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Economic Evaluation and Determinants þÿof Farmers Fertilizer Use in Parts of Amhara Region, Ethiopia

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COLLEGE OF AGRICULTURE AND ENVIRONMENTAL SCIENCES (CAES)

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Economic Evaluation and Determinants of Farmers' Fertilizer Use in Dryland Parts of Amhara Region, Ethiopia

MSc Thesis

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Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master Science (MSc.) in Agricultural Economics

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THESIS APPROVAL SHEET

As a member of the Board of Examiners of the Master of Sciences (MSc.) thesis open defense examination, we have read and evaluated this thesis prepared by **Mr. Adane Wubet Getahun** entitled "Economic Evaluation and Determinants of Farmers' Fertilizer Use in Dryland Parts of Amhara Region, Ethiopia". We here certify that, the thesis is accepted for fulfilling the requirements for the award of the degree of Master of Sciences (MSc.) in **Agricultural Economics.**

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This is to certify that this thesis entitled **“Economic Evaluation and Determinants of Farmers’ Fertilizer Use in Dryland Parts of Amhara Region, Ethiopia”** submitted in partial fulfillment of the requirements for the award of the degree of Master of Science in **“Agricultural Economics”** to the Graduate Program of College of Agriculture and Environmental Sciences, Bahir Dar University by Mr. Adane Wubet (ID. No BDU1300549) is an authentic work carried out by him under my guidance. The matter embodied in this thesis work has not been submitted earlier for the award of any degree or diploma to the best of our knowledge and belief.

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LIST OF ABBREVIATIONS

AIC	Akaike's Information Criteria
CSA	Central Statistical Agency
CVM	Contingent Valuation Method
DBDC	Double bounded dichotomous choice
DHM	Double Hurdle Model
ETB	Ethiopian Birr
HH	Household
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFDC	International Fertilizer Development Center
LRT	Likelihood Ratio Test
MoA	Ministry of Agriculture
NOT	Nutrient Omission Trials
NPS	Nitrogen, Phosphorus, Sulfur
RPM	Revealed Preference Method
SOILS	Sustainable Opportunities for Improving Livelihoods with Soils
SPM	Stated preference Method
SSA	Sub Sahara Africa
TLU	Tropical Livestock Unit
USAID	United States Agency for International Development
WTP	Willingness to Pay

Abstract

The issue of fertilizer nowadays is the important question which needs further investigations and this study conducted to explore the economic evaluation and its determinants of fertilizer use in the dryland parts of Amhara region. The study applied multistage sampling with Kothari sample size determination formula and data were collected using questionnaire and checklists from primary data sources. The data were analyzed through descriptive statistics, inferential statistics and econometric models (seemingly unrelated bivariate probit model (SUBPM) and the double hurdle model). The marginal rate of return (MRR) showed that the All-B treatment had the highest MRR of 799.93% for teff and 62.46% for sorghum in Sekota district. The 50% (All+K) treatment recorded the highest MRR for teff at 29.36% while All-B recorded the highest MRR for sorghum at 46.72% in Tehuledre district. The All-B treatment recorded the highest MRR for teff at 100.36% while 150% (All+K) recorded an MRR of 37.88% for sorghum in West Belesa district. Based on the SUBPM result, the mean willingness to pay (WTP) for the NP fertilizer is 45.65 ETB/Kg. The results showed that the use of fertilizer is determined by farmers' knowledge about fertilizer use, perception of fertilizer use, fertilizer price, and number of active workers in the household, extension service and proximity to the input center from the household residence. Education, knowledge of fertilizer application, annual income, and experience in fertilizer use, farm size and proximity to markets have significant effects on level of fertilizer utilization. Based on the findings, government and respective actors due attention for the heterogeneity of locations during fertilizer recommendations, enhancing extension services to improve their knowledge and perception, optimizing fertilizer prices, improving proximity to input and market centers.

Key Words: NP fertilizer, Economic evaluation, fertilizer users, Willingness to Pay, Double hurdle

CHAPTER ONE

1. INTRODUCTION

1.1. Background and Justification of the Study

In most of Sub-Saharan African (SSA) countries, soil fertility loss is a major limiting factor to agricultural productivity (Wilfred, 1996). Applying the right nutrient at the recommended rate, at the right time and in the right place is essential for optimizing the use of nutrients, and improving crop productivity and soil fertility (Zelleke *et al*., 2010). However, the use of improved agricultural inputs like fertilizer, and seed in SSA including Ethiopia is very low (Kelly and Naseem, 2003).

In Ethiopia, crop production increment can be achieved by expansion of the crop production area or through the increase in yield or a combination of the two (Abdulsalam, 1975). However, expansion of crop production through increasing the area of production is not a viable option because land is limited resource. Therefore, the use of improved inputs like fertilizer and improved seed is a reasonable and acceptable way to increase crop production and productivity. In this regard, enhancing crop production and productivity through crop intensification is the major solution to feed the growing population of Ethiopia (Rashid *et al*., 2013). The Ethiopian government acknowledged the importance of agricultural intensification and is putting effort into fertilizer supply and distribution. However, the current Ethiopian agricultural policies promote blanket recommendations of fertilizer per hectare of land for all parts of the country (Ekero *et al*., 2021). Such blanket recommendations are criticized due to the ignorance of the heterogeneity of crop type, rainfall, and soil fertility across agro-ecologies. Especially in the current context where there is a fertilizer supply shortfall and thereby higher prices in Ethiopia, appropriate fertilizer recommendations are not an option but a must (Ekero *et al*., 2021).

Crop response variability in nutrient use efficiencies to fertilizer application is quite common research activity under varying soil and climatic conditions (Magen, 2008). Understanding such variability is vital to develop location-specific soil nutrient management and fertilizer recommendations. Hence, to validate the location-specific fertilizer recommendations with the consideration of growing conditions and crop type International Fertilizer Development Center

(IFDC) has been working on nutrient omission trials (NOT) collaborating with partners like the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), National and Regional Agricultural Research Institutions. In 2020, fertilizer omission trials on Teff (183 sites), wheat (119 sites), and sorghum (60 sites), for a total of 362 sites were conducted in four regions (Amhara, Oromia, SNNPR, and Tigray) of Ethiopia.

The agronomic and soil data related to yield and yield components were collected and analyzed by biological researchers. Based on the results of the analysis, Nitrogen Phosphate (NP) fertilizer is recommended instead of NPS for future utilization. To make the recommendation strong and inclusive, in addition to the collected and analyzed agronomic data; economic viability of treatments, an understanding of the socioeconomic context of fertilizer uses and level of fertilizer utilization is considered as the key components. Therefore, this study aimed to evaluate the economic feasibility of the experiments, willingness to pay for NP fertilizer, and determinants of farmers' fertilizer use and level of fertilizer use in three districts of Amhara regional state.

1.2. Statement of the Problem

The rapid population growth of Ethiopia creates the higher exploitation of farming land. Because, the crop cultivation practice involve intensive soil tillage throughout the cropping season, which often results in soil degradation, erosion, and leaching of nutrients. An effort to increase agricultural production per unit of area relies on utilization of improved inputs like fertility-enhancing technologies to replenish soil nutrients required by crops. Assefa *et al*. (2021) also reported that in Ethiopia soil fertility loses and poor fertilizer application rate are the major challenges to enhancing agricultural production and productivity.

To this end, the government of Ethiopia is promoting fertilizer application (organic and inorganic) to improve agricultural productivity and more farmers become aware of the need to use fertilizers in recent years. Despite the higher demand, agricultural productivity remains low and the majority of farmers are still practicing low-fertilizer (below the recommended rate) low-output production systems. Therefore, here there is one basic question *what are the factors push the farmers to apply below the recommended rate of fertilizer?*

Different studies (Morris 2007; Tamene *et al*., 2017) indicated that fertilizer recommendations that fail to consider variations in growing conditions and poor application of recommended fertilizer rate contribute to lower crop production and productivity. For instance the recommended fertilizer in the study zones is 50 Kg ha^{-1} urea and 100 Kg ha^{-1} NPS. The aforementioned scenarios lead to validate which fertilizer type is appropriate for different locations that can recognize the important differences in growing conditions (APNI, 2022). Therefore, to fill this gap, IFDC has been implementing the Sustainable Opportunities for Improving Livelihoods with Soils (SOILS) consortium towards developing holistic solutions for enhancing soil fertility. SOILS priority areas include developing and transferring soil fertility technologies that can improve nutrient use efficiency, in alignment with the 4Rs of nutrient stewardship—right source, right time, right rate, and right place. As a result, Nutrient Omission Trials (NOTs) were carried out for major cereal crops, including Sorghum, Wheat, and Teff, across diverse growing conditions in the Amhara, Oromia, SNNR, and Tigray regions of Ethiopia in 2020. From the total experimental sites in the four regions in Ethiopia; 71 trials were covered by this study. Subsequently, NP fertilizer was recommended by soil fertility researchers due to its optimal crop yield.

Hence, analysis should be conducted to check the economic feasibility associated with the NP fertilizer to ascertain whether the biologically optimum fertilizer aligns with economic optimality. Additionally, beyond the economic analysis, analyzing farmers' capacity to afford the NP fertilizer is important for further exploration in other research endeavors and the formulation of developmental pathways. Lastly, data from unpublished reports and informal communications with agricultural experts in the study areas indicate a poor application rate of the existing fertilizer (*i.e.* not applied based on the recommended rate). While there are some studies (Weyessa, 2014; Bedilu *et al*., 2016; Amsalu and Alebachew, 2021) on factors influencing the use and level of agricultural inputs in various parts of Ethiopia. However, as the best of my knowledge, there is no study conducted on the above mentioned issues in the study areas. Hence, understanding the factors that determine the fertilizer use and level of fertilizer application has an important role in giving direction to researchers, development actors to conduct gap filling interventions, and used as a spring board for other researchers to conduct further researches in the issue of fertilizer.

Therefore, this study has been conducted to analyze the economic incentives of the recommended fertilizer, to analyze farmers' WTP for NP fertilizer, and to investigate the determinants of fertilizer adoption and intensity among smallholder farmers in the three districts of Amhara region, Ethiopia.

1.3. Research Questions

The research questions answered by this research are:

1. Which fertilizer treatments have better economic incentives on major cereal crops under different growing conditions in the study areas?
2. How much small holder farmers willing to pay for recommended NP fertilizer for major cereal crops in the study areas?
3. What are the determinants of smallholder farmers’ inorganic fertilizer use and use intensity on major cereal crops in the study areas?

1.4. Objectives of the Study

1.1.1. General objective

The general objective of the study is to conduct economic evaluation and its determinants of farmers fertilizer use in the study areas.

1.1.2. Specific objectives

1. To evaluate the economic incentives of different fertilizers used in NOTs on major cereal crops under different growing conditions in the study areas
2. To analyze small holder farmers’ willingness to pay for recommended NP fertilizer for major cereal crops in the study areas.
3. To analyze determinants of smallholder farmer's fertilizer use and its intensity on major cereal crops in the study areas

1.5. Scope and Limitation of the Study

This research was carried out in the three districts —Sekota, Tehulederie, and Western Belesa located in the dryland parts of Amhara Region, Ethiopia, where NOTs were conducted. The scope of economic analysis focused on experimental data only, WTP analysis also focused only mean WTP for NP fertilizer and determinants of fertilizer use and level of NPS utilization. The results of this study are therefore limited to these districts and districts having similar agro ecologies. This study focused on inorganic fertilizer and this can be taken as the one limitation of this study. Sampled respondents provide information based on recall because they have not keep records of their farming activities, obtaining accurate and reliable farm level information was the major limitations of the study. Lack of accurate and updated secondary data from the district agricultural office is also taken as limitation to this study. The cost data in relation to experimental data for economic analysis were not fully recorded and analyzed using fertilizer cost only (other costs citrus paribus) this also the other limitation.

1.6. Significance of the Study

Various stakeholders and partners involved in the fertilizer issue, such as farmers, policymakers, agricultural offices, research institutes, universities, and non-governmental organizations, could benefit from the findings of this study. By taking into account various growing conditions; this study generates information on the economic benefits of fertilizer use on major cereal crops. This study also provides details on the factors that influence farmers' fertilizer use and intensity of fertilizer use. Furthermore, by analyzing farmers' opinions of the significance of fertilizer use to their farm productivity and income, the outcome will provide information on strategic insights to guide decisions for IFDC in the direction of future study. The findings of this study can also be used as a basis for more research in the study areas and beyond.

1.7. Organization of the Proposal

The paper has five chapters. The first chapter includes introduction parts; second chapter covers a literature review to the concepts and empirical evidence. The third chapter describes the methodology of the study including a description of the study area, research design, sampling techniques, data collection, and data analysis. Chapter four is devoted to results and discussion, while the final chapter concludes with recommendations.

CHAPTER TWO

2. LITERATURE REVIEW

This chapter includes a comprehensive overview of both theoretical and empirical aspects of the study. Aligned with the study objectives, it delves into subjects encompassing economic incentives for fertilizer use, determinants influencing farmers' adoption, and the intensity of fertilizer use across major cereal crops in diverse growing conditions. The chapter concludes by presenting the theoretical and conceptual framework that underpins the study.

2.1. Conceptual Literature Review

2.1.1. Definition and basic concepts of fertilizers

Fertilizer is a substance containing chemical elements necessary for enhancing plant growth, production, and productivity (Stewart, 2022). Fertilizers are available in different forms such as solid, liquid, and gaseous, and crafted from an array of natural and manufactured materials (Savoy, 2020). Fertilizers are broadly categorized into organic and inorganic. Organic fertilizers are derived from natural and organic materials. The focus of this study inorganic fertilizers (like NPS and Urea) are crafted from chemical components containing essential nutrients, offering a rapid means of enhancing productivity within a short time. Manufactured from different sources and inorganic fertilizers are typically more concentrated than their organic counterparts (AGPCLC, 2021).

2.1.2. The concept of fertilizer economic incentives for fertilizer use

Economic incentives for fertilizer use refer to the financial motivations or benefits that encourage farmers to invest in and apply fertilizers to their crops (Erench, 1956). These incentives are rooted in the expectation of achieving increased agricultural productivity, and ultimately, improved economic returns. Farmers may perceive economic gains through factors such as enhanced crop quality, higher marketable yields, and increased income from the sale of agricultural produce. The economic incentive for fertilizer use is often driven by the belief that the cost of purchasing and applying fertilizers is outweighed by the potential financial gains resulting from improved crop performance and yields. Additionally, some agricultural policies, subsidies, or support programs may contribute to economic incentives by making fertilizers more accessible or affordable for farmers. The economic incentive of fertilizer use for major cereal crops refers to the financial motivations and benefits that encourage farmers to invest in and apply fertilizers to cultivate crops like cereals. This incentive is grounded in the expectation that the economic returns from increased agricultural productivity and higher crop yields will outweigh the costs associated with purchasing and applying fertilizers (Shiluli *et al.*, 2004; Theriault *et al*., 2018).

In summary, the economic incentive of fertilizer use for major cereal crops revolves around the potential for increased profits. Farmers weigh the expected benefits against the costs, and factors like market dynamics, government interventions, and crop yield play crucial roles in shaping these incentives.

