COLLEGE OF BUSINESS AND ECONOMICS

DEPARTMENT OF ECONOMICS

THE IMPACT OF PESTICIDES ON MAIZE PRODUCTION IN SOUTHERN ETHIOPIA

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June, 2021

Addis Ababa, Ethiopia

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A Thesis Submitted to
The Department of Economics

Presented in Partial Fulfillment for the Degree of Master of Science in Economics (Development Economics)

June, 2021

Addis Ababa, Ethiopia

Addis Ababa University

College of Business and Economics

Department of Economics

This is to certify that the thesis prepared by Yordanos Yaynie, entitled: "***The impact of pesticides on maize production in southern Ethiopia***", submitted in partial fulfilment of the requirements for the Degree of Master of Science in Economics (Development Economics) complies with the regulations of the University and meets the accepted standards concerning originality and quality.

Signed by the Examining Committee:

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Acknowledgement

None of the blessings in my life have meaning without the presence of Almighty God in all that I do, thanks be to God above all else. I thank all who in one way or another contributed to the completion of this thesis. I thank my advisor, Dr. Mesele Araya from Addis Ababa University, for his help and supervision throughout my stay in the university.

I wrote this thesis as a Graduate Research Intern under the Dissertation Research Internship Program (DRIP) of the International Centre of Insect Physiology and Ecology (*icipe*). My research work is supported by Combating Arthropod Pests for Better Health, Food, and Resilience to Climate Change (CAP-Africa) project implemented by the *icipe*. I sincerely thank the Social Sciences and Impact Assessment Unit of the *icipe* for their technical support throughout the thesis writing. Especially, I would like to thank Drs. Zewdu Ayalew Abro and Menale Kassie, of the *icipe*, for their tremendous support and guidance throughout the thesis preparation. Dr. Zewdu and Dr. Menale have provided me with important literatures and supported me with data cleaning, proposal preparation and thesis write up. They have also given me their precious time in proofreading my work and giving me excellent comments, improving the thesis. I am also grateful to the Faculty of Business and Economics at Addis Ababa University for its financial support to pursue my M.Sc. studies.

Many thanks to my beloved family; my mother, my role model, who has always been there to show me just how much further I can reach; my father, my inspiration, who has always encouraged me to challenge myself and go after my dreams. I give deep thanks to the, lecturers, librarians and other workers of the faculty as well. I am also thankful to all my fellow students whose challenges and productive critics have provided new ideas to the work. May the Almighty God richly bless you all!

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Acronyms

ATA - Agricultural Transformation Agency

CADU - Chilalo Agricultural Development Unit

CAP-Africa - Combating Arthropod Pests for Better Health, Food and Resilience to Climate Change

C-D - Cobb-Douglas production function

CES - Constant Elasticity of Substitution

CRV - Central Rift Valley

CSA - Central Statistical Agency

CSPro - Census and Survey Processing System

EEA - Ethiopian Economic Association

EIAR - Ethiopian Institute of Agricultural Research

EPA - Environmental Protection Agency

EPID - Extension and Project Implementation Department

ESA - Ethiopian Seed Association

ETB - Ethiopian Birr

FAO - Food and Agricultural Organization

FAW - Fall armyworms

FDRE - Federal Democratic Republic of Ethiopia

GDP - Gross Domestic Product

ICIPE - International Centre of Insect Physiology and Ecology

IPM - Integrated Pest Management

IUPAC - International Union of Pure and Applied Chemistry

IVs - Instrumental Variables

MOA - Ministry of Agriculture

MOFED - Ministry of Finance and Economic Development

MPP – Minimum Package Project

NLS - Nonlinear Least Square

OLS - Ordinary Least Square

PAN - UK – Pesticide Action Network of the UK

PHRD - Professional Human Resource Development

SB - Stem borer

2SNLS - Two-stage Nonlinear Least Square

SNNP - Southern Nation Nationalities and People

UN - United Nations

UNDP - United Nations Development Program

USD - United States Dollar

VIF – Variance Inflation Factor

WADU - Wolaita Agricultural Development Unit

WHO - World Health Organization

Abstract

Maize production is an important economic activity among smallholder farmers in southern Ethiopia, serving as a major source of income and food security. Maize farmers often use pesticides to control pests, but it poses environmental and human health risks. While the productivity of pesticides has been previously studied, most studies treated pesticide as a direct yield enhancing input rather that a damage reducing one. In this study, we analyze the productivity impact of pesticides using a damage control production function. We estimated Cobb-Douglas production functions using Nonlinear Least Square (NLS) and Two Stage Nonlinear Least Square (2SNLS) methods. We use panel datasets collected in 2018 and 2020 in the southern Ethiopia by the Social Sciences and Impact Assessment Unit of the International Centre of Insect Physiology and Ecology (icipe). The results of the NLS regression indicated that pesticides have no significant effect on maize yield. However, when we use the 2SNLS to control for endogeneity of pesticides, the coefficient of pesticides remains positive and statistically significant, indicating that it increases maize yield. The first stage estimated results of the 2SNLS indicates that pesticide use is affected by pesticide prices, contact with extension agents, application of organic fertilizers and the socio-economic characteristics of households. Furthermore, the marginal product of 1 liter of pesticide is found to be 51 kg of maize yield, which indicates that pesticides reduce yield losses due to pests. Calculations of optimal amount of pesticides show that farmers could maximize their profit at an average of 8.4 liters of pesticides. An average quantity above or below this value indicates an overuse or underuse of pesticides. However, this estimate is from the private profit maximizing point of view, but it is important to consider the health and environmental effects of pesticides. To fully understand the societal cost of pesticides, future studies may need to collect data on not only the private benefits, but also the potential costs associated with public health and the environment.

CHAPTER ONE
INTRODUCTION

1.1 Background

"It is in the agricultural sector that the battle for long-term economic development will be won or lost". Gunnar Myrdal

Yield losses caused by pests, weeds and diseases are the main challenges in agricultural production (Cramer, 1967; Hertel, 2015; Oerke, 2006; Oerke et al., 1996; Popp et al., 2013). Pests negatively affect crop production as well as human health (Tinyami et al., 2014). Although there is advancement in agricultural technology, losses to pests and diseases account for 10-90 %, with an average of 35-40 %, for all potential food and fibre crops (Abang et al., 2014; IUPAC, 2010). This is anticipated to cause a reduction of over 40% of the world's food supply (Keno et al., 2018).

To increase food supply and be able to meet the rising demand for food and feed, the increased crop loss to pests must be reduced by the use of improved crop protection technologies (Popp, 2011). Crop protection methods could contribute to food security by increasing food availability and access as well as raising rural incomes through lower production costs, thereby helping to address the sustainable development goals. The most common crop protection method was the use of pesticides. The introduction of pesticides together with other technologies (i.e., fertilizers, modern varieties, irrigation and mechanization), in the 1960s green revolution, was an important beginning that brought an essential increase in agricultural production in the developing countries (Gollin et al., 2005). In this regard, crop protection intensity has increased significantly as indicated by a 46% increase in pesticide consumption worldwide (FAO & WHO, 2019).

Pesticide is an agricultural technology that is used by farmers as an input in crop production, to combat the problem of pests and weeds (Jansen & Dubois, 2014; Katerrega, 2012; Skevas et al., 2013). Pesticide refers to a wide range of chemicals including insecticides, herbicides, fungicides, rodenticides, bactericides, molluscicides and plant growth regulators. Pesticides have played an essential role in maintaining food security during the last five decades by controlling numerous pests and diseases, thereby improving agricultural productivity (Matthews, 2006).

Although pesticides enhance crop production, they could result in residue accumulation, which may affect the environment by contaminating surface water, through runoff from treated plants and soil, or through spray drift at some point of application (Perez-Lucas et al., 2018). Pesticide usage may also affect soil and beneficial soil organisms, birds and bees, as well as non-target plants and animals (Gogo et al., 2014; Macharia, 2015; Ntow, 2008). Furthermore, pesticide exposure is related to high human health risks (Teklu, 2016). According to the World Health Organization, about 3,000,000 people are poisoned with pesticides and about 220,000 die in developing countries every year (Lah, 2011). About 2.2 million people, mostly from developing countries, are highly risked to exposure from pesticides (Hicks, 2013). The effect may be severe in groups which are more exposed to pesticides like production workers, formulators, sprayers, mixers, loaders and agricultural farm workers (WHO, 2019).

This being said however, pesticide use in Ethiopia is increasing like other developing countries, to reduce production losses due to pests (Tamiru et al., 2017). The government extension systems support the use of pesticides, claiming that farmers have no substitute for its usage as an extension package (Damte & Tabor, 2015; B. Mengistie et al., 2014; MOA, 2013). According to Wilson and Tisdell (2001) pesticides are supported by market forces because: 1) Pesticides are frequently considered to be more productive than they actually are due to the lack of knowledge regarding their productivity; 2) They are part of the high yielding variety of seeds, in which high yields would not be achieved without the use of pesticides; 3) Chemical companies encourage pesticide use in production; 4) The rules and regulations that govern pesticide use are not strictly enforced. As a result, use of pesticides may be promoted over the use of other pest management approaches.

The current study focused on maize productivity. Maize is a major food security and cash crop in Ethiopia with the greatest production, accounting for 30.08% (9.2 million tons) of a total 87.97% (30.6 million tons), cereal production (CSA, 2018). In terms of cultivation, it has the second most cultivated area next to Teff (*Eragrotis tef*). Moreover, maize supplies over 21% daily calorie intake and is consumed directly as human food in different forms in Ethiopia (Dorosh & Minten, 2020). Ethiopian farmers grow maize primarily for subsistence, with 75% of output consumed at home (CSA, 2018). This shows that increasing productivity has implications for poverty reduction and economic development of the country. Besides, it could also create employment and income for tens of millions of people (Keno et al., 2018). Although maize is important as a principal food crop, its average yield in Ethiopia (3.6

tons/ha) is still lower than the world's average (5.6 tons/ha) (FAO, 2017). This is attributable to various biotic factors threatening its production. A cross-country study conducted in Ethiopia, Tanzania, Kenya, Uganda, Malawi and Rwanda, for example, showed that a combined annual loss of 0.9-1.1 billion USD is noticed due to the invasion of insect pests on maize farms (Pratt et al., 2017).

