity and efficiency. Both quantitative and qualitative findings have proven that this is largely due to expensiveness of early generation seeds (EGSs) and improved varieties, absence of supply, supply insufficiency, and the risk preference of households. It is therefore highly recommended to encourage the establishment of seed multiplication and marketing cooperatives that could solve these problems. Besides, seed aids, seed loans, seed vouchers, and financial credits geared towards smallholder farmers' seed security are strongly recommended as they can serve as an incentive for wider use of fresh and EGSs. Creating massive awareness creation campaign on scientific seed storage and treatment could also enhance farmers own saved seed quality.

- Key informants and discussants of the FGDs confirmed that social welfare programs, Village Economic, and Social Associations (VESAs) have helped some sections of the bottom poor farmers to have access to and control over production augmenting and efficiency enhancing inputs and technologies. Nevertheless, these social welfare programs and VESAs are few in number and benefit a minor portion of the society. Moreover, members of these VESAs support each other in times of agricultural labour requirement, crop production failure, livestock and human death. Yet, seed is not part of the VESAs support arrangement. Thus, it is highly recommended to scale – up and establish as many VESAs as possible and the multiple economic and social objectives in the existing VESAs should be relaxed to include village level seed saving and seed loans provisions.
- The findings in this study are based on a cross sectional data. However, farmers' seed recycling practices tend to be dissimilar on longitudinal basis. This calls for the need to undertake similar empirical investigations using panel data in the future.

CHAPTER FIVE: SYNTHESIS OF CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The study has aimed at exploring multiple issues that pertains to the CBA of seed recycling; the yield effects of plot level seed rate application; determinants of the adoption intensity of improved bread wheat seed and the associated agronomic practices; the impact of adoption intensity on farmers productivity; determinants of the TE of bread wheat production; effect of TE on bread wheat output; and the effect of seed recycling practices on farmers' TE. The study provides valuable insights about bread wheat production practices, productivity and farmers' TE in the study area. Firstly, it is evident that a notable proportion of farmers deviate from the recommended seed rates, with a significant number using seed rates above or below the recommended levels. Additionally, seed recycling has been found a common practice among farmers. From the findings, it was inferred that seed recycling practices has caused significant loss in wheat yields compared to using fresh, unrecycled seeds. Besides, increasing the seed rate up to 50 kg/ha beyond the recommended rate has enhanced wheat productivity, although exceeding the optimum rate had a diminishing effect.

In terms of adoption of recommended practices of the IBWP, only few farmers' were able to adopt the entire recommendation. Yet, it is observed that farmers who adopt multiple components of the recommended practices achieve higher bread wheat productivity compared to those who adopt fewer components. Non-adoption of improved practices results in reduced productivity compared to adopters. This highlights the importance of implementing the comprehensive set of recommended practices to maximize wheat productivity. The study further explores the factors influencing adoption decisions and adoption intensity. Older farmers with more years of farming experience, larger family sizes, and land sizes, as well as those with higher frequency of extension contact and membership in seed multiplication and marketing cooperatives, are more likely to adopt improved bread wheat practices. On the other hand, higher dependency ratios and seed rates discourage farmers from adopting improved practices. Gender, educational level, and credit amount do not show a significant impact on adoption decisions.

Moreover, the study examines the production function and technical efficiency of farmers in the study area. It is found that farmers operate at 79.99% of their potential, indicating room for improving technical efficiency. Increasing labor, capital, fertilizer, pesticide, and machinery inputs had positively contribute to bread wheat production. However, allocating additional land has a negative effect on productivity. Farmers in the study area face increasing returns to scale, suggesting the potential for further increasing bread wheat production. Factors such as years of experience, animal ownership, credit amount, and membership in cooperatives are found to reduce technical inefficiency, while the dependency ratio and seed recycling increase inefficiency. The study highlights the negative relationship between seed recycling and technical efficiency, as recycled seeds are more likely to be contaminated with impure and genetically inferior seeds, leading to lower productivity and efficiency. In conclusion, farmers in the study area can optimize wheat productivity by adhering to recommended seed rates, using fresh, unrecycled improved bread wheat seeds, and adopting multiple components of the recommended practices. It is important to consider factors such as years of experience, animal ownership, credit access, and cooperative membership to reduce inefficiency. Increasing labor, capital, fertilizer, pesticide, and machinery inputs can enhance bread wheat production, while additional land allocation should be carefully managed. By implementing these strategies, farmers have the potential to achieve higher yields, improve net income, and maximize their technical efficiency in wheat farming.

5.2. Recommendations

Based on the findings of the study, the authors' made the following recommendations that must be implemented by bread wheat producing farmers' and other stakeholders involved in the sector. To enhance wheat farming productivity and maximize net income, farmers in the study area should focus on implementing a comprehensive set of optimized practices. The authors do have a strong conviction that bread wheat production will be improved; farmers' TE and adoption of improved practices and technologies will be enhanced upon the implementation of the recommendations.

Recommendations to bread wheat-producing farmers: We strongly recommend that farmers in the study area should optimize the application of different wheat farming practices to enhance productivity and maximize their net income. Firstly, farmers should adhere to the recommended seed rates for wheat cultivation. Deviations from the recommended rates have been observed, with a significant proportion of farmers using seed rates above or below the recommended levels. To achieve optimal yields, it is crucial for farmers to follow the recommended seed rates closely. Additionally, farmers should prioritize using fresh, unrecycled improved bread wheat seeds. The study has shown that seed recycling leads to a loss in yields compared to using fresh seeds. By using fresh seeds, farmers can improve their productivity and ultimately increase their net income. Secondly, farmers should consider adopting multiple components of the recommended practices for wheat cultivation. The study has found that farmers who adopt a comprehensive set of recommended practices achieve higher bread wheat productivity compared to those who adopt fewer components. It is therefore important for farmers to implement the complete set of recommended practices to maximize their yields. This may include factors such as sowing method, row spacing, and other agronomic practices that have been positively affecting productivity. By adopting these practices, farmers can improve their overall efficiency and profitability.

Lastly, farmers should aim to optimize their input allocation, particularly labor, capital, fertilizer, pesticide, and machinery. The study has demonstrated that these inputs have a significant positive impact on bread wheat production. Farmers should ensure that these inputs are utilized at their optimum levels to maximize yields. However, it is important to note that additional land allocation has been found to have a negative effect on productivity. Therefore, farmers should carefully manage their land allocation and focus on optimizing other inputs to achieve higher productivity and boost their TE. Key informants and FGD participants have frequently disclosed that they do have three to four fragmented small plots of land. They have also mentioned that farmers often have to travel from two to eight hours between their residence and agricultural land carrying farm implements and inputs. Therefore, land consolidation through voluntary land exchange could ease this difficulty. In summary, the overall recommendation for farmers in the study area is to adhere to the recommended seed rates, use fresh, unrecycled improved bread wheat seeds, and adopt multiple components of the recommended practices. Additionally, farmers should optimize their input allocation, paying particular attention to labor, capital, fertilizer, pesticide, and machinery. By implementing these recommendations, farmers have the potential to significantly improve their wheat productivity, increase their net income, and achieve greater overall efficiency in their farming operations.

Recommendation to other stakeholders in the sector:

- Farmers’ in the study area face significant production challenges due to the lack of accessible and affordable early generation seeds (EGSs) and improved varieties, leading to seed recycling practices that hinder productivity and efficiency. To address this issue, ensuring the supply of fresh seeds by encouraging seed parastatals, establishing new seed production and marketing cooperatives, and promoting varietal diversification is highly recommended.

- Additionally, providing seed aids, loans, and vouchers to smallholder farmers can incentivize the use of fresh and EGSs, training on seeds management, promoting seed security, and encouraging the wider adoption of the complete bread wheat package are strongly recommended. Interventions geared towards encouraging the use of fresh and unrecycled Improved Bread Wheat Seeds (IBWS) through strategies such as selective and targeted agricultural credit schemes and price subsidies to reduce economically wasteful seed recycling practices is highly essential. This will improve farmers' TE, productivity, income, and food security.

- The agricultural extension advisory service should focus on promoting the adoption of the entire package to maximize productivity and TE gains.

- There are few number of farmers’ with the highest TE score suggesting the feasibility of group extension methods such as Farmers' Field School (FFS), field days, and excursions to facilitate knowledge sharing and learning among farmers. These methods can help improve bread wheat productivity and enhance technical efficiency by allowing farmers to learn from their peers. Implementing group extension methods alongside individual approaches may have a complementary effect and serve as a financially viable way to diffuse technology and provide training within the existing extension system.

5.3. Suggestions for Future Research

- The findings in this study are based on a cross sectional data. Yet, farmers’ seed recycling practices tend to be dissimilar on longitudinal basis. This calls for the need to undertake similar empirical investigations using panel data in the future. Besides, the specific year chosen for the study may introduce biases due to the influence of input supply and climatic conditions on the adoption of improved bread wheat practices and efficiency levels. Thus, future studies shall consider longitudinal data to capture the temporal dynamics and its implications for long-term agricultural strategies development.

- Conduct location-specific seed rate trials and validations to determine optimal seed rates beyond existing recommendations for maximizing grain yield, and further research should investigate the yield effects of seed rates and recycling practices for different wheat varieties in various socio-economic settings and weather conditions.
- The study revolves around a specific bread wheat variety commonly grown in the study area, at the expense of other varieties. Thus, future further studies are highly commendable on other bread wheat varieties that are being used in different parts of the country. This could assist to come-up with findings that can be generalized at macro level and to other varieties.
- The efficiency analysis was conducted using the Stochastic Frontier Analysis (SFA) method, which provides relative efficiency scores compared to the best farmers in the study area, potentially leading to a misleading comparison with farmers in other locations. Future studies shall adopt methods pluralism to make findings nationally and internationally comparable.

References

ABATE, G., BERNARD, T., DE BRAUW, A. & MINOT, N. 2018. The Impact of the Use of New Technologies on Farmers Wheat Yield in Ethiopia: Evidence from a Randomized Control Trial. *Agric. Econ. ,* 49**,** 409–421. [CrossRef].

ABATE, G. T., FRANCESCONI, G. N. & GETNET, K. 2014. Impact of agricultural cooperatives on smallholders' technical efficiency: empirical evidence from Ethiopia. . *Ann. Publ. Cooperative Econ. 85, 257–286*.

ABBOYE, A. D. & TETO, A. M. 2020. The response of Seed Rates and Row Spacing on Growth, Yield and Yield Components of Wheat (Triticum aestivum L.) *Crop. J. Nat. Sci. Res. 2020, 10. [CrossRef*.

ABDULAI, S., NKEGBE, P. K. & DONKOH, S. A. 2018. Assessing the technical efficiency of maize production in northern Ghana: The data envelopment analysis approach. *Cogent Food & Agriculture,* 4**,** 1512390.

ABEBE, A. & LIJALEM, K. 2011. The recent development in seed systems of Ethiopia. . *In:* D. ALEMU, S. K., AND A. KIRUB, (ed.) *Improving farmer's access to seed empowering farmers innovation.* Addis Ababa, Ethiopia: JICA.

ABEYO, B., BADEBO, A., GEBRE, D. & LISTMAN, M. 2020. Achievements in fast-track variety testing, seed multiplication and scaling of rust resistant varieties: Lessons from the wheat seed scaling project, Ethiopia. CDMX, Mexico, and Addis Ababa, Ethiopia: The International Maize and Wheat Improvement Center (CIMMYT) and the Ethiopian Institute of Agricultural Research (EIAR).

ABID, H. & ABDUL, S. 2014. *An analysis of technical efficiency of wheat farmers in Punjab. .* Arid Agriculture University Rawalpindi Pakistan.

ABID, H., ABDUL, S., MUHAMMAD, A. K., ABDUL, Q. M. & FAYYAZ, U. H. 2019. Technical Efficiency of Wheat Production in Rain-fed Areas: A Case Study of Punjab, Pakistan. *Pak. J. Agri. Sci., ,* 49(3)**,** 411 - 417.

ABRO, Z. A., B.L, D. & M, K. 2019. The joint impact of improved maize seeds on productivity and efficiency: implications for policy. *Global Food Discussion Paper 128.* Goettingen: University of Goettingen. .

ADNAN, N., NORDIN, S. M., BAHRUDDIN, M. A. & TAREQ, A. H. 2019. A state-of-the-art review on facilitating sustainable agriculture through green fertilizer technology adoption: Assessing farmers behavior. *Trends in Food Science & Technology,* 86**,** 439-452.

ADUNGA, D. & FEKADU, B. 2019. Adoption determinants of row planting for wheat production in Munesa District of Oromia Region, Ethiopia. *Journal of Agricultural Extension and Rural Development,* 11 (2)**,** 25-34.

AFDB 2016. Federal Democratic Republic of Ethiopia Country Strategy Paper-CSP, 2016-20. Working Paper Series N0. 303. Available online: https://www.afdb.org/en/documents/publications/working-paper-series (accessed on 13 March 2021).

AHMAD, M., WARAICH, E. A., SKALICKY, M., HUSSAIN, S., ZULFIQAR, U., ANJUM, M. Z., HABIB UR RAHMAN, M., BRESTIC, M., RATNASEKERA, D. & LAMILLA-TAMAYO, L. 2021. Adaptation strategies to improve the resistance of oilseed crops to heat stress under a changing climate: An overview. *Frontiers in plant science,* 12**,** 767150.

AIGNER, D., LOVELL, C. A. K. & SCHMIDT, P. 1977. Formulation and estimation of stochastic frontier production function models. . *J. Econom. 6, 21-37.*

AJZEN, I. 1991. The theory of planned behavior. *Organizational behavior and human decision processes,* 50**,** 179-211.

AKINYI, D. P., NG'ANG'A, S. K., NGIGI, M., MATHENGE, M. & GIRVETZ, E. 2022. Cost-benefit analysis of prioritized climate-smart agricultural practices among smallholder farmers: evidence from selected value chains across sub-Saharan Africa. *Heliyon,* 8**,** e09228.

AL-ABABNEH, M. M. 2020. Linking ontology, epistemology and research methodology. *Science & Philosophy,* 8**,** 75-91.

ALEMU, D. & BISHAW, Z. 2015. Commercial behaviours of smallholder farmers in wheat seed use and its implication for demand assessment in Ethiopia. *Development in Practice,* 25**,** 798-814.