2.1.3. The Concepts of Economic Valuation

The economic valuation of market and non-market resources involves assigning a monetary value to resources that are not commonly exchanged in economic markets. In economics, the concept of "value" pertains to the price individuals are prepared to pay for acquiring a good or service (Zegeye, 2015). The term "economic value" encompasses not just what people actually pay but also what they are willing to pay or forgo (Peter, 2022)

Willingness to Pay (WTP): The concept of Willingness to Pay (WTP) or reservation price refers to the maximum price a consumer is willing to pay for a specific quantity of goods and services while staying on their indifference curve (Zegeye, 2015). It represents the highest amount of income a person is prepared to expend to enhance their circumstances or prevent a decline in quality (Tesfahun, 2014). In the context of this study, the economic concept of WTP is frequently employed to ascertain the monetary value farmers are willing to pay for the provision of NP fertilizer. Utilizing the Contingent Valuation Method (CVM), WTP serves as a standard approach for marketing researchers and economists to assess the value of goods and services through hypothetical questions.

2.1.4. Valuation techniques of willingness to pay

There are two basic theoretical approaches available to estimate willingness to pay, *viz*. the indirect or revealed preference approach and the direct or stated preference approach.

Appropriate valuation techniques for willingness to pay are based on either observed behavior toward some marketed goods or resources somehow connected to the non-marketed goods in surveys concerning the goods in question (Haab and McConnell, 2002).

Revealed Preference Method (RPM) relies on statistical models of demand that are estimated from observations of real-life decisions made by individuals. The data used to discern revealed preferences are derived from actual situations, offering a reflection of genuine preferences and circumventing potential issues linked to hypothetical responses (Luo, 2019). The measurement techniques employed in this method include the travel cost methods and hedonic pricing methods (Bateman *et al*., 2002).

The Stated Preference Method (SPM) is a direct valuation approach employed to obtain measures of value by posing hypothetical questions to individuals. In this method, individuals are directly queried about their Willingness to Pay (WTP) for goods or services, such as balanced fertilizer in this context. SPM serves as an econometric tool for discrete choice analysis, particularly in the examination of choice-based conjoint elicitations within marketing research (Yicong, 2019). Various valuation techniques within SPM for assessing farmers' willingness to pay for balanced fertilizer include choice modeling and contingent valuation (Francesco *et al*., 2004).

Generally, both RPM and SPM can be employed to assess use values, but the initial consideration is whether both options are practically feasible. In certain situations, there might be no suitable proxy markets for estimating RPM values, making some form of SPM the only viable choice. Hence, the stated preference approach, specifically the contingent valuation method, is deemed preferable to other methods for analyzing farmers' willingness to pay for balanced fertilizer in this study (Bateman *et al*., 2002).

Contingent Valuation Method (CVM): The CVM is performed based on stated preferences for goods rather than revealed preferences. CVM has the limitation that it does not use the observed behavior of consumers, but it has more advantage that it can value nonmarket goods that other methods cannot but still it is a good estimation method for marketed goods (Earl and Dirk, 2000). NP fertilizer is recommended but not in the market at this time and farmers respond their WTP hypothetically based on the given information of NP fertilizer attributes by the interviewer. In CVM, respondents to a questionnaire are asked directly for their WTP: ‘Are you willing to pay $X (Bateman *et al*., 2002).

2.2. Empirical Literature Review

2.2.1. Economic Incentives of Fertilizer Application for Smallholder Farmers

The principle of production economics increase of yield is strongly correlated with increased use of improved agricultural inputs particularly fertilizer and improved seed.

According to Koussoubé and Céline (2015) study estimated the maize yield response based on the average use of nitrogen under different soil conditions. The quantity of nitrogen that maximizes maize yield is estimated about 77 kg ha^{-1}, and the maize yield response is 14.3 kg ha^{-1} when the soil is of low quality and maize was grown on the plot the year before. Theriault *et al*. (2018) conducted a study on economic incentives to use fertilizer on maize under differing agro-ecological conditions in Burkina Faso. Based on the full model's yield function estimates, the average grain yield increases by 24.1 kg ha^{-1} for each kg of N applied ha^{-1} at the sample means across all agro ecological conditions.

Nanganoa *et al*.(2021) showed that the grain yield and all the maize growth parameters recorded ranged from 4.09 to 5.88 ton ha^{-1} and were also statistically ($P < 0.05$) higher when the fertilizer rate is increasing from 50 kg urea + 50 kg N-P-K ha^{-1} to 150 kg urea + 150 kg N-P-K ha^{-1}. The two fertilizers (Nitrogen and Phosphors) combinations i.e. 30.0 and 60.40 kg ha^{-1} are economically superior and stable within a price variability range of 20% (Shiluli *et al*., 2004).

As per the findings by Ermias et al. (2019), the application of fertilizer has the potential to enhance soil fertility and provide financial benefits for maize and wheat farmers. The study suggests that not only would additional fertilizer usage be profitable, but the integration of improved knowledge in this regard could also result significantly positive welfare effects for producers. Additionally, Bosede (2010) affirms these findings, stating that fertilizer utilization can amplify farmers' returns on investment by a considerable factor, ranging from 2.1 to 14.6. The application of 100 kg ha^{-1} NPSB and 50 kg ha^{-1} KCl, exhibiting a 26.64% and 18% advantage over scenarios with 0 kg ha^{-1} NPSB and 100 kg ha^{-1} KCl, respectively. The highest return (1,542.29%) was observed with the application of 100 kg ha^{-1} NPSB and 50 kg ha^{-1} KCl, surpassing the MRR of 0 kg ha^{-1} NPSB and 100 kg ha^{-1} KCl (725.65%) Ekero et al. (2021).

2.2.2. Determinants of Adoption Decision and Intensity for Improved Technologies

Various studies (Tewodros *et al*., 2020; Mengistu & Degefu, 2021: Atinkugn, 2022) have been undertaken to explore the factors influencing farmers' decisions to adopt improved agricultural inputs and the extent to which they intensify their usage. However, the majority of improved agricultural technology adoption studies have primarily focused on identifying the determinants of adoption decisions, neglecting an in-depth analysis of the extent or intensity of technology adoption.

According to Akpan *et al*. (2012) family size, farm size, the price of fertilizer, farming experience, the value of crop output, the frequency of extension services, and livestock ownership emerged as significant factors affecting the probability of adopting fertilizer among farming households. These variables collectively shed light on the socio-economic and agricultural factors that play a crucial role in the decision-making process related to fertilizer utilization. He also confirmed that, the level of fertilizer application also affected by age, gender, farm size, purpose of crop production, the price of fertilizer, crop yield, livestock ownership, and distance to the fertilizer selling point were all statistically significant determinants of the intensity of fertilizer use. Amsalu and Alebachew (2021) indicated that technology adoption decisions were positively influenced by factors such as family size, gender, education level, and access to extension services. On the contrary, age and access to credit services exerted negative impacts on technology adoption decisions. Additionally, education level and access to extension services were identified as significant factors influencing the level and intensity of technology adoption.

Aman and colleagues (2022) the adoption decision variables like gender, education, off-farm income, land size, and improved seed were identified as positive determinants, while age and distance from the nearest market were negative determinants. In the second hurdle, assessing the use intensity of inorganic fertilizer, gender, family size, and land size were identified as positive influencers, while age and household distance from the nearest market had negative impacts.

The empirical estimates of the adoption decision, show that farming experience, distance to cooperatives, renting a tractor and combine harvester, urea application, and net income from wheat grain sales, as factors that significantly increased the likelihood of adopting improved wheat varieties. Interestingly, households with a female head were also found to have a higher probability of adoption compared to those with male-headed households. Factors such as seed availability, row planting practices, and proximity to cooperatives were identified as significant and positive influencers on the optimal intensity of improved wheat variety use (Bedilu *et al*., 2016).

In the study conducted by Biru (2016) identified several significant factors, including household size, livestock number, extension contacts, access to information media, and membership in farmer groups, which significantly influenced the decision to adopt organic fertilizer. The truncated regression, exploring the intensity of improved Tef technology use, revealed that farm income, size of the cultivated plot, membership in farmer groups, and application frequency of organic fertilizer were significant and positive influencers on farm households' intensity of using organic fertilizer.

Following the findings presented by Tewodros (2020), the study examined various factors, and the education status of the household head, family size, active labor force, access to extension services, access to credit, membership in cooperatives, distance to all-weather roads, average distance to farm plots, farm size, use of crop rotation, number of farm plots owned, annual gross income, and agro-ecology were all identified as significant variables affecting the household's decision to adopt fertilizer technology. Notably, all these variables had a positive impact on the decision to adopt fertilizers. However, family size, the average distance to farm plots, and the number of farm plots owned were identified as variables that negatively influenced the household decision for fertilizer use. The outcomes revealed that education status, family size, membership in cooperatives, use of crop rotation, annual income, number of farm plots owned, use of soil, access to credit, water conservation, and agro-ecology had significant effects on the level of fertilizer use. Importantly, education status and family size were recognized as factors exerting a negative influence on fertilizer adoption decisions.

In a broader context, studies conducted not only in Ethiopia but also in various countries have consistently affirmed that several variables play a significant role in influencing the adoption and intensity of agricultural technologies. These variables include age, gender, education level, family size, active labor force, livestock ownership, access to extension services, availability of credit services, cooperative membership, farm size, crop yield, input prices (fertilizer & improved seed), income from agricultural output, proximity to the nearest market, number of plot holdings, annual gross income, access to training, yield, off-farm income, distance to all-weather roads, average distance to farm plots, farm size, utilization of crop rotation, land ownership, knowledge of fertilizer use, and agro-ecology. Importantly, these variables can exert both positive and negative influences on the adoption and intensity of agricultural technologies.

2.3. **Theoretical Framework**

Studies conducted by Teame Hailemariam (2011; Sandile, (2020); Mengistu Ketema & Degefu Kebede (2021) investigating the determinants of technology adoption and use intensity often employ the Tobit, Heckman, and Double Hurdle models to estimate relationships with limited dependent variables.

The Tobit model assumes that the decision to adopt a particular technology and the amount of fertilizer used are determined by the same variables, *i.e.*, the size of the coefficient estimates for fertilizer use and use intensity are assumed to be one and the same (Cameron and Ktrivedi, 2009). Amsalu and Alebachew (2021) stated that Tobit model is also statistically restrictive because it assumes that the same set of variables determine both the probability of non-zero fertilizer use and intensity of use. The Heckman selection model offers an additional alternative for the analysis of adoption and use intensity in technology studies. The two-part model achieves flexibility and computational simplicity by assuming independence between its components, specifically the decision to use and the amount used. Nonetheless, the Heckman selection model would have been suitable if there had been sample selection bias (Heckman, 1979).

2.4. Conceptual Framework

The portfolios of agricultural technologies are available to farmers; their adoption has been constrained by several factors overtime. In the study areas, fertilizer adoption was among the highly promoted agricultural technologies to improve crop productivity. However, application of fertilizer at the recommended rate remains low due to some exogenous factors determining acceptance of this technology. These factors were classified into socio-economic factors and institutional factors and plot characteristics. These factors collectively contribute to shaping individual decisions regarding fertilizer use and level of use in agriculture. The interplay of these elements is complex, and understanding these dynamics is crucial for developing effective policies and interventions to promote sustainable and efficient fertilizer use in farming practices.

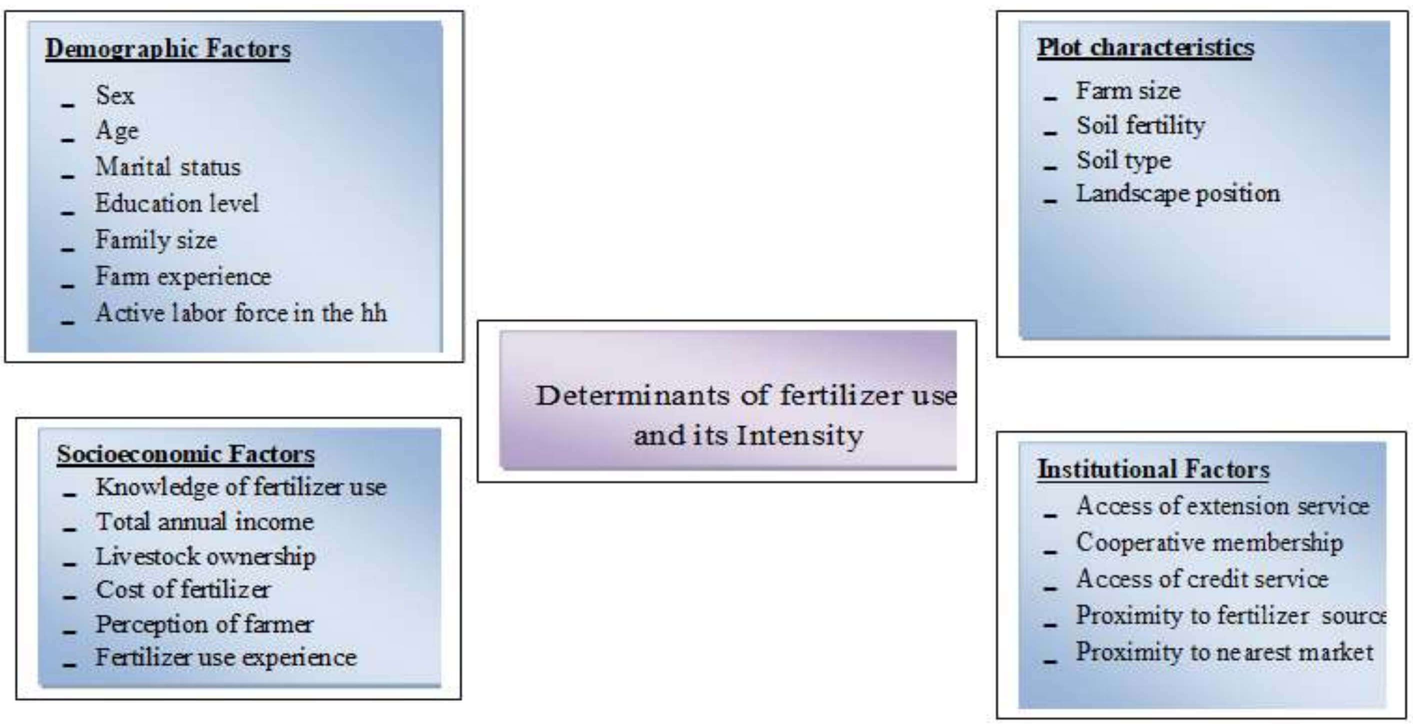

Figure 1: Conceptual Framework

Source: Own designed diagram, 2023 based on varies literatures review

CHAPTER THREE

3. RESEARCH METHODOLOGY

3.1. Description of the study areas

The study was conducted in the northeastern dryland parts of Amhara Region, specifically in three zones: Wag-himra, South Wollo, and Central Gonder zones. Like the other parts of the region more than 85 percent of farm the population depends on mixed farming system and agriculture is their priority source of livelihood (SDARC 2024, unpublished). Each zone was represented by Sekota, Tehuledere, and West Belesa districts respectively. The research primarily centered on performing fertilizer omission trials in 2020 cropping season.

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Sekota district located in the Wag-himra zone is one of the eight districts within the zone, comprising 25 kebeles. It is found approximately 720 km and 420 km distance from Addis Ababa and Bahir Dar respectively. According to the 2022 population projection available at www.citypopulation, the district has 134,790 total populations with 78.26 people per square kilometer. The district is geographically situated in the northeastern part of the Amhara region between $120^0\ 23'$ and $130^0\ 16'$ N latitude and $38^0\ 044'$ and $39^0\ 021'$ E longitude, within an altitudinal range of 1500–2200 masl (Adefress *et al*., 2000). The district experiences annual rainfall ranging from 350 to 650 mm (Kalayu *et al*., 2017). According to unpublished district agricultural report from the total area of the district only 19.65% of the land is currently cultivated land (unpublished report, 2023).