This has resulted in increased expenditure on pesticides among maize producers (Demissie et al., 2008; Emama et al., 2015; Tamiru et al., 2017). Without proper knowledge on the productivity of pesticides, farmers are increasing dosage and frequency of pesticide use (Negatu et al., 2016). However, increased pesticide expenditure lowers farm income (Rao & Morimoto, 2020). Medical costs associated with pesticide exposure also have negative effect on farm income (Pimentel, 2005; Sheahan et al., 2017). Therefore, there is a need to analyse the productivity effect of pesticides and determine whether farmers can benefit financially by increasing investment on pesticides. Using panel data collected in southern Ethiopia, this study contributes to the agricultural productivity literature by presenting econometric estimates on the impacts of pesticides on maize productivity considering the damage abatement roles of pesticides.

1.2 Statement of the Problem

The main idea behind the green revolution was the introduction of modern technologies (i.e. improved seeds, chemical fertilizers, pesticides and irrigation facilities) in order to address the problems of food insecurity and malnutrition around the world (Gollin et al., 2005). Such technologies were seen to be the important reasons for the success of Asian countries with the green revolution (Colman & Young, 1989; Gollin et al., 2005). With the use of pesticides together with other technologies, farmers were able to increase agricultural productivity, achieve food security and transform the agricultural sector across the globe (Gollin et al., 2005). However, agricultural production is challenged with the misuse, overuse and abuse of these chemicals (Schreinemachers & Tipraqsa, 2012).

In light of this, there are three strands of literature that have studied pesticides. The first strand of the literature exclusively focused on the negative consequences of pesticides use and knowledge, attitude, and practices of pesticides. It was found that most farmers did not use protective equipment and lack pesticide related training and knowledge, which explains the reason for the exposure of farmers to health risks (Nigatu et al., 2016; Amera & Abate, 2008). Moreover, there are several case studies conducted on knowledge, attitudes, perception and unsafe use of pesticides among farmers (Damte & Tabor, 2015; Gesesew et al., 2016; Tilahun & Hussen, 2014). However, all of the above studies showed that poor practice and lack of knowledge among farmers resulted in pesticide overuse and misuse, but none of them quantified the amount of pesticide overused. Furthermore, few studies stressed on the pesticide use practice among smallholders but did not provide quantitative information on the link between pesticide usage and productivity (Gizachew, 2011; Mengistie et al., 2017; Negatu et al., 2016).

The second strand of literature tried to address some of the weaknesses of the first types of studies. For instance, early studies by Campbell (1976), Carlson (1977) and Headley (1968) have been conducted to analyse the productivity of pesticides in Columbia and the USA. Another study in Malawi was carried out to analyse the impact of sustainable intensification practices on food security (proxied by maize productivity), and production risk (Kassie et al., 2015). In this study, pesticides were measured as a dummy variable (i.e., 1 for adoption and 0 otherwise). Several studies in Ethiopia have also been conducted in line with the second strand of the literature. Abro et al. (2017), for instance, analysed the effects of rust-resistant varieties on wheat yield. However, pesticides in this study were treated like other productive inputs (i.e., labour and fertilizer), which biases implications regarding pesticide productivity. Similarly, Getachew & Degu (2019) analysed the effect of technology adoption on crop production, using a fixed effects model. The use of fixed effects eliminates the effect of time invariant variables in the model. Moreover, the treatment of pesticides as standard inputs has led to the underestimation of pesticide productivity. Another cross sectional study by Semreab (2018) analysed the impacts of technology adoption on Teff productivity in Ethiopia.

Nonetheless, the studies in the second strand of the literature uses traditional production functions in which all inputs are treated similarly, i.e., they are considered to contribute to production in the same way. These studies were criticized to produce an overestimate of the marginal productivity of pesticides because they ignore the true nature of pesticides as damage abatement agents (Lichtenberg & Zilberman, 1986). According to Lichtenberg & Zilberman (1986), who are a pioneer on the econometrics of pest control, these studies might be misleading regarding the marginal effect of pesticides since the damage control framework is not properly accounted for.

The last strand of the literature, which is also the focus of this study, estimates productivity by considering the unique characteristics of pesticides as a damage control agent (Carrasco-Tauber & Moffitt, 1992; Grovermann et al., 2013; Huang et al., 2002; Praneetvatakul et al., 2002; Sun et al., 2020; Wang et al., 2018; Zhang, Guanming, et al., 2015). This line of the literature addresses the key weaknesses of the second strand of the literature by treating pesticides as a damage control agent and modifies the production function to account for the non-linear relationship between productivity and pesticides use. For example, Carrasco-Tauber & Moffitt (1992), Jha & Regmi (2009) and Wang et al. (2018) estimated the productivity of pesticides for the year 1987, 2006 and 2016 respectively. However, due to the cross-sectional nature of their data used, productivity variation across time was not captured. Moreover, these studies did not control for fixed effects. The inclusion of fixed effects is crucial to capture spatial and temporal variation in the data (Carpentier & Weaver, 1997). Grovermann et al. (2013) and Schreinemachers et al. (2020) also analysed pesticide productivity in Southeast Asia. However, these studies did not exclusively study the financial return that farmers can get with the use of pesticides. They mainly focused on the social problems. Moreover, recommendations from these studies may not suit well, as there is difference in the political and economic structure between different countries. Overall, the studies in this line are few and emerging.

From the above studies, we can see that despite all the controversy about pesticide use and hazardousness, little empirical evidence exists about the relationship between pesticides and productivity and little is known about whether farmers are getting enough return from their investment in pesticides. While this thesis acknowledges that previous studies have provided insights into many areas of pesticide issues, it argues that there are still considerable gaps in our understanding of whether pesticides are "overused" or "underused" by Ethiopian farmers. To fill this gap, we define and measure productivity in the context of economic rationalization by estimating the marginal productivity of pesticides. Estimating the marginal productivity of agricultural pesticides may: 1) offer certain conclusions regarding agricultural production efficiency in terms of private costs and returns and give some information about the economic context within which farmers operate; and 2) give an indication of the cost, (i.e., in terms of agricultural output lost), of limiting pesticide use for the sake of protecting the environment. Therefore, by using a production function with exponential damage control specification, this paper estimates the productivity of pesticides in Ethiopia.

1.3 Research Questions

This paper aims at addressing the following research questions using panel data collected in Hawassa-Zuria District, southern Ethiopia:

i. What are the factors affecting pesticide use?
ii. To what extent did use of pesticides increase maize productivity?
iii. Are pesticides overused or underused in maize production?

1.4 Objectives of the Study

1.4.1 General Objective

The general objective of this study is to estimate the productivity of pesticides in southern Ethiopia.

1.4.2 Specific Objectives

The Specific Objectives are to:

i. Examine factors affecting pesticide use,
ii. Estimate the marginal productivity of pesticides,
iii. Estimate marginal product and optimal amount of pesticides, and
iv. Generate policy implications.

1.5 Hypothesis of the Study

This study is designed to test the hypothesis that:

i. Pesticide quantity measured in litre per hectare (l/ha) has a positive effect on maize productivity,
ii. Pesticide quantity is negatively related to price of pesticide quantity, and
iii. Pesticide quantity is negatively related to contact with extension agent.

1.6 Significance of the Study

Results of our analysis have implications for the continuing debate on the role of chemical pesticides in agricultural productivity. Moreover, the study will give direction on what must be done to sustain agricultural productivity and improve the welfare of farmers, which are the main actors of the sector. It also serves as a basis for future related research works.

1.7 Scope and Limitation of the Study

The major focus of this study is to analyse the productivity of pesticides in Ethiopia. Related issues such as theory and measurement of agricultural productivity and pesticide productivity measurement were part of the study. The research area selected for the survey study was southern region of Ethiopia. This means interpretation and generalizations of the study are limited to these areas.

The major limitation of the study is that it failed to incorporate the human health and environmental costs associated with pesticide use in the estimation of production function and optimal use of pesticides.

1.8 Organization of the Study

The rest of the thesis is organized as follows; Chapter 2 reviews the theoretical and empirical literature and develops conceptual framework of the study. Chapter 3 presents the research methodology. This section includes the data type and sources, sampling and survey design, as well as data processing and analysis. It also outlines the regression model used in the study. Chapter 4 concentrates on presentation and discussion of results and findings of the study. Finally, Chapter 5 presents the summary, conclusion and policy recommendations of the study.

CHAPTER TWO
LITERATURE REVIEW

2.1 Theoretical Literature

2.1.1 Definition of Key Concepts

Pests: include all animals or plants which are harmful to humans or human concerns. Agricultural pests include animals, insects, fungi, viruses and bacteria that lead to loss of crops or reduction in crop yield (Sexton et al., 2007).

Pesticide: according to FAO and WHO's definition; "Pesticide means any compound or mixture of compounds designed for the purpose of killing, reducing, controlling or repelling pests. Agricultural pesticides are chemicals that farmers use to keep pests from reducing the growth and productivity of agricultural crops (FAO & WHO, 2019). This definition of pesticide is consistent within this study.

Pesticide Overuse/underuse: is defined as the application of pesticides at a sub-optimal level. Optimum amount is where the marginal returns from the use of pesticides equals its marginal cost (Grovermann et al., 2013).

2.1.2 Pesticide Use in Ethiopia

Pesticide use in the Ethiopian agriculture was introduced with the establishment of commercial farms in the early 1960s (EPA, 2004; MoA, 2013). After its introduction, smallholder farmers began using pesticides following the implementation of integrated package project including the Chilalo Agricultural Development Unit (CADU), Wolaita Agricultural Development Unit (WADU), and Minimum Package Project (MPP) under the Extension and Project Implementation Department (EPID) of the Ministry of Agriculture (Tadesse, 2016)

Import of pesticides also started in that period with the objective of intensifying government-owned agricultural farms and controlling malaria (EPA, 2004). The country imported 3,800 tonnes of pesticides annually. Of this, 80% were used by commercial farmers while the remaining 20% were used by small-scale farmers (Loha et al., 2018).

Even if most of the pesticides are imported, some pesticides are formulated locally. The country has a pesticide formulation plant near Adami Tulu (Tadesse, 2016). The Adami Tulu pesticide Plc. is the only company producing pesticides in Ethiopia. Between 2000 and 2012, a total of 17,662 tonnes (t) of pesticides were formulated both for agricultural and public health purposes. Out of this, a significant share (8,858t) was used by the public health sector (MOA, 2013).

Recently, many studies have shown that pesticide usage in Ethiopia is on the rise (Amera & Abate, 2008; B. T. Mengistie et al., 2017; PHRD, 2015; Tamiru et al., 2017). Research indicates that pesticides were utilized by producers for a number of objectives including insect, fungus / mould / rust, rodent, and weed control and veterinary use (Kalayou & Amare, 2015)**.** Although the volume fluctuates across pesticide types, a total of 4,128 tonnes of pesticides were used in Ethiopia in 2018. From this, herbicides accounted for the largest share (75%), followed by insecticides (15%) and fungicides (9%), while the remaining 1% included others such as rodenticides and disinfectants (FAO, 2020).