ALEMU, L. & ABERA, D. 2013. Comparison of chemical fertilizer, fish offalÃ¢â,¬â„¢ s fertilizer and manure applied to tomato and onion. *African Journal of Agricultural Research,* 8**,** 274-278.

ALI, A. & JAN, A. U. 2017. Analysis of technical efficiency of sugarcane crop in Khyber Pakhtunkhwa: A stochastic frontier approach. *Sarhad Journal of Agriculture,* 33 (1)**,** 69-79.

ALI, O. & SOAR, J. 2018. Technology innovation adoption theories. *Technology Adoption and Social Issues: Concepts, Methodologies, Tools, and Applications.* IGI Global.

ALMAZ, G. & BEGASHAW, M. 2019. The role of gender on adoption of row planting of tef [Eragrostis Tef (Zucc.) Trotter] in Central Ethiopia. *Ethiopian journal of science and technology* 12 (1)**,** 19-43.

ALSTON, J. M. & PARDEY, P. G. 2017. Transforming traditional agriculture redux.

ALTAYE, S. & MOHAMMED, H. 2013. Linking seed producer cooperatives with seed value chain actors: Implications for enhancing the autonomy and entrepreneurship of seed producer cooperatives in southern region of Ethiopia. *International Journal of Cooperative Studies,* 2**,** 61-65.

ANBES, T. 2020. Sources of productivity growth in Ethiopian agriculture. *African Journal of Agricultural Research,* 15**,** 19-32.

ANTENEH, A. & ASRAT, D. 2020. Wheat Production and Marketing in Ethiopia: A Review Study. . *Cogent Food Agric.,* 6.

ARAVINDAKSHAN, S., ROSSI, F. J. & KRUPNIK, T. J. 2015. What does benchmarking of wheat farmers practicing conservation tillage in the eastern Indo-Gangetic Plains tell us about energy use efficiency? An application of slack-based data envelopment analysis. *Energy,* 90**,** 483-493.

ARSLAN, A., FLORESS, K., LAMANNA, C., LIPPER, L., ASFAW, S. & ROSENSTOCK, T. 2020. The adoption of improved agricultural technologies. *A meta-analysis for Africa. IFAD Research Series,* 63.

ASFAW, M., GETA, E. & MITIKU, F. 2019. Economic efficiency of smallholder farmers in wheat production: the case of abuna gindeberet district, western Ethiopia. *Review of Agricultural and Applied Economics (RAAE),* 22**,** 65-75.

ASHENAFI, G. & OLIYAD, S. 2020. Factors affecting adoption and its intensity of malt barley technology package in Malga woreda Southern Ethiopia *Journal of agricultural economics and rural development,* 6 (1)**,** 697 - 704.

ASSEFA, A. 2016. Technical Efficiency of Smallholder Wheat Production in Soro District of Hadiya Zone, Southern Ethiopia. A Thesis Submitted to the School of Agricultural Economics and Agribusiness, School of Postgraduate Program Directorate, Haramaya University.

ASSEFA, E. & HANS-RUDOLF, B. 2016. Farmers' perception of land degradation and traditional knowledge in Southern Ethiopia—resilience and stability. *Land Degradation & Development,* 27**,** 1552-1561.

ASSEFA, W., BERHANU, A. & DEMELASH, K. 2014. Participatory Evaluation and Selection of Bread Wheat (Triticum aestivum L.) Varieties: Implication for Sustainable Community Based Seed Production and Farmer Level Varietal Portfolio Managements at Southern Ethiopia. . *World Journal of Agricultural Research,* 2 no.6.

ATA 2015. Agricultural Transformation Agency. *A Training Manual on Cereal Production.* Addis Ababa, Ethiopia: Agricultural Transformation Agency.

ATILAW, A., ALEMU, D., BISHAW, Z., KIFLE, T. & KASKE, K. 2016. Early generation seed production and supply in Ethiopia: Status, challenges and opportunities. *Ethiopian Journal of Agricultural Sciences,* 27**,** 99-119.

ATINAFU, A., LEJEBO, M. & ALEMU, A. 2022. Adoption of improved wheat production technology in Gorche district, Ethiopia. *Agriculture & Food Security,* 11**,** 3.

AYE, G. C. & MUNGATANA, E. D. 2011. Technological innovation and efficiency in the Nigerian maize sector: Parametric stochastic and non-parametric distance function approaches. *Agrekon,* 50**,** 1-24.

AYELE, A. 2016. *Technical Efficiency of Smallholder Wheat Production in Soro District of Hadiya Zone, Southern Ethiopia.* Haramaya University.

BAGLAN, M., MWALUPASO, G. E., ZHOU, X. & GENG, X. 2020. Towards Cleaner Production: Certified Seed Adoption and Its Effect on Technical Efficiency. *Sustainability,* 12**,** 1344.

BARNES, A. P., SOTO, I., EORY, V., BECK, B., BALAFOUTIS, A., SÁNCHEZ, B., VANGEYTE, J., FOUNTAS, S., VAN DER WAL, T. & GÓMEZ-BARBERO, M. 2019. Exploring the adoption of precision agricultural technologies: A cross regional study of EU farmers. *Land use policy,* 80**,** 163-174.

BATTESE, G. E. & COELLI, T. J. 1995. A model for technical inefficiency effects in a stochastic frontier production function for panel data. *Empirical economics,* 20**,** 325-332.

BECKER, S. O. & ICHINO, A. 2002. Estimation of average treatment effects based on propensity scores. *The stata journal,* 2**,** 358-377.

BEDILU, D. Z., ADEM, K. G., HUSSIEN, H. K. & SISAY, A. 2021. Determinants of adopting improved bread wheat varieties in Arsi Highland, Oromia Region, Ethiopia: A Double-Hurdle Approach. *, Cogent Economics & Finance,* 9 (1).

BEKELE, S., MENALE, K., MOTI, J. & CHILOT, Y. 2014. Adoption of improved wheat varieties and impacts on household food security in Ethiopia. *Food Policy,* Volume 44,**,** Pages 272-284,.

BEKELE, S., SMALE, M., BRAUN, H.-J., DUVEILLER, E., REYNOLDS, M. & MURICHO, G. 2013. Crops that feed the world 10. Past successes and future challenges to the role played by wheat in global food security. *Food Security,* 5**,** 291-317.

BENTI, B. B. How effective is microfinance on poverty reduction? Empirical evidence on ACSI (Ethiopia). Proceedings of the 15th International RAIS Conference on Social Sciences and Humanities, 2019. Scientia Moralitas Research Institute, 303-310.

BENTIVOGLIO, D., BUCCI, G., BELLETTI, M. & FINCO, A. 2021. A theoretical framework on network's dynamics for precision agriculture technologies adoption. *Revista de Economia e Sociologia Rural,* 60.

BESHIR, H. 2014. Factors affecting the adoption and intensity of use of improved forages in North East Highlands of Ethiopia. *American Journal of Experimental Agriculture,* 4**,** 12.

BEZABEH, E., HAREGEWOIN, T., HAILEGIORGIS, D., DANIEL, F. & BELAY, B. 2014. Change And Growth Rate Analysis In Area, Yield And Production Of Wheat In Ethiopia. . *Int. J. Dev. Res. ,* 4(10)**,** 1994 - 1995.

BISHAW, Z. & ATILAW, A. 2016. Enhancing agricultural sector development in Ethiopia: The role of research and seed sector. *Ethiopian Journal of Agricultural Sciences,* 27**,** 101-130.

BISHAW, Z., STRUIK, P. C. & VAN GASTEL, A. J. G. 2011. Wheat and barley seed system in Syria: Farmer’s varietal perceptions, seed sources, and seed management. . *Int. J. Plant Prod.,* 5**,** 323 - 347.

BISHAW, Z., STRUIK, P. C. & VAN GASTEL, A. J. G. 2012. Farmers' seed sources and seed quality: 1. physical and physiological quality. *Journal of Crop Improvement,* 26**,** 655-692.

BIZUWORK, T. D. & YIBEKAL, A. 2020. Optimizing blended (NPSB) and N fertilizer rates for the productivity of Durum wheat (Triticum turgidum L.var. durum) in Central Highlands of Ethiopia. Cogent Food & Agriculture (2020), 6: 1766733. SOIL & CROP SCIENCES. https://doi.org/10.1080/23311932.2020.1766733.

BONNY, S. 2014. Taking stock of the genetically modified seed sector worldwide: market, stakeholders, and prices. *Food Security,* 6**,** 525-540.

BRYSON, A., DORSETT, R. & PURDON, S. 2002. The use of propensity score matching in the evaluation of active labour market policies.

BUREAU OF FINANCE AND ECONOMIC DEVELOPMENT 2013a. Amhara National Regional State, Bureau of Finance and Economic Development. Development Indicators of the Amhara Region. www.amharabofed.gov.et. .

BUREAU OF FINANCE AND ECONOMIC DEVELOPMENT 2013b. Development Indicators of the Amhara Region. . *In:* DEVELOPMENT., B. O. F. A. E. (ed.). Bahir Dar: Amhara National Regional State, .

CENTRAL STATISTICAL AGENCY, C. 2018. Agricultural Sample Survey. Report on Area and Production of Major Crops (Private Peasant Holdings, Meher Season), Volume I. Addis Ababa, Ethiopia.

CHANDIO, A. A. & JIANG, Y. 2018. Factors influencing the adoption of improved wheat varieties by rural households in Sindh, Pakistan. *AIMS Agriculture and Food,* 3**,** 216-228.

CHANDIO, A. A., JIANG, Y., GESSESSE, A. T. & DUNYA, R. 2019. The nexus of agricultural credit, farm size and technical efficiency in Sindh, Pakistan: A stochastic production frontier approach. *Journal of the Saudi Society of Agricultural Sciences,* 18**,** 348-354.

CHIONA, S., KALINDA, T. & TEMBO, G. 2014. Stochastic frontier analysis of the technical efficiency of smallholder maize farmers in Central Province, Zambia. *Journal of Agricultural Science,* 6**,** 108.

CIMMYT 2012. Wheat for food security in Africa. Africa's food security and the changing demand for wheat over the coming decades.

CLAYTON, G. W., BRANDT, S., JOHNSON, E. N., O'DONOVAN, J. T., HARKER, K. N., BLACKSHAW, R. E., SMITH, E. G., KUTCHER, H. R., VERA, C. & HARTMAN, M. 2009. Comparison of Certified and Farm-Saved Seed on Yield and Quality Characteristics of Canola. . *Agron. J.,* 101**,** 181-1588.

COELLI, T., P. RAO & BATTESE., G. 1998. An introduction to efficiency and productivity analysis. *Kluwer Academic Publishers, Norwell, Massachusetts.*

COELLI, T. J., PRASADA RAO, D. S., O'DONNELL, C. J. & BATTESE, G. E. 2005. Additional topics on data envelopment analysis. *An introduction to efficiency and productivity analysis***,** 183-208.

COLEMAN, M. & MARKS, H. 1998. Topics in dose-response modeling. *Journal of food protection,* 61**,** 1550-1559.

COLMAN, D. & YOUNG, T. 1989. Economics of agricultural production: Theoretical foundations. In Principles of Agricultural Economics: Markets and Prices in Less Developed Countries (Wye Studies in Agricultural and Rural Development, pp. 5-29). . *Cambridge: Cambridge University Press.***,** 5 - 29.

CRAGG, J. G. 1971. Some statistical models for limited dependent variables with application to the demand for durable goods. Econometrica: Journal of the Econometric Society. *Econometrica: Journal of the Econometric Society***,** 829-844.

CSA 2018a. Agricultural Sample Survey. Report on Area and Production of Major Crops (Private Peasant Holdings, Meher Season). *In:* SURVEY, A. S. (ed.). Addis Ababa, Ethiopia.

CSA 2018b. Agricultural Sample Survey. Report on Area and Production of Major Crops (Private Peasant Holdings, Meher Season). Addis Ababa, Ethiopia.

CSA 2021a. (Central Statistical Agency). THE FEDERAL DEMOCRATIC REPUBLIC OF ETHIOPIA CENTRAL STATISTICAL AGENCY AGRICULTURAL SAMPLE SURVEY 2020 / 2021 (2013 E.C.) (September – January 2020/2021) VOLUME VII REPORT ON CROP AND LIVESTOCK PRODUCT UTILIZATION (PRIVATE PEASANT HOLDINGS, MEHER SEASON).

CSA 2021b. THE FEDERAL DEMOCRATIC REPUBLIC OF ETHIOPIA CENTRAL STATISTICAL AGENCY AGRICULTURAL SAMPLE SURVEY 2020/21 (2013 E.C.) VOLUME I REPORT ON AREA AND PRODUCTION OF MAJOR CROPS (PRIVATE PEASANT HOLDINGS, MEHER SEASON).

DAWIT, T. 2012. Profitability of Contractual Bread Wheat Seed Production in Mecha District of Amhara Region, Ethiopia. DOI: https://doi.org/10.5513/jcea.v13i1.1077. *Journal of Central European Agriculture, 2012, 13(1), p.142-149,* 13**,** 142-149.

DEBEBE, S., HAJI, J., GOSHU, D. & EDRISS, A.-K. 2015. Technical, allocative, and economic efficiency among smallholder maize farmers in Southwestern Ethiopia: Parametric approach. *Journal of Development and Agricultural Economics,* 7**,** 282-291.

DEGLA, P. 2015. Technical Efficiency in Producing Cashew Nuts in Benin's Savanna Zone, West Africa. *Quarterly Journal of International Agriculture,* 54**,** 117 - 132.

DEMISSIE, B., KEDIR, A., KOMICHA, H. H. & ASEFA, S. 2015. Determinants of adopting improved bread wheat varieties in Southeastern Highland of Ethiopia: A Double-Hurdle Approach. *Ethiopian Economics and Ethiopian Strategy S (ESSP) of***,** 101.

DEREJE, D., DEGEFA, T. & ABRAHAM, S. 2021. Analyzing the contribution of crop diversification in improving household food security among wheat dominated rural households in Sinana District, Bale Zone, Ethiopia. *Agriculture & Food Security,* 10**,** 1-15.

DEREJE, D., T. DEGEFA, AND S. ABRAHAM 2021. Analyzing the contribution of crop diversification in improving household food security among wheat dominated rural households in Sinana District, Bale Zone, Ethiopia. *Agriculture & Food Security, 2021. 10(1): p. 1-15.,* 10**,** 1-15.