Tehuledere Woreda, found within South Wollo zone. The district includes "Dega" (13%), "Weina Dega" (72%), and "Kolla" (15%) agro-ecological zones (Mohammed, 2013).. Geographically located 430 km from Addis Ababa and covers a total area of 44,030 hectares.

The altitude of the woreda varies from 1488 to 2900 masl. Tehuledere Woreda is located at 11° 170’ N latitude and 39° 420 E longitude in the northeastern part of the Amhara region. The district has a mean annual rainfall of 1030 mm and an average temperature of 21 °C per year. The district has a total population of 152,891, making it the most populous district in the zone (Wassie et al., 2018).

West Belesa district is located the northeastern part of the Amhara region specifically in Central Gonder zone. It is far approximately 706 and 82 Km from Addis Ababa and Gondar town respectively. The district situated in the Tekeze lowland sorghum and goat livelihood zones and the topography is characterized with three distinct climatic zones of lowland (60%), midland (5%), and highland (35%) regions (Aragie, 2020). The district's coordinates are approximately 12°15’ N latitude and 37° 45 E longitudes, covering an altitudinal range from 1500 to 2000 masl (Tebabel *et al*., 2020). The mean annual rainfall falls within the range of 800 to 1200 mm and average temperature of 33.50 °C (CSA 2013, cited by Ahmed *et al*., 2022).

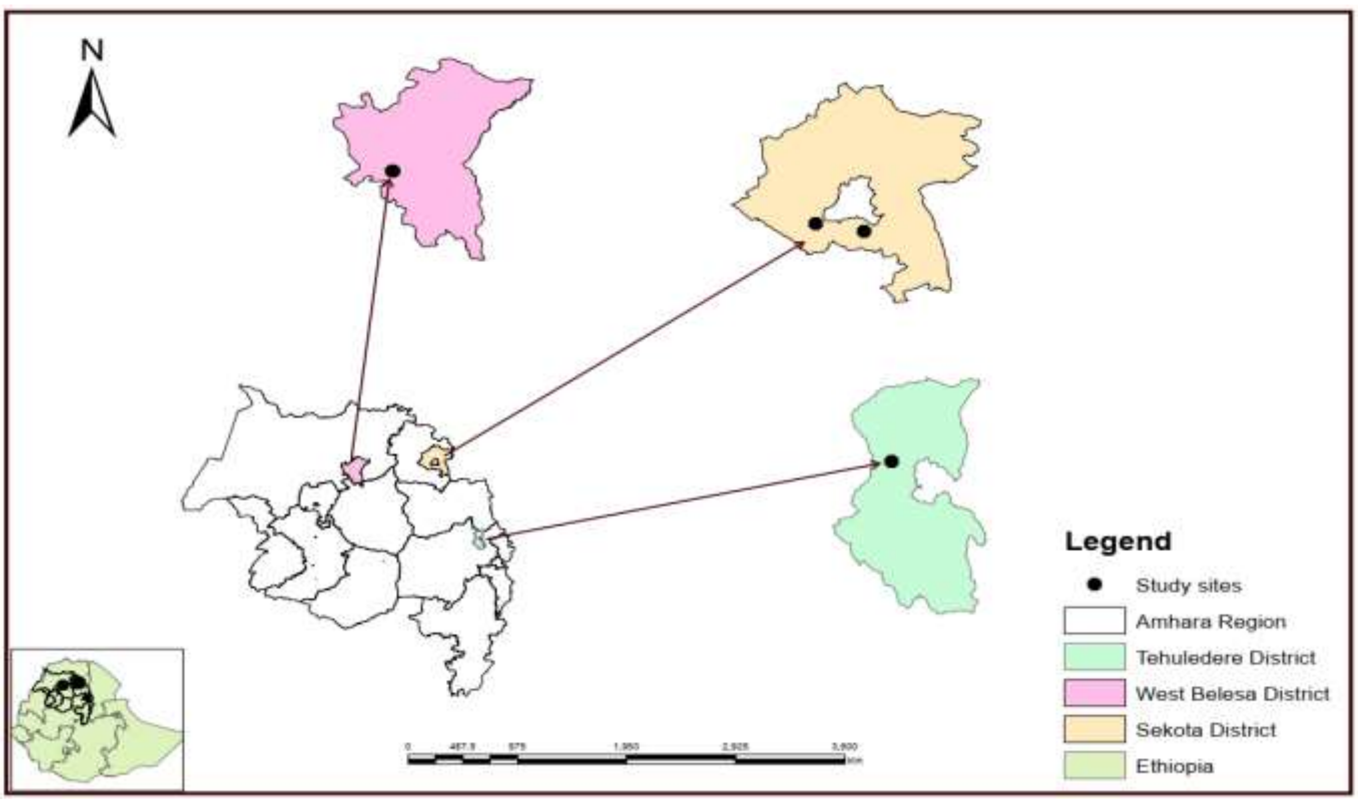

Figure 2: Location map of the study area

Source: survey data 2023

3.2. Sampling procedures and sample size

The sampling strategy focused on both fertilizer users and non-users, living in the same kebele and cultivating Teff and Sorghum crops. The process involved a multi-stage sampling procedure designed to collect data from a representative samples within the study areas. Initially, three zones (Wagihimra, North Wollo, and Central Gonder) and their corresponding districts (Sekota, Tehuledere, and West Belesa) were purposively selected. This selection was based on the fertilizer omission trials previously conducted in these areas. In the second stage, five kebeles were purposively selected from each district. This selection was also based on the locations where the fertilizer omission trials were conducted. Sample households were then stratified into two distinct groups: fertilizer-user households and non-user households. This stratification made to ensure proper representation from both stratums. Finally, 313 households were randomly selected from each stratum using a simple random sampling technique proportionally. This process aimed to select representative sample size fertilizer users and non-users of the study areas.

The total sampling frame was 1673 of Teff and Sorghum producer smallholder farmers at the time of the study in the study areas. From the total population, 1031 and 642 households are users and non-users from all districts and 192 and 121 samples were selected from each stratum. Sample size were determined using Kothari (2004) sample size determination formula based on the concept of estimating the sample size needed to achieve a desired level of precision (margin of error) and confidence. The formula is as follows:

$$n = \frac{Z^2.P.q.N}{e^2(N-1)+Z^2.P.q} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (1)$$

Where: n is the sample size, *Z* is the Z-value corresponding to the desired confidence level (1.96 for a 95% confidence level), *p* is the estimated population proportion (0.5), q is 1-p, *and N* is the population size.

$$n = \frac{(1.96)^2\ (0.5)(1-0.5)1673}{(0.05)^2(1673-1)+(1.96)^2\ (0.5)(1-0.5)} = \frac{1606.7492}{5.1404} = 312.6 \approx 313$$

Table 1: Sample size across districts from users and non-users

Districts	Population			Sample size calculated			Non-response sample	
	Users	Non-users	Total	Users	Non-users	Total Sample	users	Non-users
Sekota	351	225	576	65	42	107	-	6
West Belesa	349	194	543	62	40	102	-	1
Tehuledere	331	223	554	65	39	104	1	1
Total	**1031**	**642**	**1673**	**192**	**121**	**313**	**1**	**8**

From the total sample of 313 households, which comprised one user and eight non-user, a total of 9 samples that were not collected correctly (equivalent to a 2.875% non-response rate) were rejected from the data analysis. Consequently, data from 304 samples were utilized for the data analysis.

3.3. Method of Data Collection and Sources

In this research, both qualitative and quantitative data were collected from primary and secondary data sources. Two primary data sources were used for this study: the first data source is data from NOTs collected by soil fertility researchers for the purpose of economic analysis to get insights on the economic implications of fertilizer treatments. The second primary data source were survey data collected using questionnaires and checklists from farmers, for the analysis of determinants of fertilizer use and its intensity, and farmers willingness to pay (WTP) for NP fertilizer.

Individual interviews and focus group discussions (FGD) were the principal methods for data collection, using closed-ended questions for individual interviews and open-ended checklists for FGD. Before the main survey, training was delivered to enumerators and pre-tests were conducted to scrutinize the consistency and relevancy of questions to the survey instruments. The final edition was made based on pre-test feedback and after finalization of the questionnaire; the main survey was carried out from January to February 2023 under the careful supervision of the researcher to ensure the quality and reliability of the collected data. Secondary data were collected from both published and unpublished documents, including books, reports, and working papers from various institutions.

3.4. Methods of Analysis

The analysis of the collected data involved employing various statistical techniques; both descriptive and inferential statistics, plus the application of econometric models such as seemingly unrelated probit model and the double hurdle model. The analytical procedures were conducted using Stata software.

3.4.1. Descriptive and Inferential Statistics

Descriptive Statistics: The data analysis involved the utilization of descriptive statistics, specifically focusing on measures of central tendency such as the mean, and measures of dispersion, including the standard deviation. These statistical methods were employed to provide a detailed description of the basic features of socioeconomic data, offering a comprehensive summary of the demographic characteristics of the households under study.

Inferential analysis: The analysis involved the application of an independent t-test to compare mean values of continuous variables between two groups, namely those who are willing and not willing, as well as fertilizer users and non-users. Additionally, the chi-square test was employed to analyze dummy data, encompassing nominal and categorical data. This test aimed to determine if a significant difference existed between the observed and expected frequencies, with both types of frequencies considered in the computation of the chi-square statistic (Ruth, 2011).

The economic evaluation, which involved partial budget analysis with dominance and marginal analysis, followed procedures outlined by CIMMYT (1988). According to CIMMYT (1988), partial budget analysis is used to organize experimental data and evaluate the costs and benefits associated with various alternative treatments. In the assessment of fertilizer treatments, this approach was applied. Costs that were consistent across all treatments, such as plowing, planting, weeding, and seed costs, were assumed to be constant (citrus paribus) for all experimental data. The term "partial budget" is indicative that not all production costs are included in the budget; only those influenced by the alternative treatments under consideration are taken into account. Variable costs of inputs and gains of outputs were derived from market prices of inputs at planting time and the farm's price for outputs. All costs and benefits were calculated on a per-hectare basis in Ethiopian Birr (ETB/ha). The calculation of MRR offers a quantitative measure of the economic incentives linked to each treatment, providing valuable insights for decision-makers and farmers. To further evaluate the economic viability of each treatment, the MRR was calculated using the following formula:

$$MRR = \frac{\triangle NB}{\triangle TVC} x100 \tag{2}$$

Where: MRR is the marginal rate of return, NB is the net benefit, TVC is a total variable cost

3.4.2. Econometric Models

The econometric analysis includes the Double Hurdle Model to analyze determinants of farmers' fertilizer users and its intensity. A seemingly unrelated bivariate probit model was also applied to determine the mean willingness to pay for the recommended fertilizer using STATA Software.

3.4.2.1. Determinants of Smallholder Farmer's Fertilizer Use Decision for Major Crops

The double-hurdle model was selected for this study because it accommodates the distinction between the determinants of the decision to use fertilizer and the amount of fertilizer used across two distinct stages. The double hurdle model is used when there are two decision processes involved in determining the outcome.

The Double Hurdle model, initially formulated by Cragg (1971), is a modeling approach that posits a two-step decision process. In this model, it is assumed that there is no selectivity bias, effectively addressing issues of dual endogeneity and heteroscedasticity between the decision to adopt and the use intensity of organic fertilizer (Bhekani, 2020). This modeling framework assumes that farm households encounter two hurdles in their agricultural decision-making process: first, the decision to use, and subsequently, the decision regarding use intensity (amount of use).

The double hurdle modeling procedure involves the utilization of probit regression and truncated regression models to discern factors influencing the decision to use fertilizer from all samples in the initial stage. Subsequently, in the second stage, the analysis focuses on the use intensity of fertilizer for the subset of the sample that successfully passed the first hurdle. In this study, the first stage of the double hurdle model was employed to investigate the factors influencing the decision to adopt fertilizer, employing probit regression. Equation (2) denotes the initial stage of the Double Hurdle model deals with the decision of fertilizer adoption (Cragg, 1971).

$D_i = Z'_i\,\alpha + u_i,\ u_i \approx N(0,1)$ -(3)

$D_i^* = Z'_i\,\alpha + u_i$, where Di =1 if $D_i^* > 0$, 0 otherwise

Where; i = 1, 2, 3, …n, Y^*_i is the latent (unobservable) variable for the decision to adopt fertilizer, X_i is a vector of coefficient estimates for explanatory variables that were hypothesized to influence the decision to adopt fertilizer, β is a vector of parameters, and V_i is an error term (random and normally distributed with a zero mean and constant variance). D_i is the observable decision made by the ith smallholder farmer to adopt inorganic fertilizer. Therefore, D_i = 1 if the respondent has adopted fertilizer and *Di* = 0 otherwise.

The second stage of the double-hurdle model involves applying a truncated regression model to estimate the intensity of fertilizer use. This stage is crucial for determining the level or extent of organic fertilizer use among respondents who reported using it. According to Greene (2002), this intensity equation is a truncated regression part of the model.

$Y^*_i = \beta x_i + V_i,\ V_{i \approx N(0,\delta^2)}$ . . . . (4)

$Y_i = Y^*_i$ if $Y_i^* > 0$ and $D_i > 0$, Yi= 0 otherwise

Where, Y^*_{i2} represents the intensity of inorganic fertilizer usage, which depends on the latent variable Y^*_{i1} being greater than zero and conditional on the decision to use D_i fertilizer. X_i is the vector of explanatory variables hypothesized to determine the intensity of inorganic fertilizer usage, and Y_i is the intensity of inorganic fertilizer usage, which depends on the latent variable $Y*_i$ being greater than zero and conditional on the decision to use D_i fertilizer, β refers to unknown parameters to be estimated in the model, and V_i is respective error terms assumed to be independent and distributed. According to Cragg, (1971), assuming that the error terms are independent, the log-likelihood for the double-hurdle model is given by the following expression:

$$\mathrm{LogL_{DH}} = \sum\nolimits_0 [1 - \Phi\,(Z'\mathrm{i}\,\alpha)] + \sum\nolimits_+ [\Phi(\alpha_i X_i)\,\frac{1}{\sigma}\,\emptyset\left(\frac{y_i - \beta X_i}{\sigma}\right)] \text{. . . . . (5)}$$

Where: Φ is the standard normal cumulative distribution function, and Ø is the density function.

The log-likelihood function comprises two components: the first part (on the left-hand side) pertains to the probit, while the second part (on the right-hand side) relates to the truncated regression with truncation at zero. In the initial stage, a household chooses the adoption of a specific new practice or technology. Subsequently, the level or intensity of adoption is determined based on the farmer's decision to adopt (Nazziwa *et al*., 2017). In the context of adopting fertilizer, farmers initially decide whether to use it or not. Following this decision, the second stage determines the extent or quantity of fertilizer (kg ha^{-1}) used.