2.1.3 Pesticide Policies in Ethiopia

Policies are important for the implementation of any regulations by the government. Considering the risks related to pesticide usage, the Ethiopian government has developed pesticide manufacturing and usage rules as well as adopted and approved different international conventions and agreements. The Ministry of Agriculture (MOA) and the Regional States' Agriculture Bureaus are the primary government entities in charge of pesticide policy regulation and implementation (Mengistie, 2016).

The first pesticide regulation was the Plant Quarantine Decree No. 56 of 1971. This was a single article which assigned the Ministry of Agriculture (MOA) with regulating pesticide imports, manufacture and sales in the country. Crop Protection and Regulatory Division was created within the MOA, in 1972. Although pesticide use and sell spread rapidly due to emphasis on pest control, the decree was not effective in establishing a pesticide registration mechanism.

Later on in 1990 another decree, The Pesticide Registration and Control Special Decree No. 20 was established. Pesticide registration was granted based on its effectiveness and safety to humans, non-target organisms and the environment. The decree was based on FAO's recommendations which included 5 sections and 29 articles. This decree prohibited the manufacturing, importation, sale or use of unlicensed pesticides. However, it was insufficient because it did not cover international obligations and agreements to which Ethiopia is a member of. Moreover, lack of definition of key terms, lack of scope and little power given to inspectors and authorities in combating illegal trade were among the major drawbacks.

In order to address the problem with previous policies and to deal with the increasing quantity and types of pesticide imports, the government of Ethiopia formulated the Pesticide Registration and Control Proclamation No. 674 in 2010. This is the current proclamation which aims to establish a control mechanism that minimizes the detrimental effects of pesticides to humans, animals and the environment. It also recognizes the need for comprehensive control of pesticide manufacturing, formulation, importation, exportation, storage, distribution, sale, use, and disposal. Under this proclamation, all pesticides ought to be registered by a pesticide registration team before they are imported (FDRE, 2010).

2.1.4 Environmental Policy

The 1995 Constitution of Federal Democratic Republic of Ethiopia Proclamation No 1, article 43 stated that “people have right to a clean and healthy environment and proper compensation provision”(FDRE, 1995). Monetary or alternative compensation is needed whenever the livelihoods of people are adversely affected by any development project undertaken by the government.

The environmental policy of 1997 provides general guidance on the conservation and sustainable use of the country’s natural resources. The objective is to enhance the country's long-term socio-economic development by proper management of natural resources (Damtie & Bayou, 2008). This requires the prevention of pollution while environmental regulations regarding soil husbandry and sustainable agriculture encourage the use of biological and cultural pest management approaches, as well as the protection of environmental health through adequate pesticide regulation (EPA, 2004).

2.1.5 Beekeeping Policy

The government of Ethiopia has established a policy for the apiculture sector under the agriculture Growth and Transformation Plan (MoFED, 2010), which is the Apiculture Resource development and Protection Proclamation of 2009 (No. 660). This proclamation presents guidelines for the authorization of beekeeping activities and for the conservation of biodiversity of honeybees together with the improvement of the apiculture and production of honey products. With regard to pesticide use, the proclamation states that “any person engaged in crop protection, shall have the responsibility to take proper precaution to damage that may occur to honeybees due to improper use of chemical pesticides”(FDRE, 2009).

2.1.6 Health and Environmental Risks of Pesticides

Use of pesticides has been reported to cause negative externalities on both animals and humans. In 2006, a report indicated that Ethiopian farmers and their families may be exposed to pesticide poisoning as a result of inefficient pesticide management (PAN-UK, 2006). Since pesticides are sprayed a few days before harvesting, consumers are frequently exposed to serious health concerns. The effect of pesticide use on the respiratory health of agricultural field workers was also investigated among 203 field workers from Ethiopia's upper awash region (Mekonnen & Agonafir, 2002). In a similar study, Mekonnen & Ejigu (2005) reported the exposure of 81 pest control workers to Chlorpyrifos and Profenofos (OCPs) during pesticide spraying. High rates of poisoning (71% cases) in Ethiopia were also observed on women and children (Gebremichael et al., 2013).

Additionally, pesticides may also have a negative effect on the environment and its ecosystem. Pesticides may contaminate aquatic rivers and ponds, posing risks both directly and indirectly to humans and animals that live in water or use water as a source of drinking (Deribe et al., 2011; Teklu, 2016; Yohannes et al., 2013). Reduction in honeybee has also been reported due to direct exposure to pesticides during pollination (Fikadu, 2020). Moreover, animals who feed on treated plants and seeds are also exposed to pesticide related diseases (Mengistie et al., 2016)

2.1.7 Theories and Measurement of Agricultural Productivity

Agricultural productivity is the measurement of the quantity of agricultural output produced for a given quantity of input or set of inputs. It is a measure of how efficiently inputs are used in agriculture to produce a given level of output (Krugman, 1994; Ruttan, 2002). Productivity is considered to be optimum when the combination of inputs provides the greatest output. Increased production resulting from improved productivity is essential (EEA, 2002).

Two ways of measuring productivity are the total factor productivity and partial factor productivity. Total factor productivity is a change in output resulting from a change in the level of all inputs, whereas partial factor productivity is the change in output resulting from a change in a single input (Colman & Young, 1989; Murray, 2016). The computed coefficients of partial factor productivity measure the marginal productivity of each input under specified assumptions.

The production function can be described in a variety of ways. The Cobb-Douglas production function presents the relationship between inputs and outputs in a generalized form. In addition, different econometric problems like multicolinearity, heteroskedasticity, and autocorrelation can be effectively treated (Bhanumurthy, 2002). However, it imposes restriction on the elasticity of substitution between inputs (Kim, 1992). Alternatively, the trans-log function allows estimation of partial elasticity of substitution for a variety of inputs. It is flexible and thus does not impose restrictions on the elasticity of substitution and returns to scale (Kim, 1992). However, there is a substantial correlation between the variables and interpreting the interaction terms is difficult (Kumbhakar & Lovell, 2000).

In addition to the above, there are other production functions like the Leontief and Constant elasticity of substitution (CES). The Leontief production function uses a fixed proportion of inputs and no substitution is possible (i.e. it assumes strict complementarity between inputs). This means that a change in one input without a change in another input has no effect on output (Sickles & Zelenyuk, 2019). The CES, on the other hand assumes that a change in input results in a constant change in the output (Arrow et al., 1961).

2.1.8 Measuring Marginal Productivity of Pesticides

The productivity effect of pesticides is measured in terms of the yield obtained by a producer as a result of reduced yield loss from pests. The value of output loss avoided as a result of pesticide use is a measure of pesticide productivity. One key feature in the damage abatement concept is the distinction between standard production inputs (i.e. land, labour, fertilizer etc.) and the damage control agents (i.e. pesticides, biological control etc.). This distinction is important because damage control inputs do not directly increase productivity as standard inputs do, but rather indirectly contribute to output by reducing the damage caused by pests.

Lichtenberg & Zilberman (1986) were the first to indicate the need to use the damage control framework to estimate a production function. They explained that specifications, that neglect the damage reducing characteristic of pesticides and treat them as standard inputs can overstate their marginal contribution. Previous studies incorporated productivity impacts of other factors to pesticides due to; misspecification of production functions; absence of information on pest infestation; and use of pesticide expenditure as a variable rather than total cost of abatement. In their analysis, Lichtenberg & Zilberman (1986), suggested that the actual output be considered as a combination of: 1)potential output (the maximum possible amount of output obtained from a given set of inputs); and 2) losses caused by damaging agents like pests and weeds, can help to improve understanding of the roles of damage control agents in production.

In the damage control framework, pesticide productivity can be estimated by its potential to destroy the pest or its contribution to the reduction of damage. Abatement can be calculated using the percentage of the target pest population that is destroyed by the use of pesticides (Lichtenberg & Zilberman, 1986). The production function is made up of a standard production input vector, Z, and an abatement function, G(X). G(X) is an abatement function with the features of a cumulative probability distribution specified on the (0, 1) interval. Maximum abatement is achieved at a point where G=1, which means that losses are equal to zero and actual output equals potential output. Alternatively, maximum destruction occurs at a point where G=0 which means that output is at the minimum level.

According to Lichtenberg & Zilberman (1986), the damage control function can be represented in four different specifications;

Exponential: $G(X) = \left(1 - e^{-\lambda X}\right)$

Logistic: $G(X) = [1 + e^{(\mu - \sigma X)}]^{-1}$

Weibull: $G(X) = \left(1 - e^{-X^{c}}\right)$

Pareto: $G(X) = \left(1 - K^{\lambda} X^{\lambda}\right)$;

Where G (.) represents the damage reduced by the use of pesticides; X is the amount of pesticide used and λ, μ, σ, c and k are the parameters to be estimated. These functions are incorporated into the production function as $Y = f(Z).G(X)$, where Y is the output, and Z's are the conventional production inputs.

2.2 Empirical Literature

2.2.1 Empirical Evidence from the Rest of the World

Many empirical studies have been done regarding pesticide productivity. Most of the studies differ with the methodologies they use. Early studies by Campbell (1976) and Headley (1968) estimated productivity of pesticides while considering pesticides as a productive input in the standard production function. Campbell (1976) analysed a sample of 57 tree-fruit farms in Okanagan Valley of British Columbia and concluded that a $1 expenditure on pesticides results in a $12 increase in output. The findings of this study further suggest that the marginal cost of pesticide reduction is greater than its benefits.

Headley (1968) evaluated the marginal productivity of pesticide in the United States, by using state level cross-sectional data for 1963. The results showed that $1 spent on pesticides increased the value of output by $4. This has led to the conclusion that productivity could be enhanced by applying more pesticides. However, the productivity effects of pesticides were probably overestimated because information on pest levels or the effects of other damage control factors were not considered in the analysis.

Asfaw et al. (2011) analysed the impacts of pesticides on cabbage productivity in Tanzania and Kenya. The authors included pesticides in the damage control framework. They also recognized potential endogeneity problems with pesticide use and used a two-stage least squares (2SLS) estimation to estimate the effect of pesticide on cabbage productivity.