DESSALE, M. 2019. Analysis of technical efficiency of small holder wheat-growing farmers of Jamma district, Ethiopia. *Agriculture & Food Security,* 8**,** 1-8.

DESTA, B. T. & ALMAYEHU, Y. 2020. Optimizing blended (NPSB) and N fertilizer rates for the productivity of Durum wheat (Triticum turgidum L.var. durum) in Central Highlands of Ethiopia. *Cogent Food & Agriculture,* 6**,** 1766733.

DONG, H., WANG, H. & HAN, J. 2022. Understanding ecological agricultural technology adoption in China using an integrated technology acceptance model—theory of planned behavior model. *Frontiers in Environmental Science,* 10**,** 927668.

DOROSH, P. A. & MELLOR, J. W. 2013. Why agriculture remains a viable means of poverty reduction in Sub - Saharan Africa: The case of Ethiopia. *Development Policy Review,* 31**,** 419-441.

EDHS 2016. Demographic and Health Survey: Key Findings.

ETHIOSIS (ETHIOPIAN SOIL INFORMATION SYSTEM) 2014. Soil analysis report agriculture transformation agency [Unpublished]. Ministry of Agriculture and Agriculture Transformation Agemcy.

ETWIRE, E., ARIYAWARDANA, A. & MORTLOCK, M. Y. 2016. Seed delivery systems and farm characteristics influencing the improved seed uptake by smallholders in Northern Ghana. *Sustainable Agriculture Research,* 5.

EUNICE, E., ANOMA, A. & MIRANDA, Y. M. 2016. Seed Delivery Systems and Farm Characteristics Influencing the Improved Seed Uptake by Smallholders in Northern Ghana. Sustainable Agriculture Research; Vol. 5, No. 2; ISSN 1927-050X E-ISSN 1927-0518. Published by Canadian Center of Science and Education.

FARRELL, M. J. 1957. The measurement of productive efficiency. *Journal of the Royal Statistical Society Series A: Statistics in Society,* 120**,** 253-281.

FATIMA, H. & KHAN, M. A. 2015. Influence of Wheat Varieties on Technical Efficiency and Production of Wheat Crop in Pakistan (In Selected Area of Punjab). *Sarhad Journal of Agriculture,* 31.

FINGER, R. & EL BENNI, N. 2013. Farmers adoption of extensive wheat production and Determinants and implications. *Land Use Policy,* 30**,** 206-213.

FISHER, M., ABATE, T., LUNDUKA, R. W., ASNAKE, W., ALEMAYEHU, Y. & MADULU, R. B. 2015. Drought tolerant maize for farmer adaptation to drought in sub-Saharan Africa: Determinants of adoption in eastern and southern Africa. *Climatic Change,* 133**,** 283-299.

FURTAS, R. 2016. Overview of Certified Seed and Farmer Saved Seed. In "An Updated Version of External Release by the Economic and Competitiveness Branch of the Alberta Government; Economics and Competitiveness Branch, Economics Section, Alberta Government: Stettler, AB, Canada.".

GASHAW, T., TULU, T., ARGAW, M., WORQLUL, A. W., TOLESSA, T. & KINDU, M. 2018. Estimating the impacts of land use/land cover changes on Ecosystem Service Values: The case of the Andassa watershed in the Upper Blue Nile basin of Ethiopia. *Ecosystem Services,* 31**,** 219-228.

GAVIGLIO, A., FILIPPINI, R., MADAU, F. A., MARESCOTTI, M. E. & DEMARTINI, E. 2021. Technical efficiency and productivity of farms: a periurban case study analysis. *Agricultural and Food Economics,* 9**,** 11.

GEBRE, G. G., ISODA, H., AMEKAWA, Y. & NOMURA, H. Gender differences in the adoption of agricultural technology: The case of improved maize varieties in southern Ethiopia. Women's studies international forum, 2019. Elsevier, 102264.

GEBRIE, A. & MADA, M. 2018. TECHNICAL EFFICIENCY OF SMALLHOLDER WHEAT PRODUCERS IN SIMADA DISTRIC OF AMHARA REGION, ETHIOPIA.

GHIMIRE, R. & HUANG, W.-C. 2015. Household wealth and adoption of improved maize varieties in Nepal: a double-hurdle approach. *Food Security,* 7**,** 1321-1335.

GOODWIN, K. B., OFFENBACH, A. L., CABLE, T. T. & COOK, S. P. 1993. Discrete/Continuous contingent valuation of private hunting access in Kansas. . *Journal of Environmental Management. ,* 38 (1)**,** 1 - 12.

GRILLI, L. & RAMPICHINI, C. 2021. Propensity scores for the estimation of average treatment effects in observational studies. *Training sessions on causal inference, Bristol***,** 28-29.

GUJARATI, D. N. & DAWN, C. P. 2009. Basic Econometrics *McGraw-Hill International Edition, 5th ed., Boston,***,** 269 - 261.

GUTH, M. & KATARZYNA, S.-A. 2022. Economic resources versus the efficiency of different types of agricultural production in regions of the European union. *Economic Research-Ekonomska Istraživanja,* 33**,** 1036-1051.

GUTH, M. & SMĘDZIK-AMBROŻY, K. 2020. Economic resources versus the efficiency of different types of agricultural production in regions of the European Union. *Economic research-Ekonomska istraživanja,* 33**,** 1036-1051.

HAACK, S. 2011. *Pragmatism, old and new: Selected writings*, Prometheus Books.

HABTEWOLD, T. M. 2021. Impact of climate-smart agricultural technology on multidimensional poverty in rural Ethiopia. *Journal of Integrative Agriculture,* 20**,** 1021-1041.

HAM, M. 2020. 1. Theories of Innovation Adoption and Real-World Case Analyses. *Driving Educational Change: Innovations in Action***,** 15.

HARASTY, C. & OSTERMEIER, M. 2020. Population Ageing: Alternative measures of dependency and implications for the future of work. ILO Working Paper. ILO Working Paper.

HECKMAN, J. 1979. Sample Specification Bias as a Selection Error. . *Econometrica.,* 47 (1)**,** 153 - 161.

HOTHERSALL, S. J. 2016. Epistemology and social work: Integrating theory, research and practice through philosophical pragmatism. *Social Work and Social Sciences Review,* 18**,** 33-67.

HUFFMAN, W. E. 2020. Human capital and adoption of innovations: policy implications. *Applied Economic Perspectives and Policy,* 42**,** 92-99.

HUNDE, K. & ABERA, N. 2019. Technical efficiency of smallholder farmers wheat production: the case of Debra Libanos District, Oromia National Regional State, Ethiopia. *J. Agri. Res,* 4**,** 000232.

HUSSAIN, M. A., ELYAS, T. & NASSEEF, O. A. 2013. Research paradigms: A slippery slope for fresh researchers. *Life Science Journal,* 10**,** 2374-2381.

IDRISA, Y. L., SHEHU, H. & NGAMDU, M. B. 2012. Effects of Adoption of Improved Maize Seed on Household Food Security in Gwoza Local Government Area of Borno State, Nigeria. . *Global Journal of Science Frontier Research,* 12 (5).

JALETA, M., KASSIE, M., MARENYA, P., YIRGA, C. & ERENSTEIN, O. 2018. Impact of improved maize adoption on household food security of maize producing smallholder farmers in Ethiopia. *Food Security,* 10**,** 81-93.

JOHNSON, N. L., LILJA, N. & ASHBY, J. A. 2003. Measuring the impact of user participation in agricultural and natural resource management research. *Agricultural systems,* 78**,** 287-306.

JONDROW, J., C. A. K. LOVELL, S. MATEROV. & P. SCHMIDT. 1982. On the Estimation of Technical Inefficiency in the Stochastic Frontier Production Function Model', Journal of Econometrics, Vol. 19, pp. 233-238.

KALSA, K. K. 2019. Farmers' attitudes and practices towards variety and certified seed use, seed replacement and seed storage in wheat growing areas of Ethiopia. *African Journal of Science, Technology, Innovation and Development,* 11**,** 107-120.

KASSA, B. & ALEMU, D. 2016. Agricultural research and extension linkages: Challenges and intervention options. *Ethiopian Journal of Agricultural Sciences,* 27**,** 55-76.

KAUSHIK, V. & WALSH, C. A. 2019. Pragmatism as a research paradigm and its implications for social work research. *Social sciences,* 8**,** 255.

KEBEDE, D., KETEMA, M. & DECHASSA, N. 2017. Disparity in adoption of wheat production technology packages in eastern ethiopia. *Review of Agricultural and Applied Economics (RAAE),* 20**,** 22-29.

KIBAARA, B. W. & KAVOI, M. M. 2012. Application of stochastic frontier approach model to assess technical efficiency in Kenyaâ€™s maize production. *Journal of agriculture, science and technology,* 14**,** 3-20.

KIDANE, A. T. 2020. Technical Efficiency of Smallholder Agriculture in Developing Countries: The Case of Ethiopia.

KIDANE, G. 2015. Dryland agriculture production systems in Ethiopia. . *National Publishers.*

KOLAPO, A., DIDUNYEMI, A. J., ANIYI, O. J. & OBEMBE, O. E. 2022. Adoption of multiple sustainable land management practices and its effects on productivity of smallholder maize farmers in Nigeria. *Resources, Environment and Sustainability,* 10**,** 100084.

KRISHNA, V. V., SPIELMAN, D. J., VEETTIL, P. C. & GHIMIRE, S. 2014. An Empirical Examination of the Dynamics of Varietal Turnover in Indian Wheat. 2014. IFPRI Discussion Paper 01336. Available online: https://ssrn.com/abstract=2417342 (accessed on 30 January 2020).

KUMBHAKAR, S. C. & LOVELL, C. K. 2003. *Stochastic frontier analysis*, Cambridge university press.

LEATHERS, H. D. & SMALE, M. 1991. A Bayesian approach to explaining sequential adoption of components of a technological package. *American Journal of Agricultural Economics,* 73**,** 734-742.

LEMA, A. & DEGEBASSA, A. 2013. Comparison of chemical fertilizer, fish offal's fertilizer and manure applied to tomato and onion. *African Journal of Agricultural Research,* 8**,** 274-278.

LI, S., VLASSIS, N., KAWALE, J. & FU, Y. 2016. Matching via Dimensionality Reduction for Estimation of Treatment Effects in Digital Marketing Campaigns. *IJCAI***,** 3768-3774.

LOLLATO, R. P., RUIZ DIAZ, D. A., DEWOLF, E., KNAPP, M., PETERSON, D. E. & FRITZ, A. K. 2019. Agronomic practices for reducing wheat yield gaps: a quantitative appraisal of progressive producers. *Crop Science,* 59**,** 333-350.

LOUWAARS, N. P. L. & DE BOEF, W. S. 2012. Integrated seed sector development in Africa: A conceptual framework for creating coherence between practices, programs, and policies. . *J. Crop Improv,* 26.

MAHMOOD, Z. H., BASHAR;, A. S. & NASIR, S. A. 2018. Estimating Profit and Cost Functions and Economic and Technical Efficiencies of Wheat Production in Nejaf Province. *Iraqi Journal of Agricultural Sciences,* 49 (3).

MAMO, T., GETAHUN, W., CHEBIL, A., TESFAYE, A., DEBELE, T., ASSEFA, S. & SOLOMON, T. 2018. Technical efficiency and yield gap of smallholder wheat producers in Ethiopia: A Stochastic Frontier Analysis. *African Journal of Agricultural Research,* 13**,** 1407-1418.

MANDA, J., ALENE, A. D., GARDEBROEK, C., KASSIE, M. & TEMBO, G. 2016. Adoption and impacts of sustainable agricultural practices on maize yields and incomes: evidence from Rural Zambia. . *J. Agric. Econ.,,* 67 (1), **,** 130 - 153.

MANGO, N., MAKATE, C., HANYANI-MLAMBO, B., SIZIBA, S. & LUNDY, M. 2015. A stochastic frontier analysis of technical efficiency in smallholder maize production in Zimbabwe: The post-fast-track land reform outlook. *Cogent Economics & Finance,* 3**,** 1117189.

MANGO, N., MAKATE, C., TAMENE, L., MPONELA, P. & NDENGU, G. 2020. Impact of the adoption of conservation practices on cereal consumption in a maize-based farming system in the Chinyanja Triangle, Southern Africa. . *Sustain Future,* 2**,** [CrossRef].

MANJUNATHA, A. V., ASIF, R. A., SPEELMAN, S. & NUPPENAU, E. A. 2013. Impact of land fragmentation, farm size, land ownership and crop diversity on profit and efficiency of irrigated farms in India. *Land Use Policy,* 31**,** 397-405.

MANZANO, R. M. & PÉREZ, J. E. 2023. Theoretical framework and methods for the analysis of the adoption-diffusion of innovations in agriculture: a bibliometric review. *Boletín de la Asociación de Geógrafos Españoles***,** 4.

MARTEY, E., WIREDU, A. & ETWIRE, P. 2015a. Impact of credit on technical efficiency of maize producing households in northern Ghana. Selected Paper Prepared for Presentation at the Centre for the Study of African Economies (CSAE) Conference 2015. *University of Oxford.*

MARTEY, E., WIREDU, A. N. & ETWIRE, P. M. 2015b. Impact of credit on technical efficiency of maize producing households in Northern Ghana, Selected Paper presented at the Centre for the Study of African Economies (CSAE) Conference, pp. 22–24.

MBURU, S., ACKELLO-OGUTU, C. & MULWA, R. 2014. Analysis of economic efficiency and farm size: A case study of wheat farmers in Nakuru District, Kenya. *Economics research international,* 2014.

MEDOFF, M. H. 1993. An empirical analysis of adoption. *Economic inquiry,* 31**,** 59-70.

MEEUSEN, W. & J. VAN DEN BROECK. 1977. Efficiency Estimation from Cobb-Douglas Production Functions with Composed Error. *International Economic Review,* 18 (2)**,** 435-444.

MEHMOOD, Y., RONG, K., ARSHAD, M. & BASHIR, M. K. 2020. Do liquidity constraints influence the technical efficiency of wheat growers: evidence from Punjab, Pakistan. *The Journal of Animal and Plant Sciences,* 27**,** 667-679.