To corroborate the choice of using the DH model, the log-likelihood values generated from an individual estimation of the Probit, Truncated and Tobit regression models were used to conduct a restriction test using the likelihood ratio test statistic shown in the equation (Greene, 2002). To validate the decision to employ the DH model, log-likelihood values obtained from individual estimations of the probit, truncated, regression models were utilized to perform a restriction test. This involved using the likelihood ratio test statistic, as indicated in the equation (Greene, 2002).

$$\Gamma = -2\,[ln_{LT} \; - (ln_{LP} + ln_{TR})] \sim \chi^2 k \ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

Where: L_T = likelihood for the Tobit model with the same coefficients

L_P = likelihood for the Probit model, fit separately

L_{TR} = likelihood for the truncated regression model, fit separately

If the likelihood ratio test statistic (Γ) surpasses the appropriate chi-square critical value, it implies the rejection of the Tobit model (Martey *et al*., 2014), making the DH model more suitable. In the presence of sample selection bias, the Heckman selection model could have been considered. To tackle this issue, Heckman initially estimates the selection equation using the Probit model and then incorporates the correction factor (the Inverse Mills Ratio [IMR] calculated from the Probit model) into a second stage of the Ordinary Least Squares (OLS) regression (Adem, 2023). The findings from the Heckman selection model in this study indicated that the IMR was statistically insignificant, suggesting the absence of sample selection bias. Therefore, the Heckman selection model was deemed inappropriate.

3.4.2.2. Farmers WTP for Recommended Fertilizer use

The seemingly unrelated probit regression model is well-suited for the estimation of the parametric Mean Willingness to Pay (MWTP) for fertilizer use (Francesco *et al*., 2004; Kidane *et al*., 2020; Tilahun & Tadesse, 2022). This model is utilized to clarify the willingness to pay, assuming that the two decisions in the double-bounded format and their associated error terms are interconnected, thereby enhancing the efficiency of estimation.

In the double-bounded dichotomy modeling approach, sampled farmers are presented with a two-tiered bid. The response to the subsequent bid depends on the reply to the first bid, with the respondent farmer either accepting or rejecting the initial bid based on the utility derived from different scenarios. The appropriate econometric model for estimating the Mean Willingness to Pay (MWTP) for double-bounded data is structured as follows (McConnell & Haab, 2014).

$$WTP_{ij} = \mu_{ij} + \varepsilon_{ij} \text{------------------------------} (7)$$

Where: WTP_{ij} is the jth respondent WTP to fertilizer use and i = 1, 2 represents first and second answers of the respondent, μ_i = mean value for the first and second answer and ε_{ij} = unobservable random factor.

Following the methodology proposed by Haab and McConnell (2002), constructing the likelihood function involves first calculating the probability of observing each potential two-bid response sequence (yes-yes, yes-no, no-yes, no-no). For instance, the probability that respondent j responds "yes" to the first bid and "no" to the second bid can be formulated as:

$P(\text{yes, no}) = P(WTP_{1j} \geq \beta^1, WTP_{2j} < \beta^{2)} \Rightarrow P(\mu_1+\varepsilon_{1j} \geq \beta^1, \mu_2 +\varepsilon_{2j} < \beta^2)$

$P(\text{yes, yes}) = P(WTP_{1j} > \beta^{1,} WTP_{2j} \geq \beta^2) \Rightarrow P(\mu_1+\varepsilon_{1j} > \beta^1, \mu_2 +\varepsilon_{2j} \geq \beta^2)$

$P(\text{no, yes}) = P(WTP_{1j} < \beta^{1,} WTP_{2j} \geq \beta^2 \Rightarrow P(\mu_1 +\varepsilon_{1j} < \beta^1, \mu_2 +\varepsilon_{2j} \geq \beta^2)$

$P(\text{no, no}) = P(WTP_{1j} < \beta^{1,} WTP_{2j} < \beta^2 \Rightarrow P(\mu_1 +\varepsilon_{1j} < \beta^1, \mu_2 +\varepsilon_{2j} < \beta^2)$

Where: β^1 = first bid price, β^2 = second bid price

The jth contribution to the likelihood function becomes

$Lj(\mu/t=pr(\mu_1+\varepsilon_{1j} \geq \beta^1, \mu_2 +\varepsilon_{2j} < \beta^2)^{YN}$ where: -YN=1 for yes-no, 0 otherwise

$P(\mu_1+\varepsilon_{1j} > \beta^1, \mu_2 +\varepsilon_{2j} \geq \beta^2)^{YY}$ -YY=1 for yes-no, 0 otherwise

$P(\mu_1 +\varepsilon_{1j} < \beta^1, \mu_2 +\varepsilon_{2j} \geq \beta^2)^{NY}$ -NY=1 for yes-no, 0 otherwise

$P(\mu_1 + \varepsilon_{1j} < \beta^1, \mu_2 + \varepsilon_{2j} < \beta^2)^{NN}$ - NN=1 for yes-no, 0 otherwise

The formula set above (bivariate discrete choice model) assumes normally distributed error terms with a mean of zero and respective variances σ_1^2 and σ_2^2, then WTP_{1j} and WTP_{2j} have a bivariate normal distribution with means μ_1 and μ_2, variances σ_1^2 and σ_2^2, and correlation coefficient ρ. The j^{th} contribution to the bivariate Probit likelihood function is given as:

$$Lj(\mu/t = \emptyset\varepsilon_1\varepsilon_2((d_{1j}\left(\frac{t_1-\mu_1}{\delta_1}\right), d_{2j}\left(\frac{t_1-\mu_1}{\delta_2}\right), d_{1j}d_{2jp} \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Where: $= \emptyset\varepsilon_1\varepsilon_2$the bivariate normal cumulative distribution function with zero means

Y_{1j} =1 if the response to the first question is yes, and 0 otherwise, Y_{2j} =1 if the response to the second question is yes, and 0 otherwise, ρ = correlation coefficient and δ = standard deviation of the error. After running a regression of the dependent variable (yes/no indicator), depending on the normality assumption of WTP distributions, the mean WTP value is determined as follows:

$$MWTP = \mu = \frac{-\alpha}{\beta} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

Where: MWTP = the mean willingness to pay for fertilizer use; α = coefficient for constant (intercept) term, β is the coefficient of the “bid” value posed to the respondent in the seemingly bivariate probit model. The dependent variables used in the models are described in Table 1.

3.4.2.3. Operational definitions

Fertilizer: in this research context, fertilizer indicates inorganic fertilizer only.

Major cereal crops: in this research context, cereal crops mean Teff and Sorghum crops produced by farmers living in the study areas.

Economic incentive: the economic incentive of fertilizer use for major cereal crops refers to the financial motivations and benefits that encourage farmers to invest in and apply fertilizers to cultivate crops like cereals.

Users: Fertilizer users are individuals or farmers who have actively incorporated fertilizers into their farming routines.

Non-users: are individuals or farmers who have not incorporated the use of fertilizers into their farming practices.

Economic valuation: in this research context it means assigning a monetary value for NP fertilizer it is not in the market nowadays.

Dependent variable

WTP bids: It is a binary variable indicating an individual's decision regarding the highest price they are willing to pay for the existing bid and/or the higher/lower bid for the recommended fertilizer (Endalew *et al*., 2018). This variable signifies households' willingness to pay a specific amount for the NP fertilizer. The dependent variables of the model, denoted as Y_1 and Y_2 for Bid_1 and Bid_2, respectively, are both dichotomous, representing whether a household is willing (assigned the value 1) or not willing (assigned the value 0) in each case.

Adoption decision (Yi): It is a binary outcome dependent on the factors influencing smallholder farmers' decisions regarding fertilizer use. If the farmer applied fertilizer, Y_i =1; if not it = 0.

Intensity of Adoption: the extent of inorganic fertilizer use by the respondents who are reported as fertilizer users.

Independent Variables

Age: it is a continuous variable, reflecting the age of the farmer. Existing studies (Tsehaye, 2008; Palmas and Chamberlin, 2020) suggest that as farmers age increase, they tend to be less likely to adopt new technologies. Hence, we hypothesis that an increase in the farmer's age resulted in decrease of using fertilizer.

Experience: it is the continuous variable and it signifies the farming experience of the household head, measured from the time when they began farming. The hypothesis posits that greater farming experience correlates with a higher likelihood of adopting new agricultural inputs like improved seed and fertilizer (Dabessa *et al*., 2021).

HH's active labor force: it is a continuous variable representing the count of family members capable of engaging in agricultural activities (age > 15 years). The hypothesis suggests that a larger number of active family labor forces is associated with the adoption of improved agricultural technologies (Assefa *et al*., 2021). Thus, the hypothesis posits that a higher number of active family labor forces contributes to an increased use of fertilizer.

Education level: this variable represents the educational attainment of the household head, measured on a continuous variable. The hypothesis suggests that farmers with higher levels of education are more likely adopt new farming practices (Dabessa *et al*., 2021).

Income: this variable is a continuous measure indicating the income level of the household. Various studies have corroborated that households with better access to income opportunities are more inclined to adopt new agricultural technologies (Wilfred, 1996; Kelly and Naseem, 2003). Consequently, the hypothesis suggests that farmers with higher income levels are more likely to use fertilizer.

Livestock Holding (TLU): This variable is a continuous measure representing the livestock ownership of farm households. Farmers keep livestock for farming activities, selling them during poor crop harvests, repaying debts, or purchasing agricultural inputs to enhance crop output (Biru, 2016; Assefa *et al*., 2021). The hypothesis posits that households with a higher number of livestock are likely to use more fertilizer.

Land Size: it is a continuous variable and measured in terms of hectares per household. The large farm area needs more resources and greater capacity to invest in farmland, purchase inputs, and have the confidence to take risks in adopting new technologies. Therefore, farmers who have relatively more farmland are hypothesized to be more likely to be fertilizer users (Tewodros, 2020).

Plot slop: this categorical variable indicates the slope of the farmland owned by the household. An increase in the slope of the farmland is likely to lead to a decrease in the household's fertilizer use. Thus, we can hypothesize that the slope of the farmland has a negative effect on the household's utilization of fertilizer (Tewodros, 2020.

Soil fertility: this categorical variable represents the fertility of the farmland owned by the household. If farmers have relatively fertile farmland, they might be less inclined to use fertilizer. Therefore, it is hypothesized that the more fertile the soil, the lower the likelihood of fertilizer use by the household.

Extension service: this dummy variable indicates the access of households to extension services. Extension services are a crucial means of disseminating new technological information to farmers. It is hypothesized that farmers who receive frequent extension services are more likely to use fertilizer compared to those who do not (Ishara *et al*., 2023.

Credit Service: this dummy variable indicates households' access to credit for their agricultural activities. Small farmers often encounter cash constraints when purchasing new inputs for their plots. Thus, it is anticipated that households with access to credit for agricultural activities are more likely to be positively influenced in their decisions to use fertilizer (Deresse and Tekilu 2019).

Cooperative membership: this is a dummy variable indicating the cooperative membership status of the household. It is expected that households with access to cooperative membership will have more information and higher access to new technologies. Therefore, it can be hypothesized that cooperative membership increases the likelihood of households making fertilizer use decisions (Biru 2016).

Training: this is a dummy variable indicating the training access of the household on fertilizer use. Proper training can encourage farmers to use more fertilizer. Therefore, it is hypothesized that farmers who receive more training in fertilizer use are more likely to use fertilizer (Tesfaye 2008).

Table 2: Definition, measurement, and the hypothesis of variables

Variable	Type Variables	Definition and measurement	Values	Hypothesis
Outcome Variables				
WTP Bids	Dummy	HHs Willingness to Pay for the use of fertilizer	1=Yes, 0=otherwise	
Adoption Decision	Dummy	HH decision to fertilizer use	1=Yes, 0=otherwise	
Intensity of fertilizer	Continuous	Amount of fertilizer used by households	Kg/Ha	
Explanatory Variables				
1) Household characteristics				
Age	Continuous	Age of the household head (years)	Years	−
Sex	Dummy	The sex of the household head	1=Male, 0 = Female	+/-
Education	Continuous	The education level of the household he	Years of schooling	+
Family Size	Continuous	Number of household family who live under	Number	+/-
Experience	Continuous	Farm experiences of the household head	Years	+
Livestock Ownership	Continuous	Number of livestock owned by the household	Number in TLU	+
2) Farm and Plot characteristics				
Land size	Continuous	Total area of the plots managed by the household	Area in hectare	+

Plot slope	Dummy	Slope of the plot cored by Teff and/or Sorghum	1=Steep/hill slop, **2**=Mid slop, 3=Flat/no slop	-
Soil fertility	Ordinal	Soil fertility of the plot covered by Teff and/or Sorghum	1=Good, 2=Medium, 3=Poor	+
Soil type	Dummy	Soil type of the plot covered by Teff and/or Sorghum	1=Black, 2=Red, 3= Sandy, 4=Sandy loam	+/-
3) Socioeconomic variables				
Extension access	Dummy	Extension access of the household head	1=Yes, 0 otherwise	+
Coop. membership	Dummy	Cooperative membership of the household head	1=Yes, 0 otherwise	+
Credit access	Dummy	Credit access of the household head	1=Yes, 0 otherwise	+
Cost of fertilizer	Continuous	Average fertilizer price	Birr	+
Distance to market	Continuous	The distance to market the HH from	Minutes walked	+
Distance to input center	Continuous	The distance to a source of the HH from	Minutes walked	+
Income of HH	Continuous	Total annual income of the household in the year	Birr	+
Perception	Ordinal	Farmers perception of fertilizer use (Lik scale)	1=Strongly dis-agree, 2=dis-agree, 3= Neutral 4=Agree 5=Strongly agree	+
KFA	Dummy	Knowledge of fertilizer application	1) Yes 0) No	

CHAPTER FOUR

4. RESULT AND DISCUSSION

The following section outlines the research findings, revealing the outcomes derived from partial budget analysis applied to the experimental data of NOTs, and employing descriptive statistics, inferential statistics, and econometric analysis for the survey data.

For the experimental data, a partial budget analysis was conducted to evaluate the economic feasibility of the treatments (NOTs). This analysis allowed us to evaluate the economic implications of the experimental variables, providing valuable insights into their effectiveness. Initially, descriptive statistics were employed to provide a comprehensive overview of the key characteristics and trends within the survey dataset. Subsequently, inferential statistics were utilized to draw meaningful inferences from different variables, shedding light on potential patterns and relationships. Furthermore, econometric analysis was applied to the survey data, employing advanced models to discern the underlying relationships and causal factors. This method facilitated a deeper understanding of the determinants of fertilizer use and intensity.

4.1. Economic Analysis for Experimental Data

The statistical analysis of yield data has conclusively confirmed a significant difference among experimental locations at $p < 0.01$ level of significance. This indicates that the yields, measured in Kg ha^{-1}, exhibit substantial variation across the different districts. Consequently, it is strongly recommended to undertake separate economic analyses for each district, recognizing and accounting for the distinct contribution of fertilizer treatments on crop yields in each location. The partial budget analysis with the dominance analysis and marginal rate of return carried out for the experimental data has shown an important influence of nutrient omission trials on net benefits for Teff and Sorghum crops. The All-B and 150% (All+K) treatments for Teff resulted in the highest net benefits at 106628.9, 118019.98, and 121531.50 Ethiopian Birr (ETB) per hectare in Sekota, Tehuledere, and West Belesa, respectively. For Sorghum, the NP, All, and 50% (All+K) treatments showed the highest net benefits at 53,573.42, 38,533.01, and 107,122.199 ETB per hectare from Sekota, Tehuledere, and West Belesa. Different treatments demonstrated significant economic returns per hectare, emphasizing the importance of using fertilizer to improve crop productivity and income.