Using data from a random sample of 47 apple trees in North Carolina, Babcock et al. (1992) studied the impacts of pesticide use on the quantity and quality of apple production. They measured the effects on quantity by including damage abatement function into the production function and concluded that fungicides reduce yield losses and quality degradation whereas insecticides reduce quality damage. They found that insecticides and fungicides are over applied in relation to the profit-maximizing level. In addition, the study supports the hypothesis that the use of the standard Cobb-Douglas (C-D) function overstates the marginal contribution of pesticides. At 41 pounds per acre of pesticide treatment, the C-D estimate of pesticide productivity exceeds the damage control estimate by 0.038 tonnes per acre.

Huang et al. (2002), using a production function with damage abatement term, studied the impact of pesticides and Bt cotton variety adoption on the productivity of cotton. Because pesticides are applied in response to pest infestation, the researchers suspect the possible endogeneity with pesticides and used a two-stage nonlinear least square method. Price of pesticides, farmer's perceptions of pest severity and farmer's contact with extension agents were used as instrumental variables. Results showed that farmers overuse around 10–40 kg of pesticides in the production of cotton in China. Rola & Pingali (1993), using a stochastic production function model that incorporated public health consequences of pesticides discovered that usage of insecticides was inefficient when health costs are considered.

On the other hand, choices of damage control specification were also seen to affect conclusions regarding pesticide productivity. For instance, Carrasco- Tauber & Moffit (1992), using the damage control framework analysed the cross-sectional data of 1987. They compared the standard C-D production function to various damage control specifications (i.e., logistic, Weibull and exponential). The exponential specification revealed that pesticide marginal productivity was less than unity, implying pesticide overuse, while others revealed pesticide underuse. Although the exponential form is commonly used to analyse pesticide productivity, there is no theoretical reason to prefer one functional form over another.

Richard & Chikuvire (2005) analysed pesticide use and farm-level productivity among smallholder farmers producing cotton in Zimbabwe. They used stochastic production frontier model considering the damage control nature of pesticides, to estimate pesticide productivity. The results showed that a $1 increase in pesticide expenditure resulted in a $2.03 worth increase in output. This shows that additional benefits could be derived by increasing expenditure on pesticides. However, this is an overestimate when human and environmental externalities are considered. In addition, determinants of pesticide adoption was also analysed using multiple linear regression. Results showed that pesticide usage increased with perceived crop loss from not applying pesticides and advice from chemical companies, while it decreased with access to extension service and knowledge of alternative pest control methods.

Jha & Regmi (2009) using data from a sample of Cauliflower and Cabbage growing households in Nepal analysed the impact of pesticides on productivity. The findings showed that the average farmer had a marginal productivity of pesticides which was close to zero. This indicates the overuse of pesticides. Although the optimal amount of pesticide was 680 grams of active ingredients, farmers on average applied 3.9 times higher pesticides than the optimum. Despite a very small increase in output resulting from pesticide use, more than 70% of the farmers overused pesticides. The findings propose that the National Integrated Pest

Management strategy and the Farmers' Field School curriculum be modified in order to achieve more effective pest control.

Zhang et al. (2015) conducted a research in China to estimate the impacts of pesticides on rice, cotton and maize production and calculate optimal amount of pesticides. Using a survey data for 2012 and 2013, a Cobb-Douglas production function with Weibull damage control specification was used in the analysis. The results showed that pesticides have a statistically significant positive productivity effect on crop yield. In Cobb-Douglas specifications, a 1% increase in pesticides would increase the yield of rice, cotton and maize by 0.05, 0.093 and 0.039%, respectively. According to Weibull damage control specifications, 1 kg of pesticides in rice, cotton and maize produced a marginal product of 71.06, 22.73 and 98.45 kg, respectively. However, 57, 64 and 17% of pesticides were overused in the production of rice, cotton and maize, respectively.

2.2.2 Empirical Evidence from Ethiopia

Empirical evidence to the area under study in the Ethiopian context is limited. Although estimating pesticide productivity was not their main objective, very few studies have analysed the effect of pesticides in their yield estimation. Others have either focused on the use practice of pesticides or their related effects.

Abro et al. (2017), using panel data of wheat farmers in Ethiopia, analysed the impact of rust resistant wheat varieties on productivity. Pesticides in this study were incorporated as one input which has a significant effect on wheat yield. However, in the production function analysis, no distinction was made between pesticides and other inputs (land, labour, fertilizer etc.); meaning that pesticides were not treated in a damage control framework. Results showed that use of pesticides positively affect production and the authors suggested that higher yield could be achieved by further increasing pesticide use.

Another study by Semreab (2018) was conducted to analyse the impacts of agricultural technology adoption (i.e. fertilizer, improved seed and row planting) on Teff productivity in Ethiopia using a cross-sectional data collected from 1200 households in 2012. The analysis was based on a multinomial endogenous switching regression to account for the endogeneity problem with technology adoption. However, herbicides were analysed as normal yield-enhancing inputs. Results of the regression showed that herbicides had a statistically significant positive effect on teff yield for non-adopters of technology.

A similar study by Getachew & Degu (2019) analysed the impact of technology adoption on wheat and barley productivity in Ethiopia, using fixed effects model. To account for the endogeneity problem with modern input adoption, the authors used a two stage procedure where first they estimated the effects of agricultural information on technology adoption and then used the predicted value to analyse the productivity effect. By treating pesticides together with modern inputs like fertilizer, the estimation results showed that pesticides increased the productivity of both wheat and barley.

Tamiru et al. (2017) analysed the adoption patterns and impacts of herbicides on labour productivity in Ethiopia. The findings revealed that smallholders' use of herbicides has increased dramatically. Based on data from large-scale Teff producers, they discovered a considerable labour productivity benefit of pesticide usage between 9 and 18%. They showed that herbicide use is substantially linked with proximity to urban centres, rural wage levels, and market access. The large growth in herbicide use in Ethiopia has substantial consequences for rural labour markets, health and environmental considerations, and capacity building for the development and successful implementation of herbicide regulatory measures.

Negatu et al. (2016) conducted a study in Ethiopia using a cross-sectional data of knowledge, attitude and practice among 601 farmers to investigate how farmers' characteristic and value impacts their pesticide using behaviour. The result indicated that farmers' gender, education level and attitude towards environmental protection have a substantial impact on their pesticide usage behaviour.

A similar finding was presented by Gesesew et al. (2016) who conducted a community-based cross sectional study among 796 farmers in Jimma Zone. They found that although farmers had awareness about pesticide exposure and the harmful effect of pesticides to human health, their practices were poor. They concluded that farmers in Ethiopia are highly exposed to pesticide and are likely to overuse/underuse them due to their poor practice.

Mengistie et al. (2017) analysed pesticide use practice among smallholder vegetable farmers in the Ethiopian Central Rift Valley (CRV). They conducted a cross-sectional study for the year 2014 and found that pesticides are abused, overused and misused by farmers in CRV. They used a social practice approach to discover that farmers misused pesticides, stored them improperly, ignored hazards and safety guidelines, did not utilize protective equipment while spraying pesticides, and disposed of pesticide containers improperly.

Fikadu (2020) assessed the practice of pesticide use and its effect on honeybee in Ethiopia. The results showed that both beekeeper and non-beekeeper farmers buy, store, and use pesticides on crops with little or no regard for the effect on bees. Pesticide usage was directly affecting the bees by poisoning, flight, and death as well as indirectly by harming honeybee's forage and thus resulting in low quantity and quality of bee products. Pesticide usage affected both the honeybee colonies and beekeepers, causing contamination of bee products and creating socio-economic conflicts among community members.

Tilahun & Hussen (2014) assessed pesticide usage, practice and risk in Gedeo and Borena Zones. The findings revealed that there is improper pesticide usage and practice in the studied locations, and the danger is considered to be high. Farmers acquire, store, apply, and dispose of pesticides without sufficient knowledge. According to the findings of this study, farmers lack adequate information on the safe handling and usage of pesticides. This might be linked to the scarcity of extension services and training. As a result, the study proposed that farmers' output be increased by improving extension services and developing training programs on pest control and the safe use of chemical pesticides.

Another study by Amera & Abate (2008) performed a cross-sectional survey to analyse pesticide usage, practice, and dangers in the Ethiopian Rift Valley, using 422 farmers chosen at random from 23 communities in the Arsi Negele and Ziway woredas. The findings revealed that 84.4 per cent of farmers rely only on farming for a living, 94.3 per cent of farmers use pesticides as an agricultural input, and 28.7 per cent of farmers use DDT for agriculture. The usage of protective equipment in the region was essentially non-existent, with 31 per cent of respondents claiming illness after spraying pesticide and 14.2 per cent indicating the occurrence of a health-related pesticide incident inside the household. Farmers were also given insufficient information on pesticide hazards, resulting in a lack of knowledge. Roughly half of the respondents said they utilized empty pesticide containers for water/food storage, and about 7% said they sold empty containers to others. About 31% of respondents kept pesticides anywhere in the house, and 6% kept pesticides even in the kitchen.

Sentayehu & Tibebu (2016) studied the impacts of herbicide use on wheat crops and honeybee populations in Ethiopia. The analysis of data revealed that the majority of beekeepers in Endamekhoni (Southern Tigray) have abandoned the use of herbicides in their wheat farms over the past and instead perform hand-weeding using family labour. They get a better yield and quality of honey. On the other hand, farmers in Dangila (Amhara region) and Agarfa (Oromia region) districts frequently use herbicides in their wheat farms. As a result, loss of population of bee colonies and reduction in honey product and quality is observed. Hence, the study calls for an integrated and sustainable crop-apiculture development strategy based on bio-intensive IPM and ecological principles and practices.

To sum up, from the above studies we can see that there were several empirical findings conducted on the productivity of pesticides using the damage control framework. There is however, scant empirical evidence on this area in the developing world and particularly in Ethiopia where there is limited number of studies.

2.2.3 Conceptual Framework

Based on the overall review of related theoretical and empirical literature, the conceptual framework for this thesis is shown in Figure 2.1, in which independent variables are placed together on the left but not in any order of significance. The dependent variable is placed on the right hand connected by an arrow. As argued in the previous studies (Grovermann et al., 2013; Huang et al., 2002) agricultural yield is jointly determined by the productive inputs and the damage control agents such as pesticides. The distinction is that productive inputs directly boost agricultural production, whereas damage control chemicals indirectly enhance agricultural production by minimizing losses due to pests (Lansink & Carpentier, 2001; Lichtenberg & Zilberman, 1986).

Firstly, it is important to note that pesticide use is determined by various factors. Price that farmers pay to purchase pesticides increases production cost of the farmers thereby reduces pesticide use. Contact with extension agent increases the information farmers have about pest infestation. Moreover, socioeconomic characteristics like age, gender and education level also have an impact on the decision to use pesticides. Older and educated people for instance are more experienced and thus tend to have lower pesticide use. Moreover, men are more likely to use more pesticides than women.