MEHRING, G. H. 2016. *Determining optimum seeding rates for diverse hard red spring wheat (Triticum aestivum L.) cultivars.* North Dakota State University.

MESAY, Y., TESAFYE, S., BEDADA, B., FEKADU, F., TOLESA, A. & DAWIT, A. 2013. Source of technical inefficiency of smallholder wheat farmers in selected waterlogged areas of Ethiopia: A translog production function approach. *African Journal of Agricultural Research,* 8**,** 3930-3940.

MIDEKSA, T., LETTA, T., BAYISA, T., ABINASA, M., TILAHUN, A., HUNDIE, B., ALEMU, W. & ABERA, M. 2017. Bread wheat varietal development and release in Southeastern Highlands of Ethiopia. *American Journal of Biological and Environmental Statistics,* 4**,** 15-19.

MIDEKSA, T., LETTA, T., BAYISA, T., ABINASA, M., TILAHUN, A., HUNDIE, B., ALEMU, W. & ABERA, M. 2018. Bread wheat varietal development and release in Southeastern Highlands of Ethiopia. *American Journal of Biological and Environmental Statistics,* 4**,** 15-19.

MIHRETIE, A. A., ABEBE, A. & MISGANAW, G. S. 2022. Adoption of tef (Eragrostis tef) production technology packages in Northwest Ethiopia. *Cogent Economics & Finance,* 10**,** 2013587.

MISAK, C. 2019. Ramsey, pragmatism, and the Vienna circle. *European Journal of Pragmatism and American Philosophy,* 11.

MOA (MINISTRY OF AGRICULTURE OF THE FEDERAL DEMOCRATIC REPUBLIC OF ETHIOPIA) 2015. Technological Package for Wheat Production: A Training Manual for Development Practitioners; MoA: Addis Ababa, Ethiopia.

MOHAMMAD, A. H., MOHAMMAD, A. A. & ABBAS, A. 2012. Impact of mechanization on technical efficiency: A case study of rice farmers in Iran. International Conference On Applied Economics (ICOAE) 2012. https://doi.org/10.1016/S2212-5671(12)00021-4. Available online at www.sciencedirect.com.

MORGAN, C. J. 2018. Reducing bias using propensity score matching. Springer.
MORGAN, D. L. 2014. Pragmatism as a paradigm for social research. *Qualitative inquiry,* 20**,** 1045-1053.
MOTI, J., KINDIE, T., ANDRZEJ, K., CHILOT, Y., ENDESHAW, H., HABEKIRISTOS, B., BEKELE, A., AYELE, B. & OLAF, E. 2020. Misidentification by farmers of the crop varieties they grow: Lessons from DNA fingerprinting of wheat in Ethiopia. . *PLoS ONE* 15(7): e0235484. .
MUBSHAR, H., SHAHID, F., KHAWAR, J., MUHAMMAD, I., ABDUL, S. & WASEEM, H. 2016. Wheat Sown with Narrow Spacing Results in Higher Yield and Water Use Efficiency under Deficit Supplemental Irrigation at the Vegetative and Reproductive Stage. *Agronomy (MDPI)*.
MUNGUIA, O. M. D. O. & LLEWELLYN, R. 2020. The Adopters versus the Technology: Which Matters More when Predicting or Explaining Adoption? . *Applied Economic Perspectives and Policy,* 42 (1)**,** 80-91.
NAZZIWA-NVIIRI, L., VAN CAMPENHOUT, B. & AMWONYA, D. 2017. *Stimulating agricultural technology adoption: Lessons from fertilizer use among Ugandan potato farmers*, Intl Food Policy Res Inst.
OGADA, M. J., MWABU, G. & MUCHAI, D. 2014. Farm technology adoption in Kenya: a simultaneous estimation of inorganic fertilizer and improved maize variety adoption decisions. *Agricultural and food economics,* 2**,** 1-18.
OKUSAA, C. 2017. Seed Replacement Rates and Its Impact on Annual Yield Growth of the Kisumu District. In A Thesis Submitted to Jomo Kenyatta University of Agriculture and Technology; Kenyatta University of Agriculture and Technology: Nairobi, Kenya.
OLUWATAYO, I. B. & OJO, A. O. 2016. Is Africa's dependence on agriculture the cause of poverty in the continent?: An empirical review. *The Journal of Developing Areas,* 50**,** 93-102.
OMER, G. M. 2015. Bread wheat production in small scale irrigation users agro-pastoral households in Ethiopia: Case of Afar and Oromia regional state. *International Journal of Agricultural Economics and Economics and Extension,* 3**,** 144-150.
PAUL, T. O., FELIX, O. I., ADEBAYO, A. A. & OLADIPUPO, O. A. 2016. DOES LAND TENURE SECURITY MATTER FOR ADOPTION OF SUSTAINABLE AGRICULTURAL TECHNOLOGY? EVIDENCE FROM AGROFORESTRY IN NIGERIA. *Journal of Sustainable Development in Africa, Clarion University of Pennsylvania, Clarion, Pennsylvania,* 17 (6).
RADA, N. E. & FUGLIE, K. O. 2019. New perspectives on farm size and productivity. *Food Policy,* 84**,** 147-152.
RAGASA, C., DANKYI, A., ACHEAMPONG, P., WIREDU, A. N., CHAPOTO, A., ASAMOAH, M. & TRIPP, R. 2013. Patterns of adoption of improved rice technologies in Ghana. *International Food Policy Research Institute Working Paper.*
RAHI, S. 2017. Research design and methods: A systematic review of research paradigms, sampling issues and instruments development. *International Journal of Economics & Management Sciences,* 6**,** 1-5.
RAHMAN, K. M., M. I. A, M. & M. K. J, B. 2012. A Stochastic Frontier Approach to Model Technical Efficiency of Rice Farmers in Bangladesh: An Empirical Analysis. . *The Agriculturists, 10(2), 9–19. ,* 10(20**,** 9-19.
REED, M. S., FERRÉ, M., MARTIN-ORTEGA, J., BLANCHE, R., LAWFORD-ROLFE, R., DALLIMER, M. & HOLDEN, J. 2021. Evaluating impact from research: A methodological framework. *Research Policy,* 50**,** 104147.
REHMAN, A. A. & ALHARTHI, K. 2016. An introduction to research paradigms. *International Journal of Educational Investigations,* 3**,** 51-59.
RICHER, E. & LINDSEY, L. E. 2016. On - Farm Investigation of Seeding Rate for Wide Row Wheat Production in North West Ohio. *Crop Forage Turff Manage*.
RITZ, C., BATY, F., STREIBIG, J. C. & GERHARD, D. 2015. Dose-response analysis using R. *PloS one,* 10**,** e0146021.

ROGERS, E. 2003. Diffusion of Innovations fifth Ed Free Press. New York. *Rezvani, Z., Jansson, J. & Bodin*.

ROSENBAUM, P. R. & RUBIN, D. B. 1983. The central role of the propensity score in observational studies for causal effects. *Biometrika,* 70**,** 41-55.

SAUNDERS, M., LEWIS, P. & THORNHILL, A. 2009. Research methods for business students. 5th ed. Harlow: Pearson Education Limited Cited in AL-ABABNEH, M. M. 2020. Linking ontology, epistemology and research methodology. Science & Philosophy, 8, 75-91.

SCHULTZ, T. W. 1966. Transforming traditional agriculture: Reply. *Journal of farm Economics,* 48**,** 1015-1018.

SCHULTZ. T.W 1964. Transforming Traditional Agriculture. (New Haven and London: Yale University Press, 1964. Pp. xvi + 212. 45s.).

SHAMSUDEEN;, A., KWAME;, N. P. & ARKOH;, D. S. 2018. Assessing the technical efficiency of maize production in northern Ghana: The data envelopment analysis approach. *Cogent Food & Agriculture,* 4**,** 1512390.

SHIKUR, Z. H. 2022. Wheat policy, wheat yield and production in Ethiopia. *Cogent Economics & Finance,* 10**,** 2079586.

SISAY, D. T., VERHEES, F. J. H. M. & VAN TRIJP, H. C. M. 2017. Seed producer cooperatives in the Ethiopian seed sector and their role in seed supply improvement: A review. *Journal of crop improvement,* 31**,** 323-355.

SIYUM, N., GIZIEW, A. & ABEBE, A. 2021. Factors influencing Adoption of improved bread wheat technologies: a double hurdle approach in Northern Ethiopia.

SOLOMON, B. W. 2014. *Technical efficiency of major crops in Ethiopia: Stochastic frontier model.*

SULTAN, S. & AHMED, S. 2014. Technical efficiency and farm size productivity: micro level evidence from Jmmu and Kashmir. Int J Food Agric Econ. 2014;2(4):27–49.

TAREMWA, N. K., MACHARIA, I., BETT, E. & MAJIWA, E. 2022. Determinants of access to agricultural credit among smallholder rice and maize farmers in the eastern and western provinces of Rwanda. *Agro-Science,* 21**,** 1-11.

TARIKU, B. 2012. *Study on the intensity and adoption of improved wheat varieties and associated agronomic practices in Kaffa zone, the case of Gesha woreda.* St. Mary's University.

TASHAKKORI, A. & TEDDLIE, C. 2021. *Sage handbook of mixed methods in social & behavioral research*, SAGE publications.

TAVVA, S., AW-HASSAN, A., RIZVI, J. & SAHARAWAT, Y. S. 2017. Technical efficiency of wheat farmers and options for minimizing yield gaps in Afghanistan. *Outlook on Agriculture,* 46**,** 13-19.

TEFERI, E. T., KASSIE, G. T., PE, M. E. & FADDA, C. 2020. Are farmers willing to pay for climate related traits of wheat? Evidence from rural parts of Ethiopia. *Agricultural Systems,* 185**,** 102947.

TEKLEWOLD, H., KASSIE, M., SHIFERAW, B. & KÖHLIN, G. 2013. Cropping system diversification, conservation tillage and modern seed adoption in Ethiopia: Impacts on household income, agrochemical use and demand for labor. . *Ecological Economics, ,* 93**,** 85 - 93,.

TENAYE, A. 2020. Technical Efficiency of Smallholder Agriculture in Developing Countries: The Case of Ethiopia. *Economies,* 8**,** 34.

TESFAYE, S., BEDADA, B. & MESAY, Y. 2016. Impact of improved wheat technology adoption on productivity and income in Ethiopia. . *Afr. Crop Sci. J. ,* 24**,** 127.

TESFAYE, W., ABDISSA, T. & YADESSA, G. B. 2015. Economic analysis of teff yield response to different sowing methods: Experience, Illuababora Zone, Ethiopia. *Journal of Economics and Sustainable Development, 6 (1)*.

TESHOME, A. & ABATE, E. 2013. Wheat technologies from where to where? The case of east Gojam zone of Amhara region, Ethiopia. *Journal of Agricultural Economics and Development,* 2**,** 226-236.

TIGABU, R. & ASFAW, F. 2016. Effects of Seed Rate and Row Spacing on Yield and Yield Components of Bread Wheat (Triticum aestivum L.) in Dalbo Awtaru Woreda, Wolaita Zone, Southern Ethiopia. *J. Biol. Agric. Healthc.,* 6**,** 58 - 67.

TIMU, A., MULWA, R., OKELLO, J. & KAMAU, M. 2014. The role of varietal attributes on adoption of improved seed varieties: the case of sorghum in Kenya. *J. Agri. and Food Sec,* 3 (9).

TIRUNEH, S., YIGESU, A. Y. & BISHAW, Z. 2015. Measuring the effectiveness of extension innovations for out-scaling agricultural technologies. *African Journal of Agricultural Science and Technology (AJAST),* 3**,** 316-326.

TOBIN, J. 1958. Estimation of relationships for limited dependent variables. *Econometrica: journal of the Econometric Society***,** 24-36.

TSEGAYE, D. 2012. Profitability of Contractual Bread Wheat Seed Production in Mecha District of Amhara Region, Ethiopia. . *J. Central Eur. Agric. ,* 13**,** 142 - 149.

TSEGAYE, M. H. 2020. *Impacts of Improved Agricultural Technologies Adoption on Multidimensional Welfare Indicators in Rural Ethiopia.* PhD A Dissertation Submitted in partial fulfillment of the requirements for the degree of Philosophy of Doctor of Philosophy in Economics from Addis Ababa University, Addis Ababa University.

UGWU, C., EKERE, J. & ONOH, C. 2021. Research paradigms and methodological choices in the research process. *Journal of Applied Information Science and Technology,* 14**,** 116-124.

USDA 2021. United States Department of Agriculture, Grain and Feed Annual Report. Report Number: ET2021-0008. .

VAN DER, V. & C., R. L. 2013. Statistics for Analyzing Ecotoxicity Test Data. *In Encyclopedia of Aquatic Ecotoxicology; Férard, J., Blaise, C., Eds.; Springer: New York, NY, USA***,** 1081-1096.

VANDERCASTEELEN, J., DEREJE, M., MINTEN, B. & TAFFESSE, A. S. 2013. Scaling-up adoption of improved technologies: The impact of the promotion of row planting on farmers' teff yields in Ethiopia. *LICOS-Discussion paper series 344/2013***,** 1-25.

VISHAL, D., MUHAMMAD, K. K., RAFAEL, A., MUHAMMAD, U., ABDULRASHEED, Z., ABDUL, R., MUNTASIR, M. & BRAYAN, T. 2121. Variations in technical efficiency of farmers with distinct land size across agro-climatic zones: Evidence from India. *Journal of Clean Production,* 315.

WANG, J., CHEN, K. Z., DAS GUPTA, S. & HUANG, Z. 2015. Is small still beautiful? A comparative study of rice farm size and productivity in China and India. *China Agricultural Economic Review,* 7**,** 484-509.

WANKE, P., CHEN, Z., ZHENG, X. & ANTUNES, J. 2020. Sustainability efficiency and carbon inequality of the Chinese transportation system: A Robust Bayesian Stochastic Frontier Analysis. *Journal of environmental management,* 260**,** 110163.

WILLS, J. & LAKE, R. W. 2020. Introduction: The power of pragmatism. *The power of pragmatism.* Manchester University Press.