The treatments All, NP, All-S, All+K, and 150% (All+K) were found to be the most cost-dominant for Teff and Sorghum across all districts. These dominant treatments were not further analyzed for the marginal rate of return (MRR), focusing instead on economically beneficial options. The other non-cost-dominant treatments were subject to MRR analysis to evaluate the balance between costs and benefits.

The All-B treatment achieved the highest MRR at 799.93% and 100.36% in Sekota and West Belesa, while the 50% (All+K) treatment resulted in a 29.36% MRR in Tehuledere districts for Teff. Additionally, for Sorghum, the All-B treatments yielded MRR values of 62.46%, 46.72%, and 37.88% in Sekota, Tehuledere, and West Belesa districts, respectively. These MRR calculations offered valuable insights into the economic efficiency of specific treatments, assisting in informed decision-making for optimal resource allocation and agricultural practices (Appendixes 1, 2, and 3).

In general, the economic analysis underscores the variability in optimal treatments across districts and crops, highlighting the importance of tailoring agricultural practices to specific conditions. Dominance analysis and MRR calculations offer valuable insights for decision-makers and farmers, facilitating informed choices based on district and crop-specific conditions and goals.

4.1. Descriptive results

Of the total samples, 62.82% were fertilizer users, and 37.18% were non-users. The inferential analysis, specifically the independent t-test, demonstrated that there is no significant difference between user and non-user households in terms of education status. In summary, while there is a notable percentage of illiterate households in both user and non-user categories.

The presented data in Table 3 indicated that a noteworthy correlation between cooperative membership and fertilizer use decisions among smallholder farmers. Specifically, 80.10% and 68.14% of fertilizer users and non-users respectively are cooperative members, highlighting a significant difference in fertilizer adoption rates between the two groups. Contrastingly, regarding credit access, the chi-square test suggested that there is no significant relationship between credit availability and fertilizer adoption decisions. Despite 86.39% and 84.96% of adopters/users and non-adopters/users having credit access, and 13.61% and 15.04% have not credit access. This means credit access does not influence fertilizer use decisions significantly.

In terms of extension services, the data reveals a significant association with fertilizer use decisions. With 85.34% of users having access to extension services compared to only 37.17% of non-users, it implies that the provision of extension services plays a crucial role in promoting fertilizer users among smallholder farmers. Furthermore, the knowledge of fertilizer application is identified as a key determinant in fertilizer user decisions. A substantial 72.77% of users possess knowledge about fertilizer application while only 11.50% of non-user shares this knowledge. This discrepancy suggests that a farmer's understanding of fertilizer application significantly influences their adoption of fertilizers.

In summary, cooperative membership, extension services, and knowledge of fertilizer application are a significant factors impacting fertilizer use decisions among smallholders.

Table 3: summary of dummy variables (n=304)

S.N	Variables	Users		Non-users		Chi-square value
		Freq.	**%**	**Freq.**	**%**	
1	Education Status of household					0.240
	Illiterate	91	47.64	61	53.98	
	Read & write	27	14.14	9	7.96	
	Grade 1-4	16	8.38	11	9.73	
	Grade 5-8	36	18.85	20	17.70	
	Grade 9-12	21	10.99	10	8.85	
	Diploma & above	-	-	2	1.77	
2	Cooperative membership of household					0.019
	Yes	153	80.10	77	68.14	
	No	38	19.90	36	31.86	
3	Credit Access to household					0.729
	Yes	165	86.39	96	84.96	
	No	26	13.61	17	15.04	
4	Extension Service of household					0.000
	Yes	163	85.34	71	37.17	
	No	28	14.66	42	62.83	
5	Knowledge of fertilizer application					0.000
	Yes	139	72.77	13	11.50	
	No	52	27.23	100	88.50	

Source: own survey data 2023

Table 4 shows various characteristics of smallholder farmers, comparing fertilizer users and non-users. The average age of household heads for users and non-users is 44.5 and 45 years respectively with standard deviations of 11.4 and 15 years. The statistical analysis indicated no significant age difference between the two groups. Regarding farm sizes, fertilizer users have an average farm size of 1.426 hectares while non-users have an average of 1.272 hectares. However, the difference in means is not statistically significant. Similarly, the average farming experience is 24.43 and 25.15 years for users and non-users with standard deviations of 11.46 and 14.19 years respectively show that no significant mean difference between the two groups. In terms of livestock ownership, fertilizer users have an average of 5.098 Tropical Livestock Units (TLU), while non-users have an average of 4.096 TLU. The standard deviations are 3.45 and 2.58 respectively and there is no significant mean difference between the two groups for this variable. In summary, the analysis of the data in Table 4 indicated that there is no statistically significant difference in mean values between fertilizer adopters and non-adopters for all variables.

Table 4: Summary of continuous variable (n=304)

Variable	Adopters (191)		Non-adopters (113)		P-value
	Mean	*Std. Dev.*	*Mean*	*Std. Dev.*	
Age of the household	44.471	11.403	44.885	15.005	0.6420
Family size	5.393	1.737	4.858	1.917	0.6422
Active labor force	2.969	1.1648	2.885	1.223	0.7822
Farm experience	24.728	11.457	25.150	14.188	0.7358
Livestock ownership (TLU)	5.098	3.445	4.096	2.582	0.7412
Distance Input	49.162	29.626	51.903	32.094	0.2719
Distance to FTC from residence	36.518	28.829	35.973	28.503	0.4784
Distance to the market	85.052	42.55	85.221	40.33	0.5543
Number of plots owned	2.435	0.897	2.301	0.915	0.8483
Farm Size	1.426	0.762	1.272	0.694	0.7986
Annual Income from Crop	60718.429	21246.761	60336.212	22963.263	0.9278
Annual off-farm income	3732.618	8994.71	3250.442	10048.784	0.6042

Source: own survey data, 2023

4.2. Willingness to pay for recommended NP fertilizer

After pre-testing the questionnaire with some initial hypothetical bids and matching it with the actual price; the initial price of NP fertilizer was estimated to be 34.31ETB/Kg. The respondents were asked either to answer "Yes" or "No" to the initial bid. If the answer is

“Yes” the initial amount would increase by adding half of the initial bid (51.57) ETB/Kg; while the respondent says "No" the initial bid price was halved (17.16) ETB/Kg. After the farm households responded to the yes/no question they were requested their maximum willingness to pay using an open-ended question format to state the maximum amount for the “Yes” response and the minimum amount for the “No” response they were able and WTP.

Following the omission trials experiment and the analysis of biological data NP fertilizer emerged as the optimal alternative. NP fertilizer served as the positive control, and statistically, there were no significant yield differences between NP fertilizer and other types of nutrients added to NP fertilizer. In essence, this suggests that incorporating additional nutrient types alongside NP fertilizer does not significantly enhance yields, reinforcing the efficacy of NP fertilizer as the optimal choice. The survey included the binary question "Willingness to Pay" for the recommended NP fertilizer. The findings indicate that approximately 96.71% of the respondents expressed their willingness to pay for the recommended fertilizer (Table 5). These high percentages underscore a strong positive inclination among the respondents towards both accepting and financially supporting the use of the recommended NP fertilizer.

Table 5: Summary of farmers' responses for willingness to pay questions

Questions	***Binary Response***	***WTP***	
		Freq.	***Percent***
Are you willing to pay for the NP fertilizer?	No	10	3.29
	Yes	294	96.71
	Total	304	100.00

Source: own survey data 2023

As previously mentioned, approximately 97% of respondents expressed their WTP for the NP fertilizer. Further analysis using discrete choice responses revealed that 53.29% of respondents answered "yes" to the first bid values. This suggests that 46.71% of respondents had a value below the initial bid amount. For those who responded affirmatively to the first bid, a follow-up question was presented. Of those respondents, 16.67% answered "yes" to the second bid. This indicates that around 83.33% of respondents had chosen either the starting bid or some value between the initial and follow-up bid amounts offered. Table 6 provides a visual representation of these percentages, with the initial section displaying the percentages of "no" responses, followed by the percentages of "yes" responses. This information sheds light on the distribution of respondent choices and their valuation of the NP fertilizer.

Table 6: Binary responses for questions of 1st and 2nd bid of farmers WTP (n=304)

Binary Response	WTP for 1st bids		WTP for 2nd bids	
	Frequen	Percent	Frequency	Percent
No	142	46.71	127	83.33
Yes	162	53.29	35	16.67
Total	304	100	142	100

Source: own survey data (2023)

The binary responses revealed that, within the total sample of households, 11.51% of respondents accepted both the 1st and 2nd bids. Conversely, 8.88% of the total respondents did not accept any bids. The majority of respondents, comprising 41.78%, accepted only the 1st bid, while 37.83% accepted only the 3rd bid (Table 7). This data implies that more than 53.29% of respondents were willing to pay a value above the 1st bid, encompassing those who accepted both the 1st and 2nd bids as well as those who accepted only the 1st bid. The findings provide insights into the varying preferences among respondents regarding their willingness to pay for the recommended fertilizer, with a notable portion showing a preference for bids beyond the initial offer.

Table 7: Binary Responses in YY, YN, NY and NN (n=304)

Binary Responses	Freq.	Percentage
Response to WTP_1st = YES; Response to WTP_2nd = YES (Yes Yes)	35	11.51
Response to WTP_1st = YES; Response to WTP_2nd = NO (Yes No)	127	41.78
Response to WTP_1st = NO; Response to WTP_2nd = YES (No Yes)	115	37.83
Response to WTP_1st = NO; Response to WTP_2nd = NO (No No)	27	8.88

Source: own survey data (2023)

Households that expressed unwillingness to pay (UWTP) for the newly recommended fertilizer cited reasons such as a lack of confidence, concerns about affordability, and trust in the effectiveness of their current fertilizer. Conversely, those willing to pay the maximum bid value believed in the superior crop productivity potential of the newly recommended fertilizer compared to the existing one. Additionally, they held the belief that the recommended fertilizer had the potential to enhance the soil fertility status of their plots. These reasons highlight the crucial role of perceived effectiveness, affordability, and confidence in shaping households' decisions regarding their willingness to adopt and pay for the newly recommended fertilizer.

Table 8: The reasons of respondents to pay more and/or less for the fertilizer

Reasons for higher payment	**Frequency**	**Valid Percent**
Improve my crop productivity	47	83.9
Improve soil fertility	9	16.1
Total	56	100.0
Reasons for lower payment		
Lack of confidence in this fertilizer	13	13.1
Happy about the existing fertilizer	3	3.0
Cannot afford the price	83	83.8
Total	99	100.0

Source: own survey data (2023)

4.2.1. Independent t-test of continuous variables Related to Farmers' Characteristics

A test of significance was made for the continuous variables to check whether the willing and not willing households for each variable had statistically significant mean differences or not. The variables family size, livestock ownership, fertilizer use experience, number of plots owned and land holding in hectare have a significant mean difference between the two groups for the first bid values.

As presented in (Table 10) below indicated that the result of the t-test shows that the average age of the sampled farmers was 44.625 years. Statistically, there is no significant mean difference between willing and not willing sampled households. The results also indicated that the not willing households have a statistically lower family size than willing farmers at a $p<0.1$ significance level. However, willing households have more active labor force families than not willing households but statistically, there is no significant difference in active labor force in family members (family members >15 years old) between willing and not willing households.

The analysis also reveals that the average grade level of education attained by the farm household heads is approximately three. The statistical findings indicate that there is no significant difference in the education levels of respondents between the two groups, namely the willing and not-willing households. This insignificant difference implies that the education level of the farm household does have not a difference between the two groups.

The average land holding in hectare and plot number of sample households are 1.36 ha and 2.38, respectively. Statistical analysis, as depicted in the table below, reveals that willing households possess a statistically significant at ($p<0.05$) amount of landholding in hectares and plot numbers compared to their counterparts. Furthermore, the statistical results also indicate a significant difference between the two groups at ($p<0.01$) level of significance in the average numbers of livestock owned by households in TLU. Specifically, willing sampled households have an average of 5.46 TLU, while not willing households have an average of 3.89 TLU. This implies that households with a greater number of livestock are more likely to be WTP for the newly recommended fertilizer compared to their counterparts (Table 13).

As presented in the table below, the average years of fertilizer application experience differ significantly between willing and not-willing households, standing at 9.05 and 7.04 years, respectively. The statistical test shows a significant mean difference at ($p<0.01$) significance level between the two groups, indicating that households with more experience in fertilizer use are more likely to be willing to pay for the newly recommended fertilizer compared to their counterparts. This suggests that the level of familiarity and experience with fertilizer application plays a role in shaping households' willingness to adopt and pay for the recommended fertilizer. The statistical analysis revealed that there were no significant mean differences between the two groups for the variables of age, education level, working-age family members, farm experience, distance to input source and market, as well as Teff and sorghum yield. In other words, the average values for these variables have no significant difference between the two groups.

Table 9: Summary of continuous variables (n=304)

Variables	Willing Mean	Not willing Mean	t-value	Total Mean
Age	45.6543	43.4507	-1.4963	44.625
Education Level	2.9383	3.1056	0.4021	3.0165
Family Size	5.3827	4.9789	-1.9371*	5.1941
Active labor force in the family (Year)	2.9815	2.8873	-0.6903	2.9375
Farm Experience (Year)	25.8951	23.7324	-1.5057	24.8849
Livestock ownership (TLU)	5.4611	3.8860	-4.4330***	4.7254

Distance to input source (Minute)	51.2469	48.2042	-0.8606	49.8257
Distance to market	84.8765	85.3873	-0.1065	85.1151
Experience of fertilizer application	9.0533	7.0381	-2.8485***	8.22
Number of plots owned	2.4877	2.2676	-2.1282**	2.3849
Total farm size owned (Ha)	1.4667	1.2563	-2.4941**	1.3684
Teff Yield (Quintal)	8.7161	8.2089	-1.0269	8.4792
Sorghum Yield (Quintal)	13.4980	12.5436	-1.1288	13.0522

***, **, * significant at 1%, 5%, and 10%, level respectively

Source: Own survey, 2023

4.2.2. Chi-square Test of Dummy Variables Related to Farmers Characteristics

As expected, the result confirmed that there is a significant difference in willingness to pay for the recommended fertilizer between households who have access to credit and their counterfactuals at a $P<0.05$ level of significance. Therefore, reject the null hypothesis that there is no relationship between households who access credit and those who do not access it regarding their willingness to pay for newly recommended fertilizer. It means that credit plays a great role in purchasing agricultural inputs like fertilizer. The statistical chi-square test indicates that there is a statistically significant difference between households that have training access and their counterfactuals at $p<0.1$ significance level. In general, there is no evidence to reject the null hypothesis on the variables sex, cooperative membership, and access to extension services,—*i.e.*, there is no significant difference among the two groups.