The link between pesticides and productivity can be understood through the damage abatement framework. Pesticide can indirectly contribute to production through reducing crop loss to pests and thus resulting in increased agricultural production. In addition to this, other inputs have direct effect on maize production.

Productive inputs like labour, fertilizer, irrigation, manure, etc., directly increase production. Farm and farmer characteristics like age, gender, education, family size etc. also increase productivity because more educated and experienced household are more likely to have higher productivity. Various production shocks like stem borers and fall armyworm, on the other hand, have a detrimental effect on maize output.

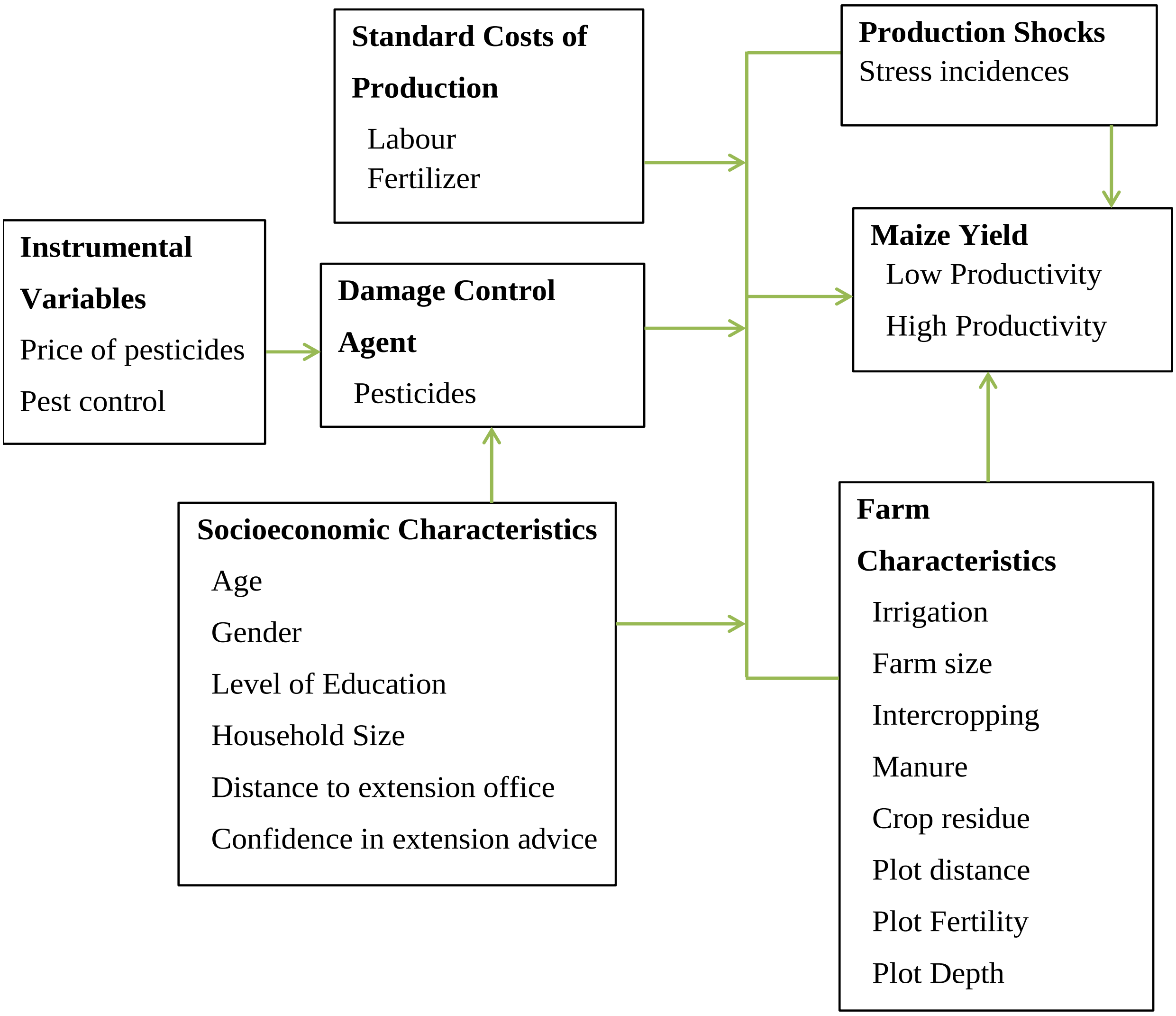

Figure 2.1: Conceptual Framework showing the relationship between independent and dependent variable.

Source: Own representation

CHAPTER THREE
DATA AND RESEARCH METHODOLOGY

This chapter presents a general description of the data and the empirical methodology used in the study. The first three sections discuss type and sources of data, study area and sampling design. The next section deals with methods of data collection and analysis. The last section presents the empirical model employed in the study and estimation strategies.

3.1 Description of the Study Area

The study was conducted in the Hawassa-Zuria District of the formerly Sidama Regional State, southern Ethiopia, which is located 290 km south of Addis Ababa and 20 km south-west of the regional capital, Hawassa. The district is one of the nineteen districts (woredas) in Sidama Zone. The district is administratively sub-divided into 23 villages (kebeles). Dore Bafano is the administrative capital of Hawassa Zuria district and is found 18 kilometres from Hawassa.

The district is bounded by Shebedino and Boricha on the south, the Oromia Region on the west and north, and Wondo Genet on the east. It has a total population of 124,472 people, with 62,774 males and 61,698 females (CSA, 2007). The annual mean maximum and minimum temperatures are 30°C and 17°C, respectively, while the annual mean rainfall is 1015 mm (Tefera & Kim, 2019).

This district was chosen for this study since it is one of the primary maize growing areas in the country. The agricultural practice of the district is mixed farming system (crop and livestock production). Other crops such as wheat, teff, barley, enset etc. are also grown. But maize covers the highest production (Kumela et al., 2019). Around 15% of total maize cultivated area and production in Ethiopia is covered by the region (Central Statistical CSA), 2017/2018). From this, the Hawassa-Zuria district accounted for 5 and 16% of total maize area and production in 2018 (Central Statistical Agency (CSA), 2018).

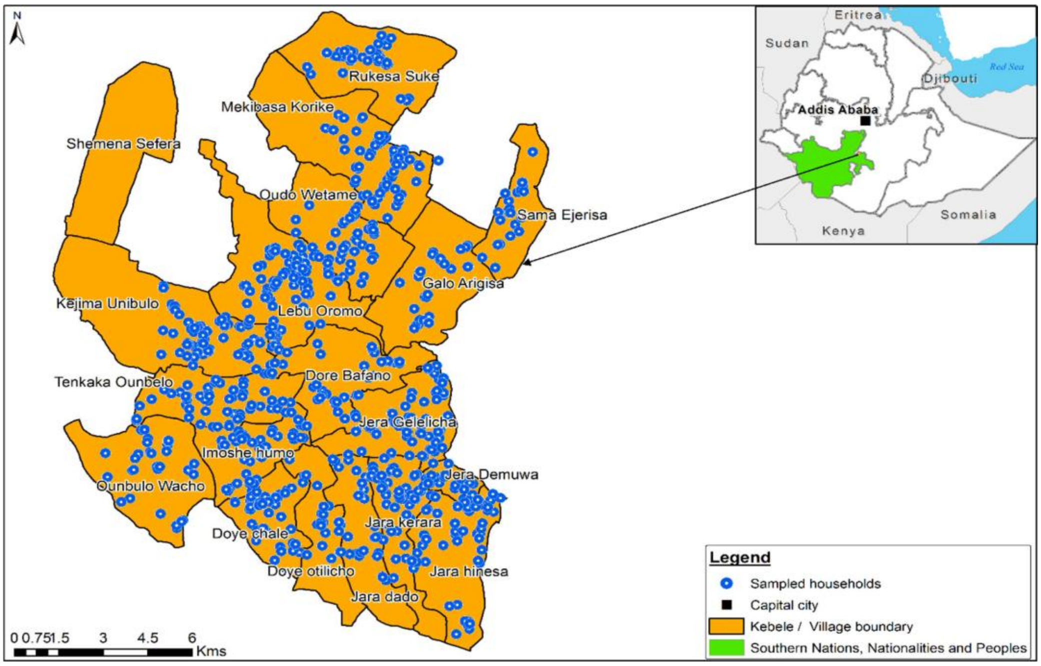

Figure 3. 1 Map of Hawassa-Zuria District
Source: (Kassie et al., 2020)

3.2 Data Type, Sources and Collection Methods

The study uses primary dataset obtained from the Social Sciences and Impact Assessment Unit of the International Centre of Insect Physiology and Ecology (*icipe*). As the research is intended to analyse the productivity of pesticides, primary data was collected from the household farmers via a structured questionnaire. The farm household survey data that were collected in two round field surveys conducted for the year 2018 and 2020 production season.

The questionnaire included information on socioeconomic characteristics of farmers (age, gender, level of education, family size) and plot characteristics (maize yield, farm size, intercropping etc.). Information on farm investment (labour, pesticides and chemical fertilizer), agricultural practices (use of irrigation and manure) and household assets (livestock, mobile) were also part of the questionnaire. These data were collected using Census and Survey Processing System (CSPro) software. Enumerators explained the aim and contents of the questionnaire and assured the confidentiality of the data submitted at the start of the interview. To participate, all respondents were asked for their verbal agreement.

3.3 Sample size and Sampling technique

A multistage proportionate random sampling was used to select sample villages and households. In the first stage of the sampling procedure, Hawassa Zuria was purposively selected based on the district's maize production potential. A sampling frame was then prepared in each of the kebeles of the district. The number of households varied depending on the size of the village (kebele). As a result, the sample size for each town was determined using the probability proportional to size sampling methodology. Based on this method, a total of 1,270 maize farmers were randomly selected from 18 villages out of the 23 villages in the district.

3.4 Data Analysis

The study uses both descriptive and econometric methods of data analysis. Descriptive statistics were used to present the summary statistics (mean and standard deviation) and relationships between variables. Econometrics methods were used to estimate the model and determine productivity of pesticides. Since pesticide use is a response to pest pressure there might be a potential endogeneity problem in estimating the model. Therefore, the production function was estimated using Non-linear least square (NLS) and two stages nonlinear least square (2SNLS) procedures. Moreover, the data analysis was done using STATA (StataCorp., 2015).