WISDOM, J. P., CHOR, K. H. B., HOAGWOOD, K. E. & HORWITZ, S. M. 2014. Innovation adoption: a review of theories and constructs. *Administration and Policy in Mental Health and Mental Health Services Research,* 41**,** 480-502.

WONDIMU, T., TESHOME, A. & GEZAHEGN, B. Y. 2015. Economic Analysis of Tef Yield Response to different Sowing Methods: Experience from Illuababora Zone, Ethiopia. . *Journal of Economics and Sustainable Development, ,* 6 (1).

WUDINEH, G. T. & ENDRIAS, G. 2016. Technical efficiency of smallholder wheat farmers: The case of Welmera district, Central Oromia, Ethiopia. . *Journal of Development and Agricultural Economics.*

WUDINEH, G. T. & GETA, E. 2016. Technical efficiency of smallholder wheat farmers: The case of Welmera district, Central Oromia, Ethiopia. Journal of Development and Agricultural Economics. *http://www.academicjournals.org/JDAE.* .

WWW.GLOBALDATALAB.ORG Institute for Management Research: Radbound University.

YAMANE, T. 1967. Statistics: An Introductory Analysis, 2nd Edition, New York: Harper and Row.

YIRGA, C., MOHAMMAD, A., KASSIE, M., GROOTE, H. D., MEBRATU, T., JALETA, M. & SHIFERAW, B. 2013a. Analysisof Adoption and Diffusion of Improved Wheat Technologies in Ethiopia. Ethiopian Institute of Agricultural Research (EIAR) and CIMMYT.

YIRGA, C., MOHAMMAD, A., KASSIE, M., GROOTE, H. D., MEBRATU, T., JALETA, M. & SHIFERAW, B. 2013b. Analysisof Adoption and Diffusion of Improved Wheat Technologies in Ethiopia. Ethiopian Institute of Agricultural Research (EIAR) and CIMMYT.

ZECEVIC, V., BOSKOVIC, J., KNEZEVIC, D. & MICANOVIC, D. 2014. Effect of seeding rate on grain quality of winter wheat. *Chil. J. Agric.,* 74**,** 23-28.

ZEWDIE, B., PAUL, C. S. & ANTHONY, J. G. V. G. 2014. Assessment of on-farm diversity of wheat varieties and landraces: Evidence from farmers fields in Ethiopia. *African Journal of Agricultural Research,* 9**,** 2948-2963.

ZOUNDJI, G. C., VODOUHE, F., HOUNGBÈMÈ, J.-F. D. & YABI, J. A. 2023. Adoption and Technical Efficiency of Organic and Fair-Trade Cashew Production in Benin (West Africa).

List of Appendices

Appendix 1: Plagiarism Assessment Report

Addis Ababa University

College of Development Studies

Office of the Associate Dean for Research and Technology Transfer

Template for Reporting Plagiarism Assessment

Name of the Center: Center for Rural Development Program of study: Regular Program level (Masters/PhD): PhD Please, check one: Regular/Continuing

Name of the Adviser/s: Dr. Bamlaku Alamirew and Dr. Zewdie Bishaw

Topic of the Dissertation/Thesis: Effects of the Adoption Intensity of Improved Bread Wheat Package and Seed Recycling Practices on Smallholder Farmers Productivity and Technical Efficiency: The Case of East Gojam Zone, Ethiopia

S/N	Name and ID.NO. of the student/candidate	Percentage of plagiarism confirmed	Comments given and improvements made by the student/candidate
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the effects of the adoption intensity of IBWP and seed recycling practices on smallholder farmers' bread wheat productivity and TE in East Gojam, Ethiopia.

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Appendix A: Tables

Appendix Table A 1. Effect of seed dose on wheat productivity.

Source	SS	df	MS			
Model	4321.22144	1	4321.22144			
Residual	10,722.0586	448	23.9331664			
Total		449	33.5039644			
Productivity	**Coef.**	**Std. Err**	**t**	$p > \|t\|$	**[95% Conf.**	**Interval]**
Seed_dose	0.0536544	0.003993	13.44	0.000	0.045807	0.0615018
_Cons	31.95563	0.5474157	58.38	0.000	30.87981	33.03145

Number of obs = 450. Root MSE = 4.8922. F (1, 448) = 180.55. R-squared = 0.2873. Prob > F = 0.0000. Adjusted R-squared =0.2857.

Appendix Table A 2. Cost–benefit analysis of recycled and non-recycled seeds

Seed Recycling Status	Mean Seed Rate (Kg ha^{-1}) (A)	Seed Cost (ETB Qt^{-1}) (B)	Total Seed Cost (ETB Qt^{-1}) (C)	Yield (Qt ha^{-1}) (D)	Unit Selling Price (ETB Qt^{-1}) (E)	Mean Income (ETB Ha^{-1}) (F	Net Income (ETB Qt^{-1}) (G)
Fresh (unrecycled)	169.2835	2300	3893.52	40.4421	1950	78,862.095	74,968.575
Recycled < 5 times	263.6364	1800	4745.46	33.7909	1800	60,823.62	56,078.16
Recycled ≥ 5 times	245.8333	1800	4424.999	33.3333	1800	59,999.94	55,574.991

Source: Own Computation (2022)

Appendix Table A 3. Frequency distribution of respondents by seed source

Seed Sources	Frequency	Percent	Cumulative
Farmers saved seed (informal sources)	42	9.33	9.33
Amhara Seed Enterprise	328	72.89	82.22
Research and academic institutions	11	2.44	84.67
Cooperatives	69	15.33	100.00
Total	450	100	

Source: own calculations (2022).

Appendix Table A 4. Status and reasons for seed recycling

Status and Reasons for Seed Recycling	Frequency	Percent	Cumulative
I do not recycle seed	328	72.89	72.89
Cost reduction	61	13.56	86.44
Expensive fresh seed	27	6.00	92.44
Timely availability and supply shortage	19	4.22	96.67
No yield difference	15	3.33	100
Total	450	100	

Source: own calculations (2022).

Appendix Table A 5. Results of Multicolinearity Test

Variables	VIF	1/VIF
Seed Recycling Frequency	5.161	.194
Household Head Age Square	5.089	.196
Family Size	4.798	.208
Land Size	4.781	.209
Row Spacing	4.199	.238
Tilling Frequency	3.161	.316
Hand Weeding Frequency	2.925	.342
Sowing Method	2.86	.35
Seed Rate	1.643	.609
Fertilizer Rate	1.634	.612
Frequency of Extension Contact	1.566	.638
Membership in Seed Multiplication and Marketing Cooperatives	1.477	.677
Gender of the Household Head	1.089	.918
Grade Level of the Household Head	1.078	.928
Credit Amount	1.057	.946
Tropical Livestock Unit	1.056	.947
Mean VIF	2.723	.

Variables	VIF	1/VIF
Dependency ratio	6.50	0.153883
Land covered by IBWSs	5.77	0.173236
Family size	5.37	0.186080
Tropical Livestock Unit	4.64	0.215538
Row spacing	4.56	0.219074
Tilling frequency	4.02	0.248609
Certified seed use experience	3.30	0.302754
Urea rate	3.05	0.327377
Pesticide rate	2.71	0.368436
Seed recycling frequency	2.50	0.400732
Frequency of extension contact/month	1.68	0.595698
Seed Rate	1.64	0.609766
NPS Rate	1.63	0.615190
Grade level	1.10	0.907768
Credit	1.05	0.950411
Mean VIF	3.26	

Appendix Table A 6. Distribution of respondents by Categorical variables

Variables	Adopter	Non-adopter	χ^2	p-value
Gender (Men)	289	119	.781	.377
Female	27	15		
Total	316	134		
Sowing Methods				
• Broadcasting	23	116	277.11	.000
• Row Planting	293	18		
Total	316	134		
Cooperative Membership				
• Member	117	0	67.046	.000
• Non-member	199	134		
Total	316	134		

Appendix Table A 7. Study assumptions and hypothesis tests for model Specifications

Hypothesis	LR Test	x^2 Critical Value (0.05)	Degrees of freedom	Decision
I. H_0 = The translog SFPF can be reduced to a CD SFPF				
$H_0 = \beta_{ij} = 0$	36.75	14.067	7	Reject H_0
II. H_0 = Technical inefficiency effects are not in the model (H_0: γ=0)				
H_0: $\gamma = \delta 0 = \delta 1 = \ldots \delta 13 = 0$)	51.14	3.84	1	Reject H_0
H_0 = The distribution of inefficiency can be reduced to half normal from truncated normal				
$H_0 = \mu = 0$	1007.52	23.65	13	Reject H_0

Source: Own Computation (2022)

Appendix Table A 8. Descriptive Statistics for continuous variables.

Variable	Mean	Std. Dev.	Min	Max
Technical Efficiency	.7996	.037	.717	1
Respondent Age	42.182	10.421	20	77
IBWS use experience	10.911	8.262	0	51
Respondent grade	1.771	2.792	0	10
Family size	5.991	3.054	1	15
Dependency ratio	.539	.255	.037	.999
Tropical Livestock Unit	6.872	5.026	0	21.5
Land size	.71	.728	0	3.375
Productivity	38.627	5.788	24	53
Total annual income	51357.591	29948.039	380	201000
Seed recycling frequency	4.72	4.053	0	19
Hand weeding frequency	1.627	.696	0	2
Row spacing	16.878	9.437	5	30
Frequency of extension contact	1.54	1.132	0	6

Credit amount	4003.784	5037.582	0	20000
Seed rate	194.389	97.093	50	450
Fertilizer rate	131.597	88.149	20	600
Pesticide rate	.557	.501	0	2
Machine rent	478.622	1186.956	0	4800
Labour (Man-day)	85.556	27.821	26	133

Source: Own Computation (2022)

Appendix Table A 9. Agronomic practices difference between adopters and non-adopters

	Adopters		Non – Adopter		Difference		t – values	Sig
Variables	Mean	Std. Err	Mean	Std. Err.	Mean	Std. Err		
Tilling frequency	2.77	.075	1.35	.064	-1.42	.098	-14.45	.0000
Row spacing	20.46	.484	8.43	.484	-12.03	.638	-18.86	.0000
Seed rate (kg)	171.36	4.15	248.69	10.46	77.32	11.26	6.87	.0000
NPS Rate (Kg)	157.54	4.85	70.42	4.93	-87.12	6.91	-12.60	.0000
Urea Rate (kg)	135.59	4.20	50.71	3.14	-84.88	5.32	-15.94	.0000
Weeding frequency	1.74	.0334	1.36	.072	-.372	.0796	-4.668	.0000
Pesticide rate	.708	.024	.199	.02677	-.5092	.0383	-13.289	.0000
Sowing Method					Total		Chi2(1)	Sig.
Broadcasting	25		83		108		150.59	.000
Row Planting	291		51		342			

Source: Own Survey (2022)

Appendix Table A 10. TE score of respondents based on seed recycling practice

TE Score	Proportion of Respondents based on Seed Recycling Practice		
	Recycled Seed Users	Fresh Seed User	Total
.70	12	1	13
.75	154	90	244
.80	80	82	162
.85	1	21	22
.90	0	4	4
.95	0	4	4
1	0	1	1
Total	247	203	450

Source: Own Computation (2022)

Appendix Table A 11: Mean and standardized difference of confounders in the treated (Adopters) and untreated (Non - adopters)

Variables	Mean in Treated	Mean in Untreated	Standardized difference
Gender	0.90	0.93	-0.087
Age	43.71	27.33	2.222
Farm experience	10.94	3.24	1.707
Grade level	1.75	2.00	-0.092
Family size	5.98	2.45	1.830
Dependency ratio	0.51	0.84	-1.524
Tropical Livestock Unit	7.32	0.25	2.253
Land Size	0.78	0.00	1.523
Seed recycling frequency	3.50	11.90	-2.647
Tilling frequency	3.73	1.31	2.562
Weeding frequency	1.75	0.45	1.966
Sowing method	1.84	1.00	3.215
Spacing between rows	18.08	5.24	1.970
Fertilizer rate	141.66	33.88	1.743
Frequency of extension contact	1.62	0.74	0.973
Credit (Birr)	4149.03	2592.86	0.337
Cooperative membership	0.42	0.05	0.981
Seed rate	180.82	326.19	-1.514
Pesticide amount	0.60	0.09	1.374
Amount of labour (Man-days)	90.72	35.40	3.167

Warning: Significant imbalance exists in all variables except gender

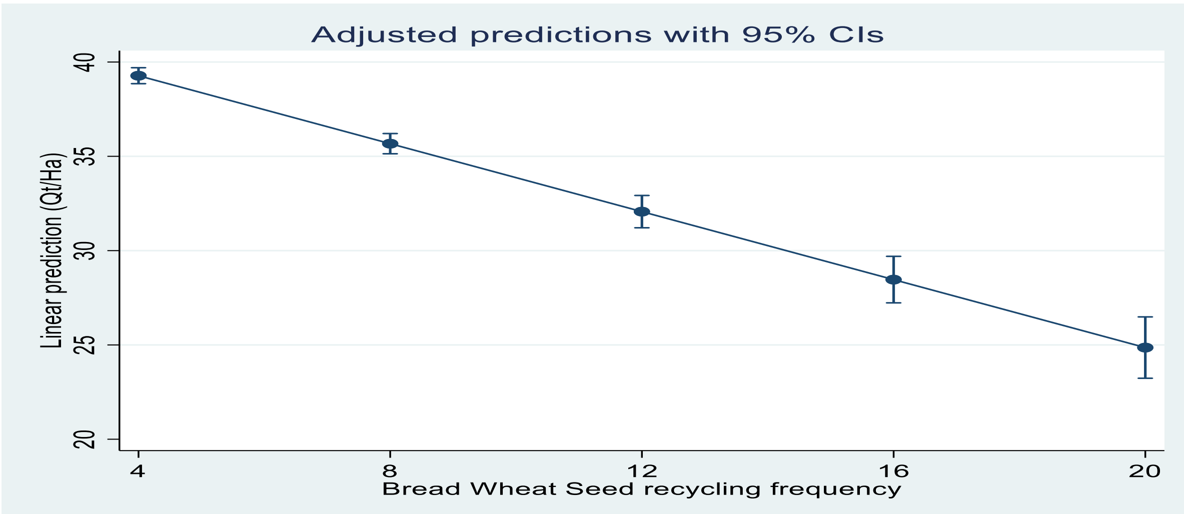
Appendix Table A 12: Comparison of the Research Philosophies by their Ontology, Epistemology, axiology, and data collection methods