Table 10: Summary of chi-square test for first bid responses for dummy variables

Variables	Labels	Responses (freq. / %)				Total	Chi-Square (P-value)
		WTP		Not WTP			
		Freq.	Percentage	Freq.	Percentage		
Cooperative membership	Yes	117	50.87	113	39.19	230	2.2229
	No	45	60.81	29	39.19	74	
Credit Access	Yes	133	49.04	128	50.96	261	4.0300**
	No	29	67.44	14	32.56	43	
Extension Access	Yes	125	53.42	109	46.58	234	0.0068
	No	37	52.86	33	47.14	70	
Training Access	Yes	108	57.14	81	42.86	189	2.9803*
	No	54	46.96	61	53.04	115	
Marital Status	Single	37	58.73	26	41.27	63	0.9450
	Married	125	51.87	116	48.13	241	

***, **, * significant at 1%, 5%, and 10%, level respectively

Source: Own survey, 2023

4.2. Estimated Farm Households' Mean WTP for NP Fertilizer

The mean WTP amount for the recommended fertilizer among respondents was estimated using contingent valuation, employing dichotomous questions with follow-up inquiries, as presented in the table below. The calculation of the mean WTP value was conducted through the utilization of the seemingly unrelated bivariate probit regression model (SUBPR model). This model utilized initial and secondary bid prices as independent variables and the corresponding responses as dependent variables, referencing the works of variables (Meseret, 2014; Muche, 2018; Tadele, 2021). As outlined in the methodology section, the mean WTP value was computed using the parameter estimates derived from the SUBPR model, following the formula specified by (Haab and McConnell, 2002)

As a result, the mean WTP estimates, calculated based on both the initial and follow-up bid values, ranged from 39.864 to 59.796 Ethiopian Birr per kilogram. The initial bid value for the recommended fertilizer is determined by referencing the price of fertilizer purchased during the treatment phase, with the initial bid value set at 39.864 Ethiopian birr per kg. The higher and lower bid prices are contingent on the respondent farmer's response to the first bid, whether they choose to accept or reject the initial bid. In case the household is not willing to pay the first bid, the subsequent bid price is 19.932 ETB/kg. Conversely, if the household is willing to pay the first bid, the subsequent bid price is set at 59.796 ETB/kg. The maximum price is determined by the household's willingness to pay the second bid price. The mean WTP in this study was determined using 39.864 ETB per kilogram, which was derived from the first equation.

As per Muche (2018), the SUBP model that effectively captured the data was constructed by regressing "yes-no" responses against bid values specifically for payment types where respondents expressed a willingness to pay (WTP) in cash. In this context, the follow-up bid variable and its constant proved to be statistically significant. The mean WTP was subsequently computed using this variable, resulting in a value of 39.864 ETB per kilogram. The Wald test demonstrates that the hypothesis that every parameter in the regression equation is zero, except for constants, is rejected.

The average Willingness to Pay (WTP) amount for the initial and subsequent bid prices in a double-bounded dichotomous choice Contingent Valuation Method (CVM) elicitation format falls within the range of 25.718 to 65.582 Ethiopian Birr per Kg, with a 95% confidence interval. Referring to Table 15 and utilizing the coefficients associated with the constant term and the bid prices, the estimation of the mean WTP for the NP fertilizer quantity among smallholder farmers can be calculated as follows:

$$\textbf{Mean WTP} = \left(\frac{\left(-\frac{\alpha 1}{\beta 1}\right)+\left(-\frac{\alpha 2}{\beta 2}\right)}{2}\right) = \left(\frac{\left(-\left(\frac{-1.92833}{0.0749812}\right)\right)+\left(-\left(\frac{4.210224}{-0.0641975}\right)\right)}{2}\right)$$

$$= \underline{\underline{45.6499 \approx 45.65}} \text{ Ethiopian Birr per Kilogram}$$

In the provided equation, α1 and α2 represent the coefficients corresponding to the constant term for the first bid and second bid responses, respectively. Similarly, β1 and β2 denote the coefficients associated with bid one and bid two, respectively. The findings also reveal that the second bid price is statistically significant and exhibits negative coefficients. This implies that an increase in the bid price is associated with a decreased likelihood of being willing to pay the specified amount for the recommended fertilizer.

Table 11: Summary result of Seemingly Unrelated Bivariate Probit Model (*n=304*)

	Coef.	Std. Err.	Z	P>|z|	[95% Conf. Interval]	
WTP_Bid1						
Bid_1	.0749812	.0217655	3.44	0.001	.0323217	.1176408
_Cons	-1.92833	.7149924	-2.70	0.007	-3.329689	-.5269704
WTP_Bid2						
Bid_2	-.0641975	.0276398	-2.32	0.020	-.1183706	-.0100244
_Cons	4.210224	1.361945	3.09	0.002	1.540861	6.879587
Mean WTP= $-\frac{\alpha}{\beta}$ ⟶ 25.718 to 65.582 ETB/Kg at 95% conf. Interval , 25.718+65.582 /2 =						

Breusch-Pagan test of independence: chi^2 (1) = 273.198, Pr = 0.0000

The Breusch-Pagan test for error independence yields a chi-square test statistic of 273.198 with a p-value below 0.01, indicating a statistically significant correlation between errors in the two equations. In the context of the Seemingly Unrelated Regression (SUR) model, the estimated coefficient can be interpreted as follows: for every 1-unit increase in the second bid, there is a corresponding decrease of -0.06420 units in the Willingness to Pay (WTP) for the second bid. Additionally, the correlation between errors in the two equations is negative, measuring -0.9480.

4.3. Determinants of Fertilizer Adoption and Intensity

Before analyzing the collected data from the survey, we checked the model specification, error test, and assumptions of the DH model. Tobit and double-hurdle models (Probit and truncated regression models) were estimated separately, and then a likelihood ratio test was conducted. Based on the log-likelihood values of the two models estimated, the LR-test results suggest the rejection of the Tobit model. This is an indication of the existence of two separate decision-making stages in which individuals make independent decisions regarding the adoption and level of adoption of fertilizer. It shows that the likelihood ratio test statistics are 234.287, which exceeds the critical value [χ^2 (21) ≈ 31.410] at the 1% level of significance (Appendix 5: Model specification test of DHM vs. Tobit Model. Thus, the decision rules reject the null hypothesis that both the adoption decision and level of adoption of fertilizer are affected by the same set of factors if the likelihood ratio (Γ) exceeds the value of the chi-square test (χ^2) from the table at the (21) degree of freedom by a 5% significance level.

The other statistical test used for comparing Tobit and DHM alternatives to the likelihood ratio test is Akaike's Information Criteria (AIC). The decision rule for this statistical test is that the model with the lowest AIC is taken as the best model among competing models. Based on this rule of thumb AIC of Tobit model is greater than the probit model result implying that the reject the use of Tobit and double hurdle is better than Tobit (Appendix 5: Model specification test of DHM vs. Tobit Model. In addition, the test statistics of the inverse mill ratio test were used to check the existence of sample selection bias for further consideration of Heckman selection model and the test result confirmed that there is no sample selection bias.

The Likelihood Ratio and Wald tests of the hypothesis indicated that all the regression coefficient estimates are jointly equal to 0 and are rejected at ($p<0.01$) level of significance. This implies that all explanatory variables included in the probit and truncated regression models well explained the variations in the smallholder farmers' probability of adopting and intensifying the use of fertilizer.

In the analysis of the decision to adopt fertilizer (first stage), six explanatory variables were statistically significant; these are knowledge of fertilizer about fertilizer use, perception of the household on fertilizer use, and fertilizer price at ($p<0.05$) significance level and number of active labor force in the household, extension service and distance to input center from the household residence at ($p<0.1$) level of significance.

Access to extension services: as expected the model analysis revealed that a positive and statistically significant relationship (at $p<0.1$) between the probability of adopting fertilizer and access to extension services. Specifically, the finding indicated that smallholder farmers with such access are approximately 9.9 percent more likely to adopt fertilizer. This emphasizes the significance of extension service agents as valuable sources of information, guidance, and training for farmers to empower and motivate farmers to accelerate fertilizer adoption —thereby enhancing their overall agricultural productivity. This finding is similar to the results obtained by several other studies (Stella *et al*., 2001; Hassen and Bezabih, 2012; Tewodros, 2020; Sandile, 2020; Atinkugn, 2022).

Distance to input source centers: it is expected that distance to the market center has a negative and significant relationship (at $p<0.1$) level of significance with a probability of adoption decision of fertilizer adoption. The model result indicates that as the distance from input center is increased by one minute, the probability of adoption of fertilizer decreases by 0.2%. The implication is that the longer the distance between farmers' residences and the input center, the lower the probability of fertilizer adoption. This may be due to the relative proximity to input a center reduces transportation costs and timely delivery of inputs to farmers especially during the active farming season, (Dady *et al*., 2001; Hassen *et al*., 2012; Bedilu *et al*., 2016).

Active labor force: Contrary to expectations, the analysis reveals an unexpected result regarding the impact of active labor force size on fertilizer adoption at $p<0.1$ level of significance. The finding suggests that an increase in the number of active labor force members in the household decreases the likelihood of adopting fertilizer. Specifically, the marginal effect indicates that a one-person increase in the active labor force within the household results in a 5.5 percent decrease in the probability of a fertilizer adoption decision. Upon exploring the rationale behind this outcome, it may be due to a shift in preference among farmers with larger active family sizes. These households are more inclined to adopt alternative options of labor-intensive, and cost-effective fertilizers such as compost and manure applications, rather than inorganic fertilizers. In the context of this research, "cereal crops" refers specifically to Teff and Sorghum crops cultivated by farmers in the study areas.

Knowledge of farmers about fertilizer application: this study also found that farmers with sufficient knowledge about fertilizer use are more likely to adopt fertilizer. As expected, farmers knowledge of fertilizer usage has a positive and significant relationship at $p<0.1$ level of significance with a probability of adoption decision. The marginal effect results show that with increasing farmers' knowledge of fertilizer usage; the probability of fertilizer usage increases by 45% percent than farmers who do not know fertilizer usage. This implies that the likelihood of adopting fertilizer increases when smallholder cereal crop producer farmers have sufficient knowledge about the application of fertilizer. The result is similar to the study conducted by (Sandile, 2020b).

Farmers' perception of fertilizer use significantly affected the smallholder farmers adoption decision associated positively at $p<0.01$ level of significance. The marginal effect results show that with increasing of farmers' perception of fertilizer usage; the probability of fertilizer adoption increases by 11.3 percent for farmers who have poor awareness and attitude about fertilizer usage. Farmers' perception of fertilizer adoption is positively associated with the adoption decision and shows that if farmers believe that the application of fertilizer improves their crop yield as compared to the non-use of fertilizer, they will be more likely to adopt fertilizer. The finding has a similar result with the research conducted by (Atinkut, 2022).

Fertilizer price: the result shows that the price of fertilizer has a negative and significant relationship at $p<0.01$ level of significance on fertilizer adoption decision. The result also revealed that, when farming household heads perceived higher prices for fertilize, the tendency to adopt fertilizer would reduce by 52.9 percent. The result satisfies the a priori expectation because farming household heads are assumed to be rational consumers and will adjust to input price change subject to budget constrained. The magnitude of the marginal effect of the perceived high price of fertilizer suggests that fertilizer price is the most important decision variable that prevents farming household heads from the application of fertilizer. The results satisfy a hypothesized expectation, and the finding is similar to other studies conducted in Ethiopia and other countries (Akpan *et al*., 2012).

Table: Summary of MLE of DHM for fertilizer use and intensity

Variables	Probit			Truncated	
	Coefficient	**Std. Err.**	**Marginal effect**	**Coefficient**	**Std. Err.**
Sex	0.094	0.482	0.020	-9.808	14.021
Age	-0.01	0.015	-0.002	-0.73	.641
Education level	0.009	0.067	0.002	0.361*	2.632
Family size	0.134	0.085	0.029	1.331	3.339
Number of active labor force in the hh	-0.255*	0.132	-0.055	-4.856	4.015
Farm experience	0.012	0.015	0.002	0.649	.575
Cooperative membership	0.004	0.257	0.001	-19.2	10.21
Credit access	0.227	0.284	0.049	-6.442	10.839
Extension access	0.463*	0.249	0.099	13.833	12.329
Livestock ownership (TLU)	-0.027	0.042	-0.006	0.52	1.445
Distance to input center	-0.008*	0.004	-0.002	-0.077	.138
Distance to market	0.002	0.003	0.000	-0.341***	.129
Fertilizer application experience	-0.008	0.02	-0.002	1.062*	.588
Knowledge of fertilizer application	2.103***	0.255	0.450	37.525***	9.855
Farm size	-0.046	0.166	-0.010	-25.745***	9.178
Soil fertility status of the plot	-0.074	0.164	-0.016	5.213	6.843
Slop of the plot	-0.013	0.13	-0.003	1.534	4.617
Perception on fertilizer	0.529***	0.184	0.113	-8.594	8.395
Fertilizer price (bid price)	-0.496***	0.107	0.106	-6.232	6.281
Income	-5.24e-07	4.26e	-0.000	0.000363**	.000169
Constant	-1.978*	1.107		115.501**	47.759
Sigma				40.82***	5.553
Observation		304		191	
Log-likelihood		-116.275		-928.133	
Wald chi-square		56.43		71.95	
Prob > chi-square		0.000		0.000	
Pseudo R^2		0.420		-	
AIC		276.552		277.823	

*Note: *** p<.01, ** p<.05, * p<.1*
Source: own data 2023

In the analysis of the use intensity of organic fertilizer (second stage), six explanatory variables were statistically significant, and these were: education, knowledge of fertilizer application, land size, and distance to market, experience of fertilizer use, and income of the household. Knowledge of fertilizer, annual income, education level, and fertilizer application experience have a statistically significant positive effect on the use intensity of fertilizer by smallholder crop producer farmers at $p<0.01$, $p<0.05$ and $p<0.1$ significance levels, respectively. However, variables like farm size and distance to market have a significant negative effect at ($p<0.01$) levels of significance.

Education level: education was hypothesized to affect fertilizer use and intensity positively since it increases the capacity of farm households to acquire information and knowledge of improved technologies and promote the decision to use them on their farms. In this study, the result confirmed that education positively and significantly affects the intensity of inorganic fertilizer use at the $p<0.1$ level of significance. As the result indicated, farm households that increase their formal education by one year will increase the intensity of fertilizer by 36.1%. The result is consistent with similar studies and the findings of Deresse and Tekilu (2019) and Hassen *et al*., (2012).

Land Size: The findings indicate that an increase in land size by one hectare results in a 4.6% decrease in fertilizer application per hectare, with statistical significance at $p<0.01$. Surprisingly, the amount of fertilizer falls with an increase in farm size, showing that farmers who have smaller farms use this input more intensively. In fact, farmers who have large farmlands focus more on gross production from their large area coverage than productivity improvement. Because the yield they get from the large farmland area coverage may be enough for their family consumption, this leads to low input use like fertilizer. While households with smaller farmland are forced to improve their farmland productivity more than total production, which leads them to use more inputs for their farmland, like fertilizer. Small landholders may intensify their farming practices out of necessity to ensure an adequate food supply for their families. These results align with previous studies (Andrew and Mulat, 1996; Akpan *et al*., 2012; and Tewodros, 2020).

Annual Income: the amount of fertilizer used by farm households was positively correlated with annual income at the $p<0.05$ level of significance, as predicted. With every additional Ethiopian birr in annual income, there was a marginal increase in the amount of fertilizer used by households (0.0363 percent). This suggests that households with higher incomes are more likely to overcome financial constraints, enabling them to purchase and use a greater quantity of farm inputs such as fertilizer. Similar findings have been reported in other studies (Martey *et al*., 2014; Tewodros, 2020; Mengistu & Degefu, 2021; Ishara *et al*., 2023).