3.5 Empirical Econometric Model Specification and Estimation Strategy

In this thesis, we use a production function specified as a combination of the standard yield enhancing inputs and damage control agents (Lichtenberg & Zilberman, 1986). The productive inputs include fertilizer, land, labour, and so on, while the damage control agent refers to pesticides. The generic production function is written as follows in equation (1):

$$Y = F(\boldsymbol{Z})G(X); \quad (1)$$

where, Y is maize yield (kg/ha), $\boldsymbol{Z}$ is the productive inputs and X is the quantity of pesticides. $G(X)$ is the damage control function that monotonically increases in X and lies in the interval of [0, 1]. In our empirical specification, we use the Cobb-Douglas (C-D) production function. There are alternative specifications (Exponential, Logistic, Pareto and Weibull) that have been used to model the damage control role of pesticides (Blackwell & Pagoulatos, 1992; Carrasco- Tauber & Moffitt, 1992; Lichtenberg & Zilberman, 1986). Several recent studies have proven that the exponential specification gives robust results (Jha & Regmi, 2009; Pemsl et al., 2005; Skevas et al., 2012). This is because it allows for clearly decreasing marginal returns to pesticide use (meaning that pesticide productivity is less likely to be overestimated) (Schreinemachers et al., 2020). Therefore, we rewrite equation (1) to incorporate the exponential specification of the pesticides in the C-D production function as specified in equation (2):

$$ln\, Y_{ijt} = \alpha + \beta \ln \boldsymbol{Z}_{ijt} + \gamma S_{ijt} + \ln\left(1 - e^{-\lambda X_{ijt}}\right) + \delta \boldsymbol{F}_{ijt} + \theta \boldsymbol{H}_j + \rho \boldsymbol{V}_j + \varepsilon_{ijt}; \ldots\ldots\ldots\ldots \quad (2)$$

where α, β, γ, λ, δ, θ and ρ are coefficients to be estimated. The subscript *i, j and t* indicate the *ith* plot, the *jth* farmer and the *tth* year. $\boldsymbol{Z}_{ijt}$ represents a vector of standard production inputs like labour and fertilizer. S_{ijt} is a dummy variable for production shocks. X_{ijt} represents pesticides use. $\boldsymbol{F}_{ijt}$ is a vector of farm characteristics like farm size, irrigation, manure, and intercropping. $\boldsymbol{H}_j$ is a vector of household characteristics like farmers' gender, education, and family size etc. $\boldsymbol{V}_j$ is a vector of village (kebele) dummy variables to control for differences across villages. ε_{ijt} is the random error term with zero mean and constant variance.

Because the abatement function (λ) is nonlinear in the parameters, equation (2) is estimated using nonlinear least square estimation approach (Greene, 2012). A major problem in equation (2) is the potential endogeneity of pesticides use. As pointed out by Huang et al. (2002) farmers apply pesticides in response to pest pressure, which is not controlled in the model. Therefore, pesticide use might be endogenous i.e. high levels of infestations may be correlated with lower yields. Hence, the covariance of X and the residuals of the yield function might be different from zero $[Cov(X, \varepsilon_{it}) \neq 0]$. In other words, pesticides used by farmers may be endogenous to yields and a systematic relationship among pests, pesticide use, and maize yields may exist.

To avoid this econometric problem, we use an instrumental variable (IV) regression. Here, a two stage non-linear least square (2SNLS) estimator is used. In the first stage, a pesticide use model (Equation 3) is estimated. The empirical specification for pesticide use is developed as:

$$lnX_{ijt} = \alpha_0 + \alpha_1 \boldsymbol{IV}_{jt} + \theta \boldsymbol{H}_j + \rho \boldsymbol{V}_j + \varepsilon_{ijt} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

where, $\boldsymbol{IV}_{jt}$ is a vector of instrumental variables. The IVs include the price of pesticides (ETB/liter) and pest control extension service which represents the amount of information the farmer has about infestation, from interactions with extension agents (a dummy variable that is equal to 1 if the farmer met with an extension agent during the year, and 0 otherwise). Other variables are defined like equations (1-2).

In instrumental variable (IV) identification strategy, the basic condition for the validity of the instrumental variables is that IVs must be highly correlated with the endogenous variable $[Cov(IVs, X_{it}) \neq 0]$ and must be uncorrelated with the error term of the yield function $[Cov(IVs, \varepsilon_{it}) = 0]$. In our context, two variables serve as instrumental variables to estimate the pesticide equation. The price of pesticides and pest control extension service may affect the quantity of pesticides used by households, but are not directly related to maize productivity. Theoretically, the two IVs meet the criteria of appropriate instruments because they directly affect the endogenous variable but not maize yield, except through their impact on pesticide use.

To empirically account for endogeneity problem, equation (3) is first estimated using ordinary least square (OLS). The predicted value of pesticide use is then used in the estimation of the production function in the second stage (Equation 2). Moreover, since the damage-control production function is nonlinear in parameters, the ordinary least squares method cannot work. Therefore, the nonlinear least square (NLS) estimation method is used. Since we repeatedly observe the same units, it is usually no longer appropriate to assume that different observations are independent. Moreover, because each household has multiple plots, there is a possibility for heteroskedasticity of the error term. To avoid this problem, we employed heteroskedasticity clustered-robust estimators to correct the standard errors.

In addition, we need to calculate the marginal effect of pesticides on maize yield to measure the change in quantities of yield attributed to a 1 unit increase in pesticide usage. Since output is measured in quantity, partial derivative of the production function (Equation 2) with respect to pesticide gives the marginal product of pesticides. The marginal product of pesticide use can be written as:

$$\frac{\partial Y}{\partial X} = \lambda e^{\alpha} Z^{\beta} e^{-\lambda X} \quad \text{……} \quad (4)$$

From equation (4), we can obtain the optimal amount of pesticides by equating value of marginal product of pesticides (i.e., marginal product multiplied by price of maize) and marginal cost (i.e., price of pesticides). Then, we obtain:

$$X^{*} = \frac{1}{\lambda} * ln\left[\frac{\lambda e^{\alpha} Z^{*\beta} P_{y}}{P_{x}}\right] \quad \text{……} \quad (5)$$

Where X^* is the optimal amount of pesticides; P_y is the price of maize; P_x is the price of pesticides and other variables are defined as above.

An estimate of the marginal product of pesticides helps in determining the additional benefits or costs derived from increasing or decreasing pesticides use by 1 unit (Norwood & Marra, 2003). It also indicates the economically optimal level of pesticides and determines whether pesticides are over utilized or underutilized from the economic perspective. The optimal point is the application rate at which farmers' profit is maximized. It is a measure of the economic efficiency of chemical pesticides compared with alternative pest management strategies. The estimate of marginal product serves as a foundation to understand the costs and benefits of adopting alternative pest control methods.

Moreover, an estimate of value of marginal product (VMP) of pesticides can be compared to the marginal cost (MC) to measure the amount of disequilibrium in farmers' pesticide usage and it may also be used to estimate the total benefits of pesticides given the price of output and pesticide price (Headley, 1968). If VMP>MC, then additional benefits can be derived from increasing pesticide usage and thus reduction in pesticide use might reduce farmer's profit, however, if VMP<MC farmers can reduce their pesticide use without affecting their profit.

CHAPTER FOUR
ECONOMETRIC RESULTS AND DISCUSSION

This chapter presents the descriptive and econometric results of the analysis. In the first section, we present a brief description of the variables used in the analysis. In the second section, we discuss household's awareness about pests. In the third section, we assess the incidence of pests (fall armyworm (FAW) and stem borer (SB)) in the study villages. In the fourth section, we discuss pesticide use by household characteristics and pest incidence. Then, we present pesticide use by pest intensity and farm size. After that, we relate maize yield loss and pesticide use. Finally, we present the econometric results of the analysis.

4.1 Description of variables used in the analysis

Table 4.1 presents the descriptive statistics. A total of 1,270 households were selected for the study. Our key variable of interest is pesticide use, measured in liters per hectare (l/ha). Farmers were asked whether they used insecticides or herbicides on their plot and if they did, the total quantity (in l/ha) was recorded by the enumerators. We created pesticide variable which is a total of insecticides and herbicides used by farmers.

Maize is the most important food and cash crop grown in Hawassa-Zuria district. The average farm size is about 1.01 ha, but more than 70 per cent of it is allocated to maize cultivation. The sample households grew maize on more than 1.7 plots on average (about 4,428 plots from 1,270 households in both years).

The study used an unbalanced panel data of two years (2018 and 2020). The respondents were residing in a place which is on average 1729.633 meters above sea level (masl) with a minimum of 1492 and maximum of 2054 masl. The majority (95%) of the respondents were males, aged 44 years on average which shows that relatively younger farmers are involved in farming. It is shown that age of the households ranged from 18-90 years. On average, six members are found in each of the household with numbers ranging from one to thirteen. Educational status of households show that around 27.1% of the respondents are illiterate, 54.7% have primary education, while the remaining 18.2% have attended secondary school or above.

Table 4. 1 Definition of variables and summary statistics

Variable	Mean	Std. Dev.	Min	Max
Outcome Variable				
Maize yield	3602.98	1783.37	200	16000
Plot investment				
Pesticide use (liter/ha)	0.79	2.41	0	40
No pesticides used (1/0)	0.74	0.44	0	1
Price of pesticides (ETB/liter)	277.10	49.10	89.40	640
Fertilizer use (kg/ha)	213.03	141.95	0.01	1327.30
Hired labor (1/0)	0.41	0.49	0	1
Plot Characteristics				
Good plot fertility (ref)	0.70	0.46	0	1
Medium plot fertility (1/0)	0.27	0.44	0	1
Poor plot fertility (1/0)	0.03	0.17	0	1
Flat plot slope (ref)	0.79	0.41	0	1
Medium plot slope (1/0)	0.18	0.39	0	1
Steep plot slope (1/0)	0.03	0.16	0	1
Shallow depth plot (ref)	0.20	0.40	0	1
Medium depth plot (1/0)	0.22	0.42	0	1
Deep depth plot (1/0)	0.58	0.49	0	1
Black soil type (ref))	0.45	0.50	0	1
Brown soil type (1/0)	0.18	0.39	0	1
Red soil type (1/0)	0.02	0.15	0	1
Grey soil type (1/0)	0.35	0.48	0	1
Farm size (ha)	1.01	0.63	0.19	3.50

Variable	Mean	Std. Dev.	Min	Max
Manure/Compost (1/0)	0.46	0.50	0	1
Irrigation (1/0)	0.02	0.13	0	1
Previous crop maize (1/0)	0.44	0.50	0	1
Crop residue (1/0)	0.32	0.47	0	1
Maize-Legume intercropping (1/0)	0.19	0.40	0	1
Stress incidence (1/0)	0.86	0.34	0	1
Plot distance from residence (1/0)	33.80	59.17	0	240
Household Characteristics				
Sex of household head (1/0)	0.95	0.22	0	1
Age of household head (years)	43.97	11.65	18	90
Education of household head (years)	5.01	4.43	0	17
Household size (numbers)	5.88	1.71	1	13
Distance to extension service office (walking minutes)	30.29	25.10	1	190
Pest control extension service (1/0)	0.56	0.49	0	1
Household confidence in extension service (1/0)	0.94	0.24	0	1
Mobile phone ownership (1/0)	0.73	0.44	0	1
Livestock (ETB)	41892.55	40950.61	0.01	256700
Altitude(Meters)	1729.63	50.56	1492	2054
Number of plots (households)				4,428(1270)

Source: Own representation

4.2 Households' awareness of Pests

Households were asked different questions regarding their awareness about pests on the farm. Enumerators also showed pictures of the major pests and recorded their response. Table 4.2 shows that out of a total of 1,270 respondents, 1,130 of them were aware of both FAW and

SB while only 64 of them were unaware of both types of pests. This means that awareness of pests among households in Hawassa-Zuria district is high. The remaining 76 of the respondents were either aware of fall armyworms or stem borers. Since farmers use pesticides and other damage reducing methods in response to pest infestation, awareness of these pests is of great significance in pest management.