Research Philosophies	Ontology	Epistemology	Axiology	Data collection methods
Positivism	External, objective, and independent of social actors	Only observable phenomena can provide credible data, facts. Focus on causality and law like generalizations, reducing phenomena to simplest elements.	Research is undertaken in a value-free way, the researcher is independent of the data and maintains an objective stance.	Highly structured, large samples, measurement, quantitative, but can use qualitative.
Interpretivism	Socially constructed, subjective, may change, multiple.	Subjective meanings and social phenomena. Focus upon the details of situation, a reality details, and subjective meanings motivating actions.	Research is value bound, the researcher is part of what is being researched, cannot be separated and so will be subjective.	Small samples, in-depth investigations, qualitative.
Realism	Is objective. Exists independently of human thoughts and beliefs or knowledge of their existence (realist), but is interpreted through social conditioning (critical relist)	Observable phenomena provide credible data, facts. Insufficient data means inaccuracies in sensations (direct realism). Alternatively, phenomena create sensations which are open to misinterpretation (critical realism). Focus on explaining within a context or contexts.	Research is value laden; the researcher is biased by world views, cultural experiences and upbringing. These will impact on the research.	Methods chosen must fit the subject matter, quantitative or qualitative.
Pragmatism	External, multiple, view chosen to best enable answering of research question.	Either or both observable phenomena and subjective meanings can provide acceptable knowledge dependent upon the research question. Focus on practical applied research, integrating different perspectives to help interpret the data	Values play a large role in interpreting results, the researcher adopting both objective and subjective points of view.	Mixed or multiple method designs, quantitative and qualitative

Source: (Saunders et al., 2009)

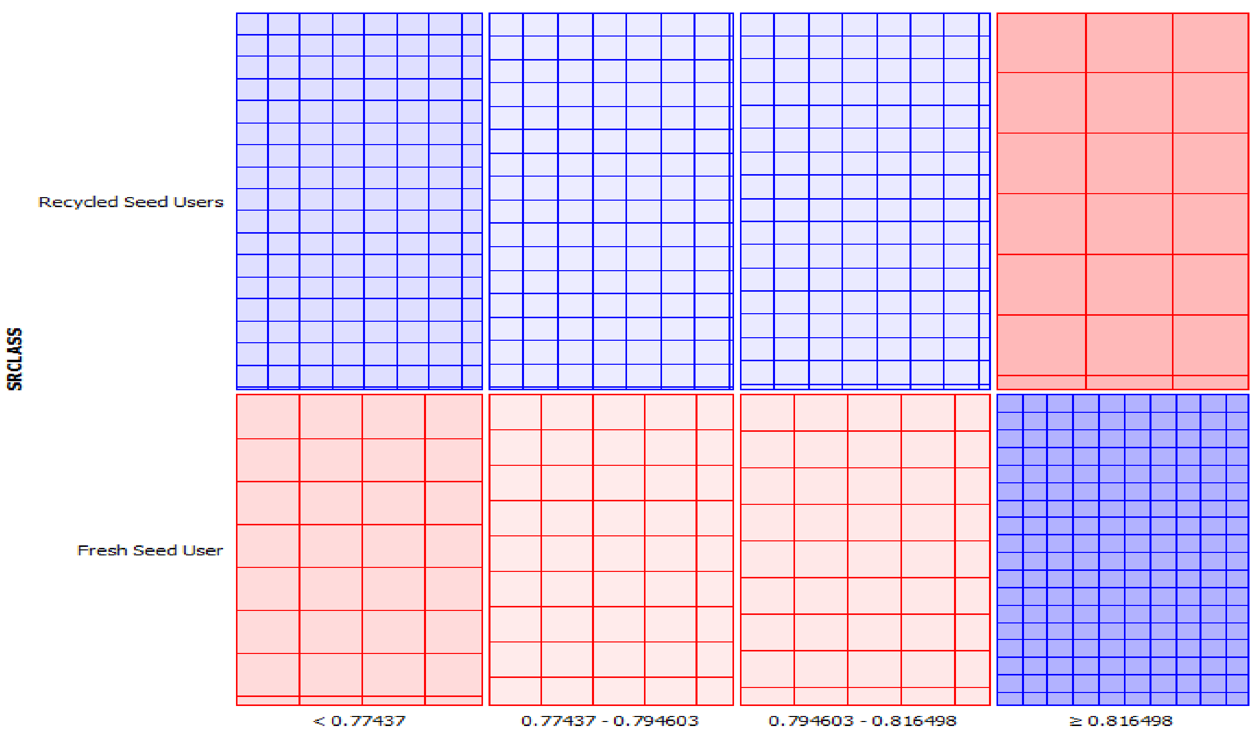
Annex Graphs

Annex Graph 1: Bread Wheat Seed Recycling Frequency and Productivity



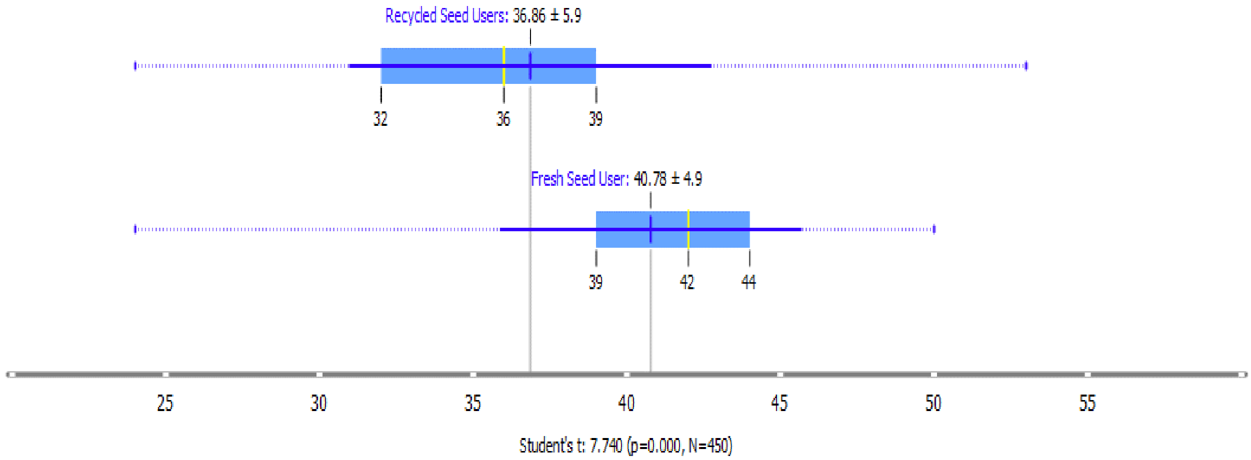
Source: Own Graphics (2022)

Annex Graph 2: Sieve Diagram on Distribution of TE Score for Fresh and Recycled Seed Users

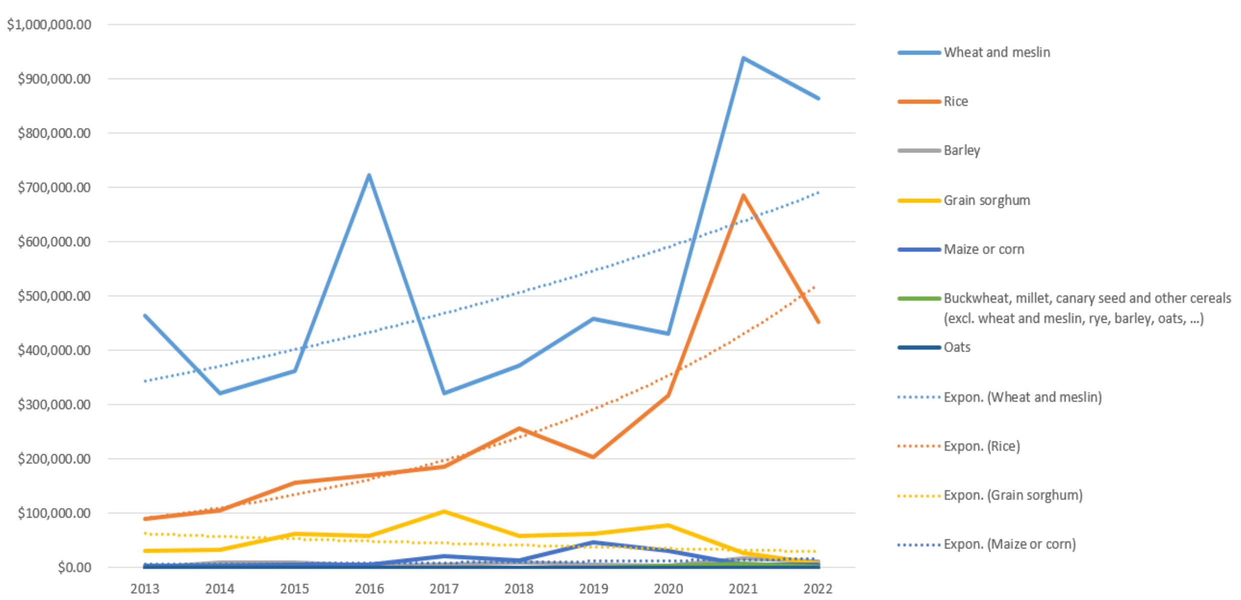


Technical Efficiency Scores (*N=450*, χ^2 = *36.68*, *p=0.0000*)

Annex Graph 3: Box plot indicating productivity difference between fresh and recycled Seed Users

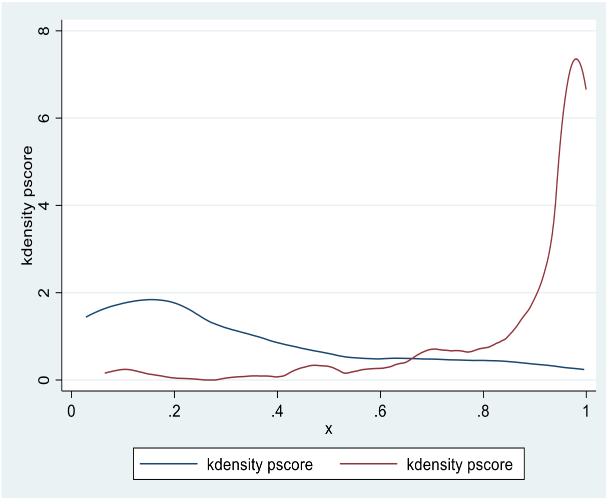


Annex Graph 4: Amount of Capital Invested for Grains Import (000 USD)

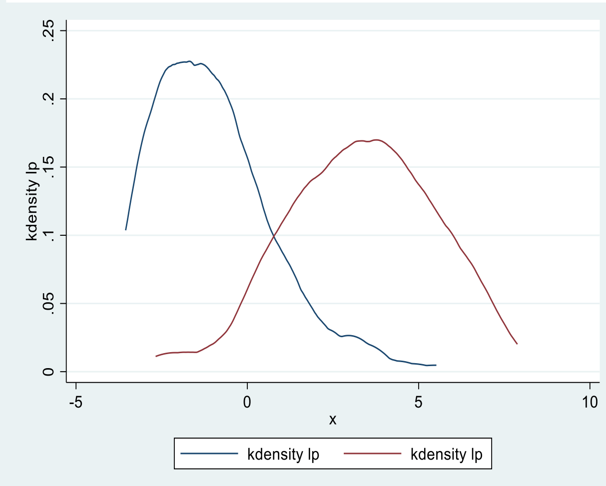


Source (https://intracen.org/resources/data-and-analysis/trade-statistics)