Distance to markets: the coefficient for the distance to the market, exhibiting the anticipated negative sign, was found to have a significant effect on the intensity of fertilizer adoption at the $p<0.001$ significance level. For every one-hour increase in the distance of the market from the residence, there was a corresponding decrease of approximately 34.1 percent in the amount of fertilizer used by farmers. This negative sign indicates the importance of proximity to regular markets, influencing factors such as enhanced access, reduced transport costs, timely delivery of inputs and output sales, and favorable output prices for farmers. The proximity of the market is crucial for obtaining necessary inputs and selling surplus output. Therefore, residing closer to the market facilitates more efficient input acquisition and output marketing. This finding aligns with the results reported by Hassen *et al*. (2012); Akpan *et al*. (2012); Aman (2022).

Knowledge of farmers about fertilizer application: this study also found that farmers with sufficient knowledge about fertilizer use are more likely to use a higher amount of fertilizer. In this study, as expected, farmer's knowledge of fertilizer usage has a positive and significant influence at the $p<0.01$ level of significance, with a probability of a higher amount of fertilizer than their counterparts. The marginal effect results show that as farmers' knowledge of fertilizer usage increases, the probability of fertilizer usage increases by 375.25 percent compared to their counterparts. The result is similar to the study conducted by Sandile (2020).

Experience in fertilizer use: this study also found that farmers with experience in fertilizer use are more likely to use fertilizer intensively than farmers who do not have experience. In this study, as expected, experienced farmers on fertilizer use have a positive and significant influence at the $p<0.1$ level of significance. The marginal effect results show that with one additional year of farmer’s experience, the probability of higher fertilizer usage increased by 106.20 percent compared to their counterparts.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATIONS

5.1. CONCLUSIONS

In conclusion, the study aimed to assess the economic incentives and profitability of various fertilizers used in the omission trials for Teff and Sorghum under different growing conditions in the study areas. Additionally, the study aimed to analyze smallholder farmers' willingness to pay for the recommended NP fertilizer for major cereal crops. Furthermore, the research tried to evaluate the determinants influencing smallholder farmers' decisions regarding fertilizer adoption and its use intensity on major cereal crops.

Across the three districts, net benefits varied, with treatments All-B and NP showing higher benefits in Sekota for Teff and Sorghum. However, 150% (All+K) emerged as the most profitable treatment in Tehuledere and West Belesa districts. The control treatment consistently yielded the lowest net benefit. MRR analysis reinforced the profitability of treatments like All-B and 150% (All+K) in different districts. The dominance analysis consistently identified treatments All-S, All+K, and NP as dominant across all districts for both crops. Non-dominated treatments such as 50% (All+K), All-B, NPSZnB, All-Zn, and 150% (All+K) showcased economic competitiveness. This comprehensive understanding of dominant and non-dominated treatments provides valuable guidance for decision-makers and farmers, facilitating informed choices based on specific conditions and goals in each district and crop.

The mean Willingness to Pay (WTP) for the recommended fertilizer among respondents, estimated through a double-bounded dichotomous choice Contingent Valuation Method (CVM), ranged from 25.718 to 65.582 Ethiopian Birr per kilogram, with a 95% confidence interval. The mean WTP, calculated using the Seemingly Unrelated Bivariate Probit Regression (SUBPR) model, was determined to be approximately 45.65 Ethiopian Birr per kilogram. The negative coefficients associated with the second bid price in the model suggest that an increase in the bid price is linked to a decreased likelihood of being willing to pay the specified amount for the recommended fertilizer. This highlights the sensitivity of respondents to price changes and provides insights for policymakers and researchers to understand farmers' economic preferences in adopting recommended fertilizers.

The analysis of fertilizer adoption and intensity highlighted the significance of various factors in influencing smallholder farmers' decisions and intensities. Positive influences included knowledge, perception, and access to extension services, while distance to input centers, larger active labor force size, and perceived high fertilizer prices. These findings emphasize the complexity of adoption decisions, incorporating educational, perceptual, and economic factors. Regarding the use intensity of fertilizer, education, knowledge, annual income, and fertilizer use experience positively affect fertilizer use. Farm size and distance to markets negatively affect adoption intensity. Education and knowledge were associated with increased fertilizer use, smaller farms used fertilizer more intensively, and higher annual income correlated with increased usage. Market proximity negatively influenced adoption intensity. These findings provide valuable insights into the multifaceted dynamics influencing smallholder farmers' fertilizer users and its intensity.

5.2. RECOMMENDATIONS

The economic evaluation result confirmed that there are different economic returns of treatments across districts. Recognizing the variability in net benefits and profitability across districts and treatments, it is recommended to adapt agricultural practices to the specific conditions and goals of each region. This could involve customizing fertilizer recommendations and strategies based on local factors to maximize economic returns.

Given the positive influence of access to extension services on fertilizer adoption, there is a need to improve access and quality of extension service. Therefore, all respective actors should be deliver through providing farmers with valuable and timely information, guidance and follow ups, and training to empower and motivate them to use optimal fertilizer rate and finally they can improve the productivity of their farms.

Recognizing the significant negative relationship between perceived fertilizer prices respective bodies especially government should be consider price optimization mechanisms to make fertilizers more affordable for smallholder farmers, thus overcoming a key barrier to use fertilizer.

In addition, considering the negative effect of proximity to input centers and market centers for farmers fertilizer use, efforts should be made to improve the accessibility of input centers. This could involve establishing more centers nearby the farmers or improving transportation infrastructure to reduce farmers' transportation costs and increase the likelihood of fertilizer use and its level of utilization.

It is clear that fertilizer is the hot issue in the current scenario and expected in the coming years. Because it the major input in the crop production process and the demand become increasing. Therefore, it is better to conduct the detail analysis on this issue by other researchers to fill the gaps/limitations of this research.

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APPENDICES

Appendix 1: Partial budget and dominance analysis of Sekota district for Teff and sorghum

Treatments	AGY (Kg/Ha)	Adj. GY (Kg/Ha)	SY (Kg/Ha)	SI (ETB)	Adj.GYI (ETB)	TR (ETB)	TVC (ETB)	NB (ETB)	MRR (%)
Teff									
Control	1117.05	1005.35	2627.34	26273.43	46469.41	72742.8	0.00	72742.84	-
50% (All+K)	1358.90	1223.00	3496.78	34967.80	56530.08	91497.9	1342.6	90155.28	12.97
All-Zn	1318.99	1187.09	3761.42	37614.24	54870.07	92484.3	2566.01	89918.3	*D*
All-B	1436.64	1292.98	4945.14	49451.44	59764.33	109216	2586.9	106628.9	799.93
All	1261.45	1135.31	4143.70	41437.02	52476.42	93913.4	2668.76	91244.68	*D*
All-SZnB (NP)	1413.77	1272.39	4139.64	41396.40	58812.88	100209	4105.17	96104.11	*D*
All-S	1481.20	1333.08	4396.05	43960.46	61618.10	105579	4289.78	101288.8	*D*
All+K	1468.34	1321.50	4462.37	44623.66	61082.77	105706	4668.76	101037.7	*D*
150% (All+K)	1439.65	1295.69	4419.67	44196.7	59889.61	104086	7027.83	97058.48	*D*
Sorghum									
Control	765.14	688.63	4679.27	20744.77	13393.82	34138.59	0.00	34,138.59	-
50% (All+K)	1354.97	1219.48	5437.03	24104.18	23718.83	47823.01	1342.60	46,480.41	9.19
All-Zn	1542.37	1388.14	5896.89	26142.870	26999.27	53142.14	2566.01	50,576.13	3.35
All-B	1709.21	1538.29	5537.13	24547.96	29919.77	54467.73	2586.9	51,880.83	62.46
All	1617.04	1455.33	6040.17	26778.07	28306.21	55084.28	2668.76	52,415.52	6.53
All-SZnB (NP)	1714.21	1542.79	6241.66	27671.34	30007.25	57678.59	4105.17	53,573.42	0.81
All-S	1547.27	1392.54	5448.37	24154.45	27084.98	51239.44	4289.78	46,949.66	*D*
All+K	1652.26	1487.03	5526.27	24499.81	28922.82	53422.63	4668.76	48,753.87	*D*
150% (All+K)	1911.36	1720.22	5404.63	23960.53	33458.35	57418.89	7027.83	50,391.06	*D*

Note: AGY=Average Grain Yield (Kg/ha), Adj.GY=Adjusted Grain Yield (Kg/ha), SY=Straw/Stover Yield (Kg/ha), SI = Income from straw/Stover, Adj. GYI = income from adjusted grain Yield, TR=Total Revenue (ETB/ha), TVC=Total Variable Cost (ETB/Kg), NB =Net Benefit (ETB/Kg), MRR= Marginal Rate of Return and VCR = Value Cost Ratio

Average field price of Teff =39.90 ETB/Kg   Average field price of Teff Straw =14 ETB/Kg

Average field price of Sorghum = 18.62 ETB/Kg   Average field price of Sorghum Stover =5 ETB/Kg

Minimum acceptable rate of return =100%,   Average yield was adjusted by 10%

Appendix 2: Partial Budget and Dominance Analysis of Tehuledere District for Teff and Sorghum

Treatments	GY (Kg/Ha)	AGY (Kg/Ha)	SY (Kg/Ha)	S. Income (ETB)	AGY Income (ETB)	TR (ETB)	TVC (ETB)	NB (ETB)	MRR (%)
Teff									
Control	718.61	646.75	1301.67	15620.00	22636.25	38256.25	0.00	38256.25	-
50% (All+K)	1580.88	1422.79	2435.47	29225.67	49797.56	79023.23	1342.60	77680.629	29.36
All-Zn	2027.43	1824.69	3413.19	40958.33	63864.06	104822.40	2566.01	102256.39	20.09
All-B	2067.75	1860.98	3211.72	38540.67	65134.12	103674.80	2586.90	101087.89	***D***
All	1972.21	1774.99	3479.19	41750.33	62124.56	103874.90	2668.76	101206.14	***D***
All-SZnB (NP)	1968.17	1771.35	2992.83	35914.00	61997.25	97911.25	4105.17	93806.08	***D***
All-S	1988.06	1789.25	3485.00	41820.00	62623.75	104443.80	4289.78	100153.90	***D***
All+K	2048.51	1843.66	3309.92	39719.00	64528.19	104247.20	4668.76	99578.43	***D***
150% (All+K)	2321.93	2089.74	4325.58	51907.00	73140.81	125047.80	7027.83	118019.98	7.81
Sorghum									
Control	1397.59	1257.83	1624.86	10832.41	18867.41	29699.83	0	29,699.83	-
50% (All+K)	1858.60	1672.74	1760.02	11733.45	25091.14	36824.59	1342.6	35,481.99	4.31
All-Zn	2027.75	1824.98	1503.03	10020.20	27374.66	37394.86	2566.01	34,828.85	***D***
All-B	1994.00	1794.60	1720.91	11472.76	26919.06	38391.82	2586.9	35,804.92	46.72
All	2048.89	1844	2031.27	13541.81	27659.96	41201.77	2668.76	38,533.01	33.33
All-SZnB (NP)	2016.83	1815.15	1396.46	9309.70	27227.25	36536.95	4105.17	32,431.78	***D***
All-S	1805.07	1624.56	1297.31	8648.73	24368.42	33017.15	4289.78	28,727.37	***D***
All+K	1763.81	1587.43	1699.90	11332.68	23811.39	35144.08	4668.76	30,475.32	***D***
150% (All+K)	1861.67	1675.50	1744.09	11627.24	26937.19	38564.43	7027.83	31,536.60	***D***

Average field price of Teff =31.27 ETB/Kg
Average field price of Sorghum = 15.61 ETB/Kg
Average field price of Teff Straw =12 ETB/Kg

Average field price of Sorghum Stover =7 ETB/Kg

Appendix 3: Partial Budget and Dominance Analysis of West Belesa District for Teff and Sorghum

Teff

Treatments	GY (Kg/Ha)	AGY (Kg/Ha)	SY (Kg/Ha)	S. Income (ETB)	AGY Income (ETB)	TR (ETB)	TVC (ETB)	NB (ETB)	MRR (%)
Control	760.26	684.24	1617.19	20700.00	27369.49	48069.49	0.00	48069.49	
50% (All+K)	1406.86	1266.18	3188.73	40815.69	50647.06	91462.75	1342.60	90120.15	31.32
All-Zn	1720.62	1548.56	3708.30	47466.23	61942.41	109408.60	2566.01	106842.60	13.67
All-B	1713.85	1542.46	3892.77	49827.45	61698.53	1115260	2586.9	108939.10	100.36
All	1705.27	1534.74	3919.73	50172.55	61389.71	111562.30	2668.76	108893.50	***D***
All-SZnB (NP)	1721.20	1549.08	3658.70	46831.37	61963.24	108794.60	4105.17	104689.40	***D***
All-S	1741.57	1567.42	3767.01	48217.66	62696.65	110914.30	4289.78	106624.50	***D***
All+K	1775.12	1597.61	4015.32	51396.08	63904.41	115300.50	4668.76	110631.70	10.57
150% (All+K)	1917.28	1725.55	4651.35	59537.25	69022.06	128559.3	7027.83	121531.50	4.62
Sorghum									
Control	2455.55	2210.00	2674.82	26748.15	34498.10	61246.25	0.00	61,246.25	
50% (All+K)	3620.00	3258.00	4134.07	41340.74	50857.38	92198.12	1342.60	90855.52	22.06
All-Zn	3568.15	3211.33	5169.63	51696.30	50128.913	101825.21	2566.01	99259.20	6.87
All-B	3968.15	3571.33	4688.89	46888.89	55748.513	102637.4	2586.90	100050.50	37.88
All	4007.41	3606.67	4860.74	48607.41	56300.07	104907.47	2668.76	102238.71	26.73
All-SZnB (NP)	3687.41	3318.67	4669.63	46696.30	51804.39	98500.68	4105.17	94395.51	***D***
All-S	3788.15	3409.33	4635.56	46355.56	53219.69	99575.25	4289.78	95285.47	***D***
All+K	3955.56	3560.00	4522.96	45229.63	55571.60	100801.23	4668.76	96132.47	***D***
150% (All+K)	4422.22	3980.00	5202.22	52022.22	62127.80	114150.02	7027.83	107122.19	4.66

Note: Price of inputs and output

Average field price of Teff =40 ETB/Kg

Average field price of Teff Straw =13 ETB/Kg

Average field price of Sorghum = 15 ETB/Kg

Average field price of Sorghum Stover =10 ETB/Kg

Appendix 4: Multicollinearity Test (n=304)

Variable	***VIF***	***Tolerance***
Sex	1.18	0.8445
Age	4.62	0.2165
Marital Status	1.18	0.8494
Education	1.21	0.8263
Family Size	2.32	0.4303
Active labor force	2.40	0.4161
Farm experience	4.37	0.2291
Cooperative Membership	1.34	0.7489
Credit access	1.23	0.8123
Extension access	1.32	0.758
Livestock ownership (TLU)	1.64	0.6104
Distance to Input source	1.51	0.6627
Distance to Market	1.83	0.5452
Fertilizer application experience	1.53	0.6539
Knowledge of fertilizer application	1.41	0.7098
Farm Size	1.39	0.7177
Soil Fertility	1.12	0.8908
Slop of plot	1.07	0.9314
Perception	1.50	0.6656
Fertilizer price	1.57	0.6383
Mean VIF 1.76		