Table 4.2 Households' awareness about FAW and SB

Awareness of FAW	Awareness of SB		
	No	**Yes**	**Total**
No	64	56	120
Yes	20	1130	1150
Total	84	1186	1270

Source: Author's Computation

4.3 Pest incidence in households' maize plot

In Table 4.3, we present pest incidence in the maize plot of farmers in Hawassa-Zuria district. In the district, around 3,441 maize plots were infested by FAW and/or SB. This accounts for over 75% of the total maize plots of the sample farmers, which is a significant amount. Only 987 plots were not affected by these pests.

It is also seen that FAW, occurring in 3,234 plots, are the major pests threatening farmers' maize plot. Next to these are stem borers which occur on 2827 maize plots. This calls for the use of different pest control methods in the district. Extension agents need to do their part in introducing pest control methods that could significantly reduce pest damage while maintaining human and environmental safety.

Table 4.3 Incidence of FAW and SB in the household's maize plot

FAW incidence	SB incidence		
	No	**Yes**	**Total**
No	987	207	1194
Yes	614	2620	3234
Total	1601	2827	4428

Source: Author's Computation

4.4 Pesticide use by household characteristics

Pesticide application levels differ across farmers' characteristics: sex, age, and education of the household. From Table 4.4, we observe that male-headed households relatively apply higher dosage of pesticides and incur higher costs than female-headed households in the district. Pesticide is even mostly used by male-headed households. Out of a total of 1,147 pesticide users, only 56 of them were females. With respect to age, pesticides are often used by households in the adult age group (i.e., 1082 adults using pesticides). Adults even apply a relatively higher dosage of pesticides. However, they incur less cost than those in the old age category. This might be because of price difference among various types of pesticides reflecting the quality of pesticides in the market.

Pesticide use by education status shows that quantity and cost of pesticides reaches a peak level for farmers with primary education. This figure is however slightly lower for farmers with secondary education and above which implies that, pesticide use reduces as farmers attend higher levels of education. This might be because more educated farmers have a better understanding of the negative effects of pesticides compared to the less educated ones (Mengistie et al., 2017; Schreinemachers et al., 2017). Source of pest control information also has an effect on the amount of pesticide used. Information from pesticide dealer, for instance, is likely to increase pesticide use than information from a research institute (Huang et al., 2001).

Table 4.4 Pesticide use by households' characteristics

Farmer's Characteristics	Frequency	Pesticide use per hectare	
		Quantity(liter)	Cost(ETB)
All farmers	1147	2.95	657.89
By sex of the head			
Male	1091	3.0	661.4
Female	56	2.36	588.8
By age			
18-24	11	2.32	351.89
25-64	1082	2.98	657.55
> 65	54	2.82	727.0

By education			
Illiterate	242	2.72	635.1
Primary school	692	3.04	664.45
Secondary and above	213	3.0	662.39
By source of pest control information			
icipe	394	2.35	515.0
Government extension service	203	3.4	762.32
Neighbor farmer	13	1.15	134.65
Farmer training/field school center	155	4.7	1154.9
Others	174	2.4	546.3
None	208	3.0	582.45

Source: Author's Computation

4.5 Pesticide uses by pest incidence

Figure 4.1 below shows the percentage of pesticide use by pest incidence. We can see that significant amounts (76.82%) of pesticides are used in areas where there is incidence of both fall armyworms and stem borers. However, percentage of pesticide quantity used in plots with no FAW or SB incidence (5.32%), is higher than those with SB incidence (1.42%). This may be due to the insufficient knowledge that farmers have about pests. A study in Ethiopia claims that farmers who are less literate are more likely to apply pesticides haphazardly, without identifying diseases and pests (Mengistie et al., 2017; Negatu et al., 2016). Another reason could be that the incidence of other diseases and insects like (cutworms, earworms, weevils etc.) in these plots.

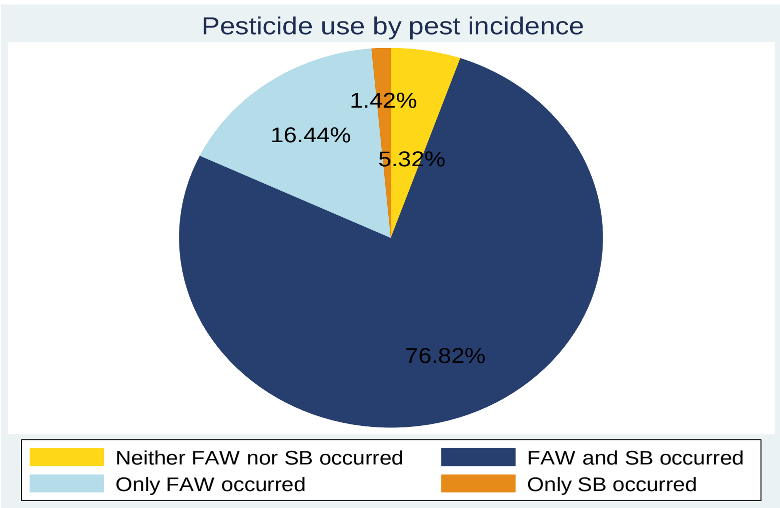

Figure 4. 1 Pesticide uses by FAW and SB incidence

Source: Author's computation

4.6 Pesticide use by FAW and SB intensity

Figures 4.2 and 4.3 below, shows difference in pesticide use for different levels of pest intensity (high, medium, and low). Both figures show that pesticide quantity increases with pest intensity. In Figure 4.2 pesticide quantity has reached a peak level of 3.1 liters/ha for a high level of FAW. In figure 4.3 we see that an average of 5.9 liters/ha is used in plots with high stem borer intensity. This is because farmers in Hawassa-Zuria district use responsive pesticide application technique, in which they apply pesticides in response to pest infestation. Therefore, higher intensity leads to higher pesticide application (Huang et al., 2002).

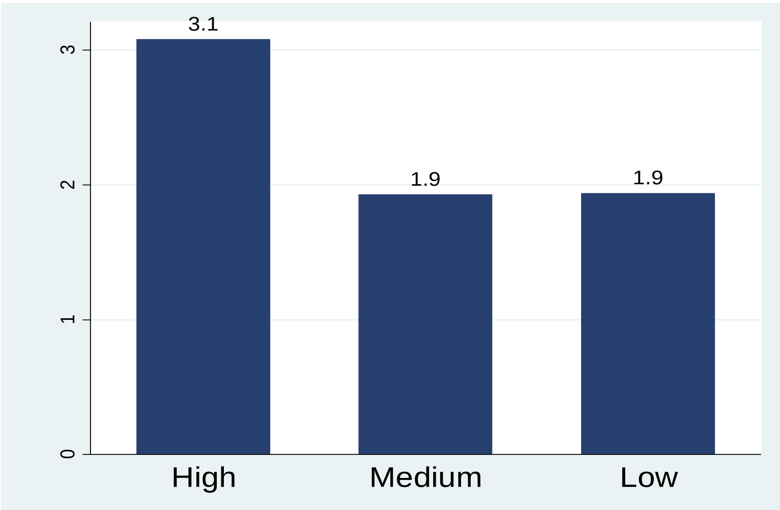

Figure 4. 2 Pesticide quantities by FAW intensity

Source: Author's Computation

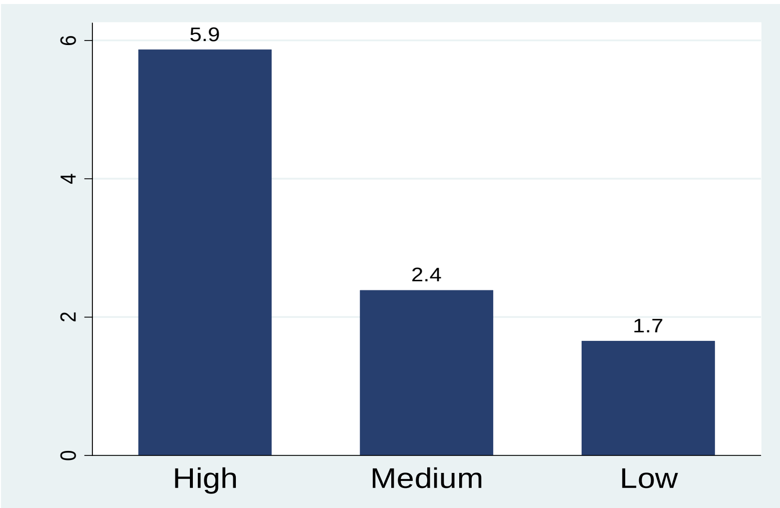

Figure 4.3 Pesticide quantities by SB intensity

Source: Author's Computation

4.7 Pesticide use by farm size

Figure 4.4 below illustrates the negative relationship that exists between farm size and pesticide quantity. We can see that pesticide quantity reaches a high level at lower farm size and reduces with an increase in farm size (Figure 4.4). The result is similar to a study in china (Wu et al., 2018; Zhu & Wang, 2021), which showed that farm size has a significant effect in reducing pesticide use. This can be attributed to two factors. 1) Pest control becomes more expensive, which means additional cost of production as farm size increases. 2) Large scale farmers generally tend to have richer knowledge and experience related to pesticide application and they are more closely supervised by the government which aims at reducing pesticide use.