Annex Graph 5: Distribution of the Propensity Score

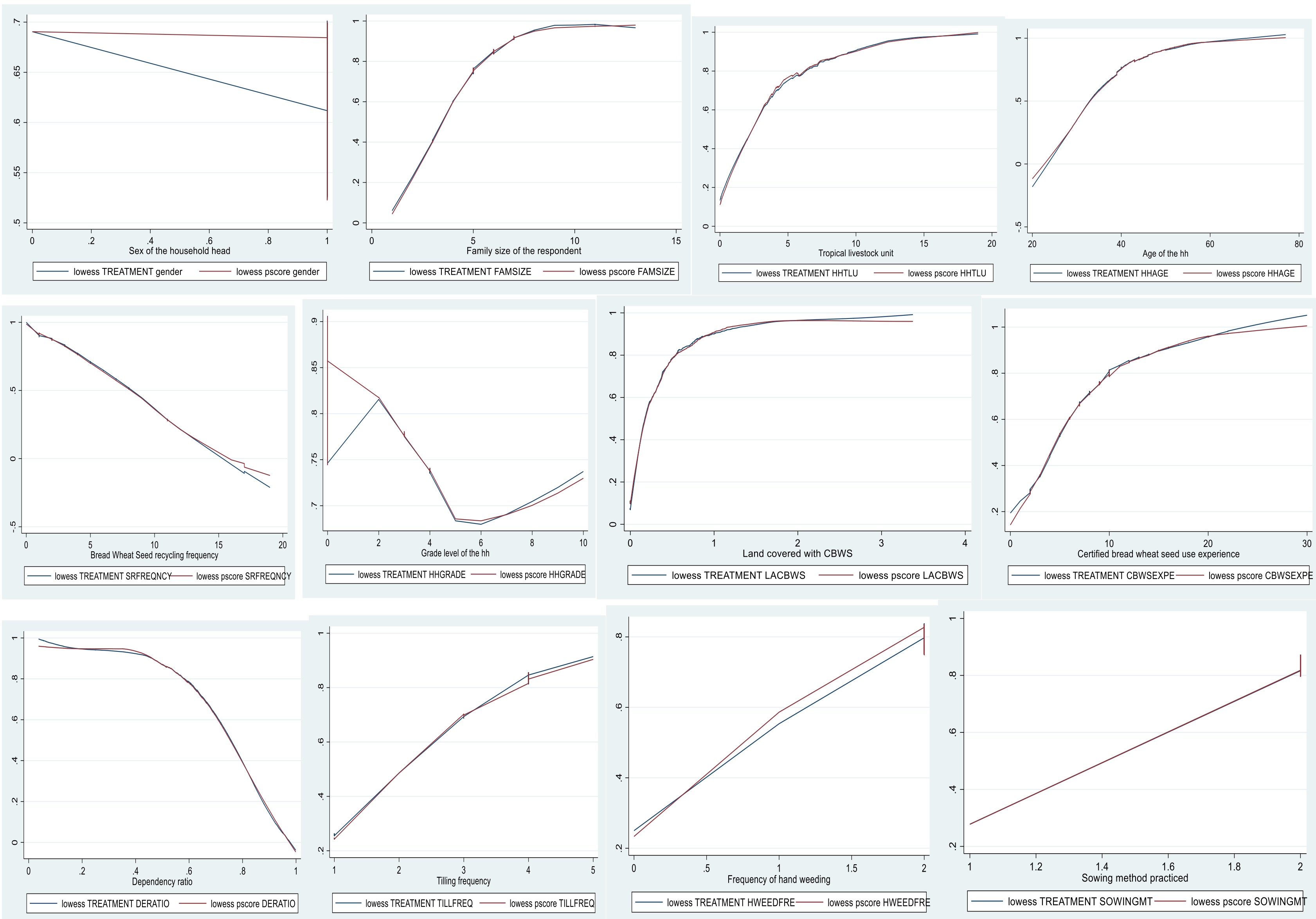


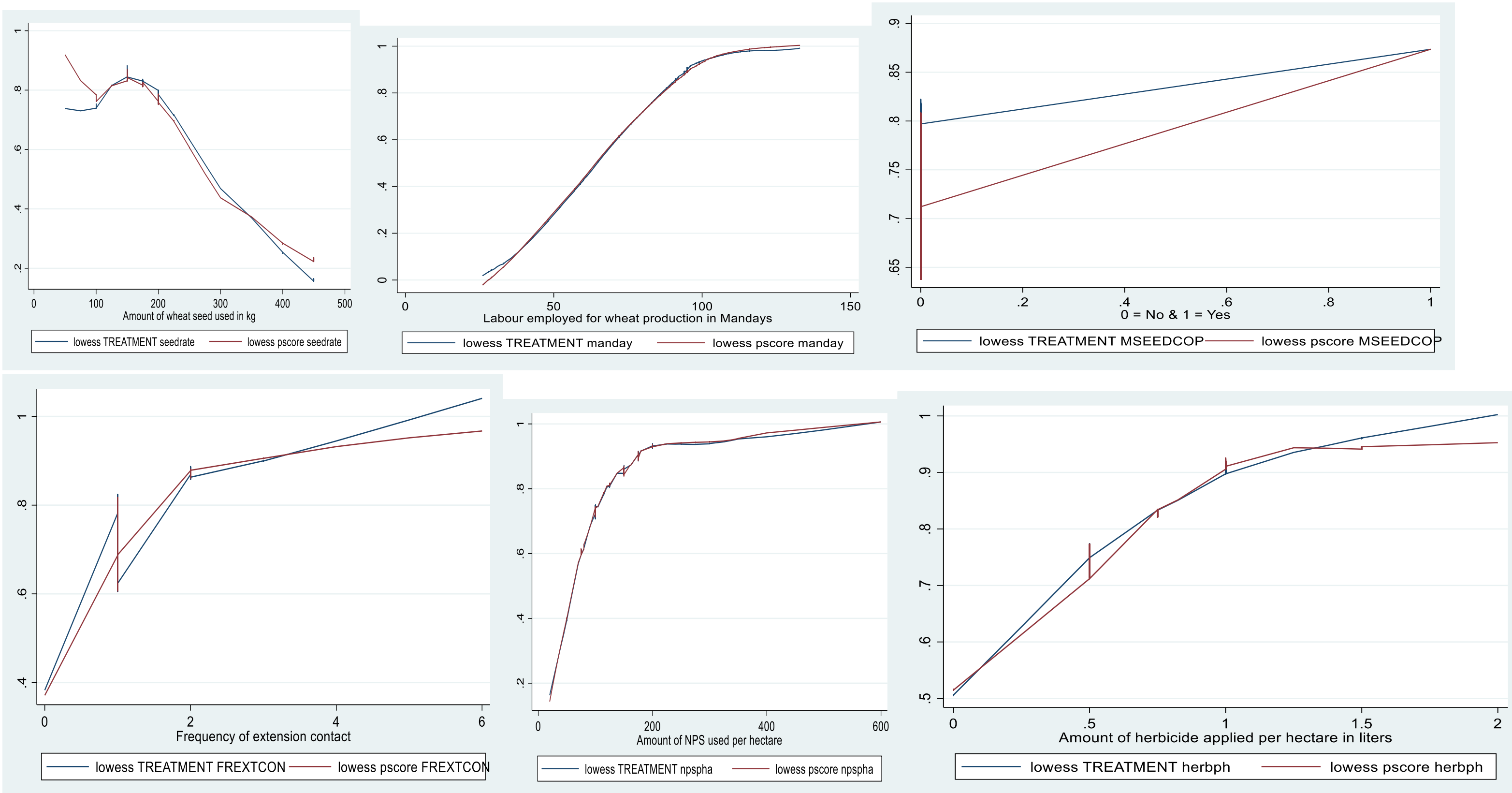
(A) Normal Propensity Score

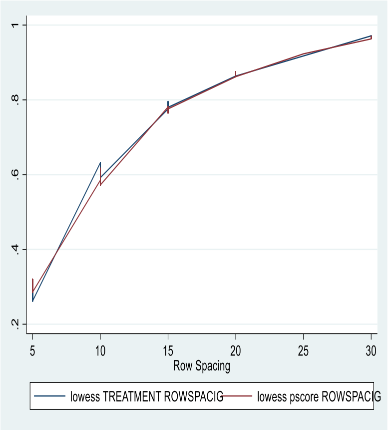


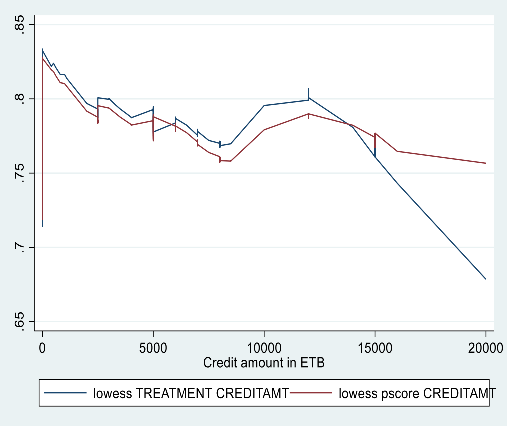
(B) Logs – odd Propensity Score

Annex Graph 6: Comparison of observed and predicted associations between confounders and treatment

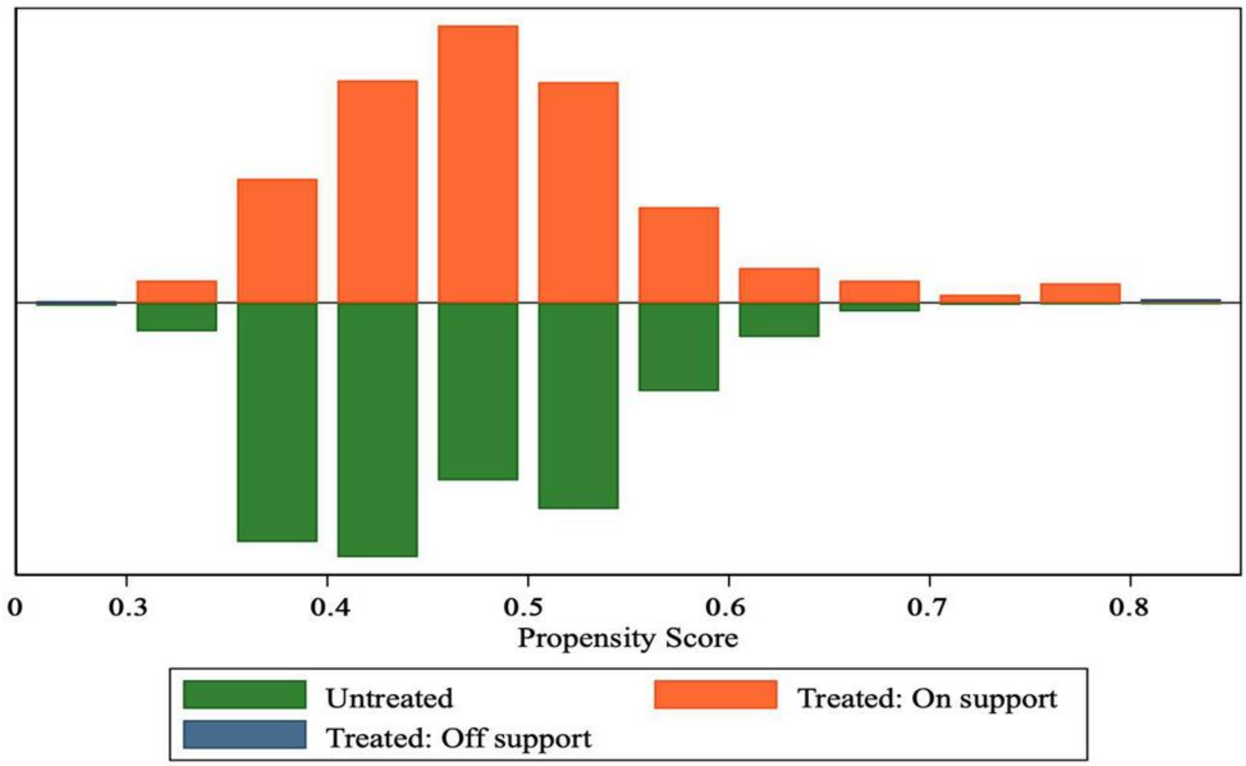



Amount of wheat seed used in kg
lowess TREATMENT seedrate
lowess pscore seedrate
Labour employed for wheat production in Mandays
lowess TREATMENT manday
lowess pscore manday
0 = No & 1 = Yes
lowess TREATMENT MSEEDCOP
lowess pscore MSEEDCOP
Frequency of extension contact
lowess TREATMENT FREXTCON
lowess pscore FREXTCON
Amount of NPS used per hectare
lowess TREATMENT npspha
lowess pscore npspha
Amount of herbicide applied per hectare in liters
lowess TREATMENT herbph
lowess pscore herbph


.2
.4
.6
.8
1
5
10
15
20
25
30
Row Spacing
lowess TREATMENT ROWSPACIG
lowess pscore ROWSPACIG


.65
.7
.75
.8
.85
0
5000
10000
15000
20000
Credit amount in ETB
lowess TREATMENT CREDITAMT
lowess pscore CREDITAMT

Annex Graph 7: Common support for propensity score estimation with a kernel matching technique



Appendix Table B

Appendix Table B 1: Household Interview Schedule

Impacts of the Adoption Intensity of Improved Bread Wheat Production Package and Seed Recycling on Smallholder Farmers' Technical Efficiency and Productivity: The Case of East Gojam Zone, Amhara National Regional State, Ethiopia.

Consent

My name is {……} I am here to collect a research data by interviewing you and other members of the community in your village. This interview schedule is designed with the chief intention of investigating the major determinants of smallholder farmers TE in bread wheat production and its nexus with seed recycling. It is also aimed at understanding the economic efficiency impacts produced because of improved bread wheat seed use and seed recycling along with capturing the major sources of inefficiencies in bread wheat production in the study area. There is no direct benefit/compensation in participating to this research. Your response to these questions would remain anonymous. Taking part in this study is voluntary. If you choose not to take part, you are free to disengage and there will be no consequences. May I Continue to the Interview?

1 = {Yes} *2 = {No}*

"Thank you for your kind co-operation"

Part I. General Information

District Name	Kebele/PA Name	HH Head Name	HHH ID	Enumerator Name	Enumerator Signature	Interview Date

Part II. Respondents Socio – Personal and Demographic Conditions

2.1. Sex, age and educational status

HHH Sex 1 = [male] 2 = [female]	Marital status 1 = [Single] 2 = [Married] 3= [Divorced] 4 = [Widowed]	HHH Age in years	Farm Experience in year	Educational status 0 = [Illiterate] 1 = [Literate]	If literate, maximum grade level attained in years

2.2. Family size of the household by age group and sex

Family members	Age	Sex 1 = [male] 2 = [female]	Educational status 0 = [Illiterate] 1 = [Literate]	If literate, maximum grade level attained in years	Permanently sick/disabled family members		
					Male	Female	Total
1.							
2.							
3.							
4.							
5.							
6.							
7.							
8.							
9.							
10.							
Total							

NB: No need to list down name of the family members and feel free to add extra columns if the family size exceeds 10

Part III. Resource Ownership and Economic Characteristics

3.1. Livestock, land and house ownership

Livestock owned	Number of livestock	Land ownership 0 = [no] 1 = [yes]	If yes, Sources of land [Code]	Amount of land [Timad/hectare]	Land use [Code]	Land size for different use [Timad/hectare]	House type [Code]	House use [Code]	Number of houses
Calves									
Bulls									
Oxen									
Heifer									
Cows									
Sheep									
Goats									
Donkey									
Mule									
Horse									
Poultry									
Total									

Codes

Land source code	Land use code	House type code	House use code
01 = [Owned from the government]	01 = [Cultivated/crop land]	01 = [Thatched roof]	01 = [For human]
02 = [Inheritance]	02 = [Grazing land]	02 = [Corrugated iron roof]	02 = [Animals]
03 =[Rented]	03 = [Forest land]	03 = [both]	03 = [Both]
04 = [Shared land]	04 = [Homestead land]		04 = [Store]
05 = [Accessed new land]	05 = [Fallow land]		05 = [Multipurpose]
06 = [Others, specify]	06 = [Others, specify]		06 = [Others]
07= [Combination, specify]			

3.2. Would you please tell us the sources and amount of average annual income you obtain from different sources during the 2011/2013 E.C production time?