Appendix 5: Model specification test of DHM vs. Tobit Model

Variables	***Tobit***	***Double Hurdle***	
		Probit	***Truncated regression***
Observation	304	304	191
Log-L	-227.1207	-116.9116	-1369.616
Wald χ^2	-	-	149.751
Prob > χ^2	0.000	0.000	0.000
Pseudo R^2	0.286	0.417	-
LR χ^2	181.80	167.372	-
AIC	499.7824	276.552	1902.266
χ^2-test : Tobit Vs Double Hurdle	$\lambda =$ 2344.287 > χ^2 (21) =32.671		

Appendix 6: Experimental Treatments of Nutrient Omission Trials

Treatment	Name of Treatments
1.	Control (No fertilizer applied)
2.	NPSZnB (All)
3.	NPZnB (All-S)
4.	NPSB (All-Zn)
5.	NPSZn (All-B)
6.	NPSZnB+K (All+K)
7.	NPSZnB-SZnB (All-B)
8.	50% (NPSZnB+K) (50% (All+K)
9.	150% (NPSZnB+K) (150% (All+K)
Where: N is nitrogen, P is Phosphorus, S is Sulfur, Zinc, Boron and potassium	

Appendix 7: Questionnaire for individual interview

PART ONE: GENERAL INFORMATION

Questionnaire Code: _______________

Household location	
Woreda	Kebele

2. Interview Information		
Name of Interviewer	Signature of Interviewer	Date of Interview

3. GPS Coordinates		
Altitude	Latitude	Longitude

4. Access to Infrastructure		
No	**Infrastructures**	**How long it takes to get to the nearest … (hour)**
1	Nearest market center	
3	DAs office/FTC	
4	Credit institution	

5	Farmers' cooperative	
6	Source of improved seed	
7	Source of fertilizer	
8	Source of chemical	
9	Main road	

PART TWO: DEMOGRAPHIC INFORMATION OF THE HOUSEHOLD

1. Sex of respondent 1) Male 0) otherwise
2. Age of respondent [_____________]
3. Marital status of respondent 1) Single 2) Married 3) Divorced 4) Widowed
4. Can you read & write 1) Yes 0) No
5. ***If yes for question #4,*** how long have you spent in formal education? [_______] years
6. How many family members do you have? (in number) [___________]
7. How many of them are in the range of working age? (15 to 65 years) [________]
8. How money years do you have farming experience? [_______] years.
9. What is your household members' main income source for living? (***please rank accordingly***)

1) Crop production only [_______] 5) Fruit & Vegetable production) [_______]

2) Livestock rearing only [______] 6) Non-farm/off-farm activities [______]

3) Mixed farming (crop & Livestock) [_______] 7) others ___________________

II. <u>Land Holding, plot characteristics and crops grown</u>

10. Do you have farm land: 1) Yes 0) No
11. ***If yes for question #10***, total size of your farm land [_______] ***(kada/Timad)***
12. Total cultivated land size in 2012/2013 E.C cropping season ***(kada/Timad)***

1) Own land [_______] 3) Rented/shared out land [_______]

2) Rented/shared in land [_________] 4) Total land [______]

Table 1: General plot characteristics

13. How many plots of farm land do you have? _________________

Questions		Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6
15.1 Plot Name							
15.2 Size of the Plot (kada)							
15.3 Form of ownership ©							
15.4 Main crops grown on the plot							
15.5 Distance from your home (minutes)							
15.6 Area covered by Teff (Kada)							
15.7 Area covered by Sorghum (Kada)							
15.9 Soil type *	Teff						
	Sorghum						
15.10 Soil fertility status+	Teff						

	Sorghum						
15.11Slop of the plot †	Teff						
	Sorghum						

© 1 = Own 4 = Gift 2 = Rented/shared in 3 = Rented/shared out	*1 = Black 2= Red 4= Sandy loam 3 = Sandy 5) Bunama	+1 = Good 2 =Medium 3 = Poor	†1 = Steep/hill slop **2** = Mid slop 3 = Flat/no slop

15.12 Amount of NPS (kg)	Teff						
	Sorghum						
15.13 Amount of Urea (kg)	Teff						
	Sorghum						
15.14 Amount of manure (Qt)	Teff						
	Sorghum						
15.15 Amount of Herbicide (L)	Teff						
	Sorghum						
15.16 Amount of Insecticide (L/kg)	Teff						
	Sorghum						

1.Total Cost of herbicide/insecticide for Teff _______Birr 3. Total Cost of herbicide/insecticide for Sorghum _______Birr
2.Total Cost of Teff seed _________ Birr 4. Total Cost of Sorghum seed _________ Birr

Households Livestock Ownership & annual income from livestock

	14. Types of livestock the household owned											Total
	Oxen	Cow	Bull	Heifers	Calves	Goats	Sheep	Donkey	Mule	Poultry	Bees	
No												

15. Income from Livestock Sale and Livestock Products							
	Livestock Sale	Butter	Milk	Egg	Honey	Others	Total
Quantity							
Unit price							
Total income							

Smallholder Households crop production & annual income

Quantity produced	16. Types of crops the household produced											Total
	Maize	Teff	Sorghum	Wheat	Barley							

17. Households Income from crop sold							
	Maize	Teff	Sorghum	Wheat	Barley		Total
Quantity							
Unit price							
Total income							

18. **Income gained from off-farm / non-farm activities**

No	Sources	Income	No	Source	Income	Remark
1)	Daily labor		7	Grain and Livestock trade		
2)	Sale of wood and charcoal		8	Remittance		
3)	Masonry &/Carpentry		9	Rent/share out land		
4)	Petty trading (like shop)		10	House renting		
5)	Weaving		11	Salary employment		
6)	Income from aid		12	Others		
	Total					

VI. Credit Service of Smallholder Households

19. Have you access to credit service for agricultural input purchases? 1) Yes 0) No

20. ***If yes to question #18,*** have you borrowed credit in the last production season? 1) Yes 0) No

21. ***If yes for question #19***, from whom you could get the credit?

1) Banks 3) Microfinance institutions 5) NGOs

2) ACSI 4) Cooperatives 6) Others ____________________

22. Amount of birr you borrowed in the last production season? ______________________

23. For what purpose did you borrow? ***(Multiple choice possible)***

1) To Purchase fertilizer 5) To purchase tillage oxen

2) To Purchase improved crop seed 6) To purchase fattening bull

3) To Purchase farm equipment 7) To purchase dairy cow

4) To buy herbicide & insecticide chemicals 8) others ______________________________

24. ***If no for question #19***, what was your reason?

1) I have sufficient capital 4) I did not want credit

2) No credit access 5) others ______________________________

3) Higher interest rate

IIV. Access of Extension Service

25. Did you have access of extension services in the last production season? 1) Yes 0) No

26. ***If yes for question #25,*** frequency of extension contacts in the last production season? [_______]

27. From whom did you get the extension service? ***(Multiple answer is possible)***

1) DAs 2) Wereda expert 3) NGO experts 4) Others specify ______________________

28. Did you get training about fertilizer utilization in the last production season? 1) Yes 0) No

29. ***If yes for question #28***, how many times have you got the training? [________]

30. Who gave you the training? ***(Multiple answer is possible)***

1) Gov.t extension service 2) Cooperatives 3) Research centers 4) NGOs 5) University

IV. Fertilizer Application and Unit Cost of the Fertilizer

31. Have you used new agricultural technologies in the last cropping season? 1) Yes 0) No

32. Did you apply fertilizer for your crop production in the last cropping season? 1) Yes 0) No

33. ***If yes for question #31***, what type of fertilizer you was used?

1) NPS 2) Urea 3) Both 4) Others specify ________________________

34. How do you perceive the price of fertilizer in the last production season?

1) Very expensive 2) Expensive 3) Fair 4) Cheap

35. For how many years you practiced fertilizer application for crop production? [_______] years

36. ***If yes for question #31***, how do you purchase the fertilizer 1) Loan 2) Cash) 3) Loan & cash

37. ***If loan for question #36***, why did you use loan?

1) Because of access to credit 3) Use the cash for other inputs

2) I have no cash 4) others ______________________________

38. Who is your fertilizer supplier (from whom did you get the fertilizer)?

1) Bureau of Agriculture 2) Cooperatives 3) NGOs 4) Traders 4) others ________________

39. ***If cash for question #36***, what was your cash source to buy fertilizer?

1) Crop sale 2) Livestock sale 3) Livestock product sale 4) Off farm income 5) Others ______

40. How do you see the difference between using different types of fertilizer?

1) Using NPS fertilizer alone is important 4) Using NPS and Urea together is important

2) Using Urea fertilizer alone is important 5) Using all together is important

3) Using organic fertilizer alone is important

41. Are you aware of about recommended rate of fertilizer? 1) Yes 0) No

42. ***If yes for question #41,*** did you use the recommended rate of fertilizer? 1) Yes 0) No

43. ***If no for question #42***, how did you use fertilizer? 1) Over rate 2) Low rate 3) Nothing do

44. What was the price of fertilizer per quintal?

1) NPS [______] Birr 2) Urea [______] Birr 3) DAP [_____] 4) Others_____________

45. How do you perceive the price of <u>NPS</u> 1) Expensive 2) Normal 3) Cheap

<u>Urea</u> 1) Expensive 2) Normal 3) Cheap

46. ***If the price is expensive***, what is your plan for the next years?

1) Stop using fertilizer 4) Substitute by organic manure & compost fertilizer

2) Continue using fertilize 5) Other Specify ______________________________

3) Minimize the amount of fertilizer used

47. How much of fertilizer do you plan to use in next year? [_______] (Quintal)

48. How many times do you produce crop per year? [____________]

V. <u>Determinants of Fertilizer Use of Smallholder Farmers</u>

49. Do you get fertilizer on time? 1) Yes 0) No

50. ***If no for question # 50***, for how long it is late?

1) It delays until the time of sowing passed 3) we never get totally

2) It delays a little 4) other ______________________

51. ***If no for question # 50***, what was the solution you took?

1) Buy from others (Traders) 3) Waite/late sowing until it arrived

2) Not apply fertilizer 4) other ________________________

52. What are the potential factors affecting farmers' fertilizer use? (***Rank problems accordingly)***

1) Fertilizer price increment [_______] 6) Lack of extension service [______]

2) Poor perception of fertilizer [______} 7) Lack of fertilizer supply [_______]

3) Lack of credit service to purchase fertilizer [____] 8) Others specify ____________

4) Distance from our residence to fertilizer supply institution [_______]

5) Lack of skills, experience and knowledge about fertilizer application [_______]

53. Do you think fertilizer is important for your Teff/Sorghum? 1) Very important 2) Important 3) Not important

VI. Cooperative Membership of Smallholder Farmers

54. Are you a member of any cooperatives? 1) Yes 0) No

55. ***If yes for question #54,*** how many years have you been a member for cooperatives? [______]

56. ***If yes for question #54***, what type of cooperative you are a member? ***(Multiple choice possible)***

1) Seed producers cooperative 4) Agricultural input supplier cooperatives

2) Multipurpose farmer cooperatives 5) If any other specify ________________________

3) Saving and credit group/association

57. What benefits do get from cooperative membership? ***(Multiple choice possible)***

1) Easy access of farm inputs (improved seeds & fertilizer)
2) Easy access of information about agricultural technologies
3) Easy access to extension services
4) Easy access to credit services 5) Others specify ______________________________

PART THREE: CONTEGENT EVALUATION/WTP QUASTIONS

58. Are you willing to adopt recommended site specific fertilizer? 1) Yes 0) No

59. ***If yes for question #58***, are you willing to pay for location specific fertilizer? 1) Yes 0) No

60. ***If yes for question #58***, would you willing to pay "X" amount of Ethiopian birr per quintal of recommended balanced fertilizer? 1)Yes 0) No

61. ***If yes for question #59***, will you be willing to pay "2X" amount of Birr per one quintal of site specific fertilizer? 1)Yes 0) No
62. ***If yes for question #60,*** what will be your maximum willingness to pay for one quintal of site specific fertilizer? [__________] Birr
63. ***If no for question #60,*** will you WTP Birr X/2 per quintal of site specific fertilizer? 1) Yes 0) No
64. ***If no for question #62***, what will be your maximum willingness to pay for recommended site specific fertilizer [________] Birr/Quintal?
65. If you want to pay your maximum willingness to pay for site specific fertilizer, why you are interested to pay for this fertilizer?

1) I believe it will improve my crop productivity

2) I believe it will restore & maintain my farm soil nutrient

3) Others specify _________________

66. If you are not willing to pay for this fertilizer, what is your reason?

1) I have not trust on this fertilizer 3) I cannot afford the price of this fertilizer

2) I am satisfied on the current fertilizers 4) others specify ______________________

67. Please give me clear answers about the following questions for your single farmland

Within the one year/ 12 months of cropping season)													
What type of Variety did you used? (66a)	What type of crop did you used? (66b)	How many hectare of land did you allocated? (66c)	How much amount of seed did you used in (Kg)? (66d)	How much amount of fertilizer did you used in (Kg)? (66e)		Did you use raw planting? (66f) *1=Yes* *0L=No*	How many labors did you used for the following farming activities? (66g) *1= Tillage,* *4=Trashing* *2=Weeding ,* *5= Total labor* *3=Harvesting*					How many times did you weeding your farm? (66h)	Tillage frequency of your farm (66i)
				Urea	NPS		1	2	3	4	5		
Local variety	Teff												
	Sorghum												
Improved Variety	Teff												
	Sorghum												
Note: *We can use the unit timad, when asking the plot size for easy communication of the respondents and change to hectare* ***(1 ha=4 timad***)													

68. What was the average daily payment to paired oxen? [________] Birr/day

69. What was the average daily wage paid to hired laborer for agricultural activities [________] Birr/day?

Farmers' perception on Fertilizer use

70. Five level Likert scale questions to measure ***farmers perception*** on fertilizer application (***Strongly Agree=1, Agree=2, Neutral=3, Dis-agree=4, Strongly dis-agree=5)***

No	***Issues***	***(1)***	***(2)***	***(3)***	***(4)***	***(5)***
70.1.	The use of new farming inputs & practices can improve crop productivity					
70.2.	I am aware of about fertilizer application merit & de-merit					
70.3.	I believed fertilizer application can increase production per hectare					
70.4.	I have taken training about fertilizer application/issues					
70.5.	I have enough knowledge & skill about fertilizer application					
70.6.	I am ready to pay the price if new type of fertilizer introduce					
70.7.	The use of optimal rate of fertilizer can be enhance plant growth					
70.8.	I am satisfied the yield gained from my plot after fertilizer application					
70.9.	Optimal rate of fertilizer uses lead to improve the livelihood of farmers					

Farmers' information about IFDC/ICRISAT

71. Have you any information about IFDC/ICRISAT? 1) Yes 0) No
72. Have you ever participated in any activity organized by IFDC/ICRISAT? 1) Yes 0) No
73. ***If yes for question #70,*** which IFDC/ICRISAT-related activity did you involve?
    1) Community meetings 3) On-farm experimentation of new agricultural technology
    2) Training 4) Demonstration field days
74. ***If no for question #71***, do you plan to participate in IFDC/ICRISAT activities in the next planting season? 1) yes 0) No
75. ***If no for question #71,*** what are your reasons for not participating?
    1) Fertilizer is not relevant 5) Fertilizer is complex
    2) Fertilizer not appropriate 4) Fertilizer is risky
    3) Fertilizer is expensive 6) I have not enough information