Sl.No.	Income sources	Average annual income (Birrs)
1.	Crop and crop products sale	
2.	Livestock and livestock products sale	
3.	Forest and forest products sale (Fuel wood, charcoal, etc)	
4.	Off – farm activities (agricultural works on others farm)	
5.	Non – farm activities (petty trading, artisanship like carpentry, handicraft, pot making, blacksmith works, etc)	
6.	Remittances	
7.	Credit	
8.	Aid/donation	
9.	Others	
9.1.		
9.2.		
9.3		
	Total	

3.3. Would you please tell us the sources and amount of average annual development expenditure?

Sl.No	Sources of Development expenditure	Average Annual expenditure (Birr)
1.	Expenditure for seed	
	1 = [local seed]	
	2 = [Improved seed] 01 = [Certified]	
	02 = [Non – certified]	
2.	Fertilizer purchasing	
	Urea	
	Dap	
	Others	
	Total	
3.	Chemical (pesticide, pesticide, ...) purchased	
4.	Farm implements purchasing	
5.	Livestock purchasing	
6.	Others, please list them	
6.1.		
6.2.		
	Total	

3.4. Would you please tell us the sources and amount of average annual expenditure for maintenance?

Sources of Maintenance Expenditure	Amount (in Birr)
1. Food	
2. Clothing	
3. Housing	
4. Medicine (Family and livestock)	
5. Other, please specify	
5.1.	
5.2.	
Total	

Part IV: Access to institutional Services

4.1. Access to Extension service, Credit, Irrigation, cooperative membership and market distance

Access to Extension 0 = [no] 1 = [yes]	If yes, frequency of contact in month	Who initiates the extension visit? 1 = Me 2 = EA	Access to credit 0 = [no] 1 = [yes]	If yes, amount of in Birr	Irrigation access 0 = [no] 1 = [yes]	If yes, rate its importance in wheat production (1=very low, 2= low, 3=moderate, 4= high, 5= very high)	Membership in seed multiplication and marketing cooperatives 0 = [no] 1 = [yes]	If yes, rate its importance in wheat production (1=very low, 2= low, 3=moderate, 4= high, 5= very high)	Market distance from homestead (Kilometers)

Part V. Crops grown, input use and price related information

5.1. General plot level crop production characteristics for 2011/12 E.C production season

Plot (Code)	Size (timad)	Crop grown (code)	Variety grown 1= Local 2= Improved	If improved, name of the variety	If improved, did you use certified seed 1= [no] 2=[yes]	If yes, source, amount and cost			Amount of production (kg)	Amount used for different purpose		
						Source	Amount (kg)	Cost (ETB)		Consumption	Commercial	Other

Codes for crops grown: 01 = [Wheat] 02 = [Teff] 03 = [Maize] 04 = [Barley] 05 = [Others] 06 = [Combination, specify]
Plot codes: Plot 1 = [01] Plot 2 = [02] Plot 3 = [03] Plot 4 = [04] Plot 5 = [05] Plot 6 = [06] Plot 7 = [07]
NB: Use common (farmers' own) units of measurement for their plot size, amount of production and other quantities

5.2. Plot level details of wheat production for 2011/2012 E.C production year.

5.2.1. Number of wheat plots, plot size, type of wheat grown, type of wheat variety grown, certified seed use, fertilizer and pesticide use

Wheat Plots (Code)	Size (timad)	Wheat type (code)	Variety grown 1=local 2= Improved	If 2, Name of the variety	If 2, is it CS? 0= [no] 1=[yes]	If 1, source	Did you use Urea fertilizer 0 =[no] 1=[yes]	If yes, Amount used (kg)	Cost (ETB)	Compost 0= no 1= yes	If 1, amount	Cost (ETB)	NPS 0=[no] 1=[yes]	If 1, amount	Cost (ETB)	Pesticide 0= no 1= yes	If 1, amount	Cost (ETB)

Codes for wheat type grown: 01 = [Durum wheat] 02 = [Bread Wheat]

Plot codes: Plot 1 = [01] Plot 2 = [02] Plot 3 = [03] Plot 4 = [04] Plot 5 = [05] Plot 6 = [06] Pot 7 = [07] Plot 8 = [08]

5.2.2. Other Information on wheat farming practices

Plot (code)	Ploughing frequency (number)	Amount of CWS/timad)	Sowing method 1=[broadcasting] 2=[row planting]	Row planting 0 = [no] 1 = [yes]	If yes, what is the spacing b/n		Amount of fertilizer/ha in kilograms			Fertilizer application method 1 = [split application] 2 = [one time application]	Sowing Date
					Seeds	Rows	NPS	Urea	Others		

Plot codes: Plot 1 = [01] Plot 2 = [02] Plot 3 = [03] Plot 4 = [04] Plot 5 = [05] Plot 6 = [06]

5.2.3. Other wheat production costs using CS

Plot (code)	Land size (Timad/hectare)	Rent for land	Labor		Wage	Oxen days	Rent for oxen/day	Lime (Kg)	Cost (ETB)	Machinery	Rent (ETB)	Other agro chemicals	Cost (ETB)	Other inputs	Cost (ETB)
			M	F											

5.3. Information on CWS use, SRR, Frequency of seed recycling practices during the 2011/2012 production season

Did you replace Wheat Variety? 0= [no] 1=[yes]	Reasons to replace variety [Code]	Reasons to stick to old varieties [List all your reasons]	Experience in using CWS [years]	Did you replace your wheat seed 0= [no] 1=[yes]	SR frequency [code]	Reasons for SRR	Reasons for seed non – replacement (List all reasons)	Seed recycling 0 = [n0] 1 = [yes]	If yes, frequency of recycling [--- times]

Codes

Code for SRR	Code for new variety use	Codes for CS sources
01 = [Every production time]	01 = [Superior yield]	01 = [Self retained from previous production
02 = [Annually]	02 = [Disease resistance]	02 = Informal sources such as gift/borrowed from neighbors/relatives]
03 =[2 to 3 years]	03 = [Drought resistance]	03 = [Private seed sellers/market]
04 = [3 to 5 years]	04 = [Higher germination rate]	04 = [State owned seed agencies]
05 = [Above 5 years]	05 = [Bigger seed size]	05 = [Higher learning institutions]
06 = [Never replaced]	06 = [Grain quality/size/color, etc]	06 = [Research institutes]
	07 = [Stalk quality/size/straw quality]	07 = [NGOs]
	08 = [Suitability for food/taste/baking time, etc]	08 = [Seed producer cooperatives]
	09 = [Less production cost]	09 = [A combination of the above, list them]

010 = [Marketability/better demand]   10 = [Others, specify]
011 = [Others, please specify]

5.5. Wheat output and marketing related information in 2019 production season

<table>
<tr><td rowspan="3">Plot (Code)</td><td rowspan="3">Size (Timad/hectare)</td><td rowspan="3">Output (kg/Qt)</td><td colspan="4">Production use</td></tr>
<tr><td rowspan="2">Consumed at home</td><td colspan="2">Sold</td><td rowspan="2">Others</td></tr>
<tr><td>Amount (kg/Qt)</td><td>Cost (ETB)</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Plot codes: Plot 1 = [01] Plot 2 = [02] Plot 3 = [03] Plot 4 = [04] Plot 5 = [05] Plot 6 = [06]

Appendix Table B 2: KII and FGD Checklists

Smallholder Farmers' Perception of CWS use, and SRR

1. Would you please tell us your own subjective judgment as far as CWS use is concerned?

____
____
____
____
____
____
____.

2. Would you please tell us your own subjective judgment as far as wheat seed replacement is concerned?

____
____
____
____
____
____
____.

3. Would you please tell us your own subjective judgment as far as the benefits and dangers of wheat seed replacement is concerned?

____
____
____
____
____
____
____.

4. Would you please provide your level of agreement based on your own subjective judgment about wheat seed replacement? (Where 1, 2, 3, 4 and 5 indicates strong disagreement, disagreement, undecided, agreement and strong agreement respectively)

Sl.No.	Perception Statements on SRR.	Agreement level				
		5	4	3	2	1
1.	Increases production and productivity (yield gains)					
2.	Improves food security and income					
3.	Helps to reduce pest and disease outbreak					
4.	Increases crop diversity					
5.	Others, please specify					
5.1.	____ __________________					
5.2.	____ __________________					
5.3.	____ __________________					

Questionnaire for Development Agents and Experts

1. How many farmers were under your service jurisdiction in the last production seasons? _______________ Households.
   1.1. On average, how many visits did you pay for each household? ____________ times.
2. Farmers of this study revealed that they plan to increase their wheat yield in the coming production season by doing the following activities. Do you think this is possible? Rate the level of the possibility of farmers' plan of increasing yield due to each reported practices on the following 5 – 1 point scale (where 5, 4, 3, 2 and 1 indicates highly possible, possible, intermediate, impossible and highly impossible respectively

Planned practices	Level of possibility				
	(5)	(4)	(3)	(2)	(1)
1. Replacing the certified seed being used					
2. Replacing the variety being used					
3. Applying more fertilizers					
4. Applying more agro–chemicals					
5. Applying row planting					
6. Other plans, please specify					
6.1.__________________________________					
6.2.___________________________________					

2. How do you evaluate the extent and level of CWS use under your jurisdiction?

Very Poor	Poor	Medium	Good	Very Good
1	**2**	**3**	**4**	**5**

2.1. What has contributed for your rating in the above questions?

3. How many modern wheat varieties were introduced in your mandate area? ___________

3.1. Would you give a list of them and for how many years they were used on average?

Sl.No	Name of the variety	Year (s) in use	Sl.No.	Name of the variety	Year (s) in use
1.			11.		
2.			12.		
3.			13.		
4.			14.		
5.			15.		
6.			16.		
7.			17.		
8.			18.		
9.			19.		
10.			20.		

3.2. How do you evaluate wheat SRR under your jurisdiction?

Very Poor	Poor	Medium	Good	Very Good
1	**2**	**3**	**4**	**5**

3.3. Give reasons for your rating in the question above

4. Please enumerate the major barriers affecting farmer's use of CWS? (Feel free to write more than the lines given)

5. Please enumerate the major barriers affecting farmer's seed replacement rate? (Feel free to write more than the lines given)

6. Please enumerate the major barriers affecting farmer's rate of varietal replacement? (Feel free to write more than the lines given)

KII Checklist for farmers

1. Would you please rate the contribution of the following reasons to use IBWS for wheat production?

Reasons	Rating				
	Significantly high (5)	High (4)	Medium (3)	Low (2)	Significantly low (1)
Seed purity from foreign materials					
Free from seed borne diseases and resistance to yellow rust and stem rust					
Better yield advantage					
High germination rate					
Early maturity/short growing season/drought resistance					
Lower seed rates					
Grain size					
Grain color					
Threshibility					
Food quality (bread and injera taste, cooking time, etc)					
Stalk size, straw quality and straw yield					
Reduces production costs					
Better market demand					
Prices are affordable					
Others, please mention as many reasons as you can					

2. Would you please rate the major reasons contributing to the non – use of CS for wheat production?

Reasons	Rating				
	Significantly high (5)	High (4)	Medium (3)	Low (2)	Significantly low (1)
Lack of access to CBWS (Unavailability)					
Expensiveness/high cost					
My own saved seed is better					
Others, please mention as many reasons as you can					

5.2.5. Would you please rate the major factors affecting the use of fertilizer in wheat production?

Reasons	Rating				
	Significantly high (5)	High (4)	Medium (3)	Low (2)	Significantly low (1)
Lack of access (Unavailability)					
Unreliable/untimely/late supply					

Lack of capital to purchase					
Incompatible/unsuitable fertilizer					
Expensiveness/high cost					
Others, please specify					

5.5.1. Respondent's view about wheat marketing.

View on current market price (code)	Who decides the market price for wheat? (code)	Is there enough demand for wheat? (code)	Mention and prioritize your answer on wheat demand	For whom do you sale your wheat product? (code)

Codes

Codes for view on price	Code for market decision	Code for wheat demand
1 = [very low]	01 = [the buyer]	0 = [no]
2 = [low]	02 = [farmer/seller]	1 = [yes]
3 = [fair]	03 =[both of them]	
4 = [high]	04 = [the government]	
5 = [very high]	05 = [other]	

5.4. **Labour and machinery use related information**

5.4.1. Please indicate the average amount of labour used and costs pertinent to labour use for various wheat production operations in the last production season.

Sl.No.	Wheat production activities/operations	Number of labour employed			Costs paid for hired labor (ETB)	Labor related problems affecting CWS use (Code)	Costs incurred if machineries were rented (ETB)
		Family	Hired	Debbo & other arrangement			
1.	Land preparation and tillage						
2.	Wheat sowing						
3.	Fertilizer application						
4.	Weeding						
5.	Pesticide and other chemical application						
6.	Harvesting						
7.	Threshing						
8.	transporting						
9.	Other activities						
10.	Total						

Codes for labour related Problems
01 = [High wage rate] 02 = [Lack of labour during peak production seasons] 03 = [Lack of skill]
04 = [High machinery cost] 05 = [lack of farm implements] 06 = [Others, specify]: ____.

Appendix Table B 3: Statuses of the Articles

Location of the article in the dissertation	Title of the article	Name of the Journal	Status and Date
Chapter 2	Yield and Cost Effects of Plot-Level Wheat Seed Rates and Seed Recycling Practices in the East Gojam Zone, Amhara Region, Ethiopia: Application of the Dose–Response Model	Sustainability (MDPI).	Published on March 29, 2021.
Chapter 3	Adoption Intensity of Improved Bread Wheat Package and Productivity Changes: Applications of Cragg's Double Hurdle and Regression Adjustment Models	British Food Journal	Given full consideration for publication, June 2, 2023
Chapter 4	Nexus Between Seed Recycling and Technical Efficiency of Bread Wheat Production in East Gojam Zone, Ethiopia: The Stochastic Frontier Approach	F1000Research	Published on May 16, 2023

Appendix Table B 4: Acceptance Letter for the Second Article

From: gabriele.baima@unito.it

To: etalem456@gmail.com, yirgsh456@gmail.com, bamlakalamirew@gmail.com, z.bishaw@cgiar.org

CC:

Subject: British Food Journal - Manuscript ID BFJ-06-2021-0614

Body: 02-Jun-2021

Dear Mr. Eshete:

Your manuscript entitled "Determinants of the Adoption Intensity of Certified Bread Wheat Seed in Ethiopia: Applications of the Cragg's Double Hurdle Model" has been successfully submitted online and is presently being given full consideration for publication in the British Food Journal.

Your manuscript ID is BFJ-06-2021-0614.

Please mention the above manuscript ID in all future correspondence or when calling the office for questions. If there are any changes in your street address or e-mail address, please log in to ScholarOne Manuscripts at https://mc.manuscriptcentral.com/bfj and edit your user information as appropriate.