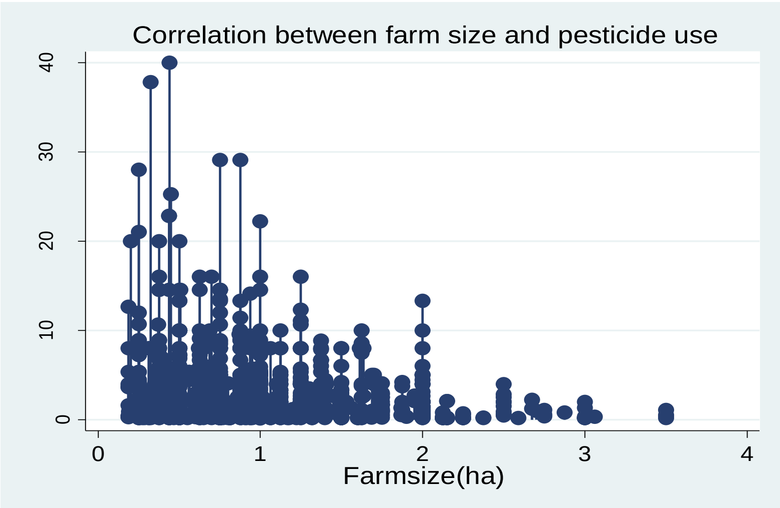

Figure 4.4: Correlation between farm size and pesticide use

4.8 Maize yield loss by pesticide use

Figure 4.5 below shows the effect of pesticide use on maize yield loss in Hawassa-Zuria district. The value, 0 is for the farmers who did not use pesticides and 1, is for those who used pesticides in their production. We can see that mean percentage of maize loss to fall armyworms and stem borers have reduced significantly as a result of pesticide use. In plots with no pesticide use, an average of 27% and 17% of maize yield is lost to fall armyworms and stem borers, respectively. This figure is however relatively lower in plots that receive pesticides. We observe that damage abatement effect of pesticide results in more than half times less yield loss in plots that receive pesticides than those which do not receive pesticides. This implies the positive productivity effect of pesticides on maize in Hawassa-Zuria district.

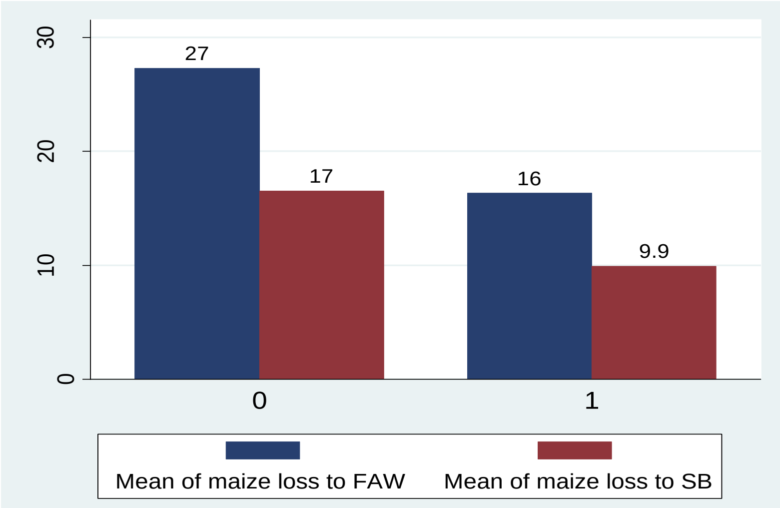

Figure 4.5: Maize yield loss due to FAW and SB

Source: Author's Computation

4.9 Econometric Diagnostic Tests

4.9.1 Multicollinearity Test

Multicollinearity is the correlation between independent variables included in the model. The interdependency between regressors might cause weak statistical inferences and bias conclusion regarding their relation with the dependent variable (Gujarati & Porter, 2009). We used the variance inflation factor (VIF) to check for the presence of multicollinearity problem among the explanatory variables included in the empirical model. From the test, we obtained a mean VIF of 1.73, which is below the rule of thumb 10. This indicates that multicollinearity might not be a problem in this study.

4.9.2 Heteroskedasticity Test

Heteroskedasticity refers to a situation in which the variance of the error term is unequal across observations (Wooldridge, 2002). The presence of heteroskedasticity biases parameter estimates and causes prediction from the regression to be inefficient. Therefore, it is important to check whether error terms possess constant variance or not.

To detect this problem, we used the Breusch-Pagan test of heteroskedasticity. Here, we test the null hypothesis of constant (homoscedastic) variance against the alternative hypothesis of non-constant (heteroskedastic) variance. With a p-value of 0.0000, the test rejects the null hypothesis of constant variance. This calls for the need of using clustered-robust standard errors, which accounts for heteroskedasticity across clusters of observations. To capture the dependency of plots within households, we cluster the standard errors by household.

4.9.3 Endogeneity Test

In econometrics, the problem of endogeneity arises when explanatory variables are correlated with the error term (Gujarati & Porter, 2009). A test for endogeneity was therefore conducted using Hausman (1978). The test is run by estimating a two stage C-D production function with both predicted and actual levels of pesticides. An F-test is then used to test whether the coefficient in predicted values of pesticide is significantly different from zero. The test rejects the null hypothesis of exogeneity at 5% level of significance, which means the endogeneity of pesticides must be controlled in the estimation.

Table 4.5 Hausman Test of endogeneity

Test for pesticide use (liter/ha)	**H0: Variable is exogenous**
Wu-Hausman F(1, 1269)	4.50
Prob > F	0.0341

Source: Author's Computation

4.10 Discussion of Econometric Results

While the main objective of this paper is to estimate the productivity of pesticides, we first begin by discussing the pesticide equation.

4.10.1 Pesticide Use Model

Table 4.6 illustrates the socio-economic factors affecting pesticide use in Hawassa-Zuria district. In the model, the first two variables (i.e., pesticide price and pest control extension advice), were used as instrumental variables explaining farmers pesticide adoption. Price of pesticide has a significant, negative effect on the amount of pesticide used by farmers. Other things constant, a 1 unit increase in the price of pesticides results in a 0.23% reduction in the quantity of pesticides used by farmers. This seems to indicate that price policies may not be effective regulation of pesticides. The reason for this could be: 1) the existence of market failure and information gap, among farmers on alternative pest control methods which reduces the substitutability of pesticides with other less harmful methods (UNDP, 2017); 2) Because farmers are already using a very small amount, an increase in price might not affect their profit.

Pest control extension service is significantly and positively related to pesticide use. Households who received pest control extension advice had a 5.9% higher pesticide usage than households who did not receive the advice. The result is consistent with the study from Northern China, which showed that pest information from extension agents resulted in higher use of pesticides (Huang et al., 2001). This may be due to the poor quality and source of extension service received by farmers. Moreover, because farmers are using insignificant amount of pesticides extension officers may promote its use to achieve a more efficient pest control. Table 4.6 also shows the link between other variables and pesticide use. These variables were also used in the production function estimation (Table 4.8). Use of manure or compost had the expected significant and positive effect on the quantity of pesticides used. Other things constant, plots which received manure or compost had a 5.5% higher pesticide usage than plots which did not receive. This might be because application of manure or compost attracts pests and increases pest infestation thereby leading to higher pesticide usage.

Household characteristics are also hypothesized to influence pesticide use in the district. Sex of the household heads had a significant, positive effect on pesticide use. Male households had a 6.9% higher pesticide usage than female households in the district. Moreover, the coefficient on farm size is negative and statistically significant which indicates that a 1% increase in farm size is associated with a 0.11% reduction in the quantity of pesticide use. The result is consistent with a recent study in China which suggests the promotion of relatively large-scale farms in order to reduce the intensity of pesticide use (Zhu & Wang, 2021).

Mobile phone ownership also has a significant, negative effect on pesticide use per hectare. Other things constant, households who owned mobile phones had a 5.54% less pesticide usage than those household who didn't own mobile phones. This is because having mobile phones increase the information flow between households, about pesticide related issues. As for other variables, the coefficients in age, education, and household size, livestock ownership and stress incidence (i.e. incidence of fall armyworm, stem borers and other shocks in the farmers' field) are statistically insignificant which indicates that these factors have no significant effect on the quantity of pesticides used.

Table 4.6 Estimation of farmers' pesticide application (liter/ha, Log)

Variables	**OLS**
Pesticide price (ETB/liter)	-0.0023***
	(0.0002)

Variables	OLS
Pest control extension service (1/0)	0.0591***
	(0.0134)
Age of household head (years)	-0.0010
	(0.0007)
Sex of household head (1/0)	0.0691**
	(0.0323)
Education of household head (years)	-0.0015
	(0.0019)
Household size (numbers)	-0.0037
	(0.0039)
Mobile phone (1/0)	-0.0528***
	(0.0170)
Manure/Compost (1/0)	0.0551***
	(0.0122)
Farm size (ha), Log	-0.1166***
	(0.0244)
Stress incidence (1/0)	0.0130
	(0.0117)
Livestock Ownership (000's ETB), Log	0.0011
	(0.0022)
Constant	1.7896***
	(0.0860)
Number of households	1,270
Number of plots	4,428
R-squared	0.0935

Source: Author's Computation

Notes: Dependent variable is pesticide use in (kg/ha, Log)

Clustered-robust standard errors in parenthesis adjusted for 1270 clusters in household id. *** $p<0.01$, ** $p<0.05$, * $p<0.1$, shows significance level at 1%, 5% and 10% respectively. Kebele fixed effects are controlled in the regression (Appendix A).

4.10.2 Instrumental Validity

To empirically test for the validity of the instruments, we conduct an F-test on all instruments to see if the instruments are jointly significant in the endogenous variable, X_{it}. Prob > F = 0.0000 from Table 4.7 guarantees the joint significance of instrumental variables.

Table 4.7 : Joint significance of the instrumental variables

Variables	**OLS**
Pesticide price (ETB/liter)	-0.0015***
	(0.0001)
Pest control extension service (1/0)	0.0458***
	(0.0135)
Constant	1.4228***
	(0.0421)
Number of households = 1,270	
Number of plots = 4,428	
R-squared = 0.0445	
F (2, 1269) = 62.17	
Prob > F = 0.0000	

Source: Author's Computation

Notes: Dependent variable is pesticide use in (liter/ha, Log).

Clustered-robust standard errors in parenthesis adjusted for 1270 clusters in household id. *** p<0.01, ** p<0.05, *p<0.1, shows significance level at 1%, 5% and 10% respectively.

4.10.3 Pesticide Productivity Regression

In table 4.8, we present the productivity effects of pesticides on maize yield. Maize productivity in both models is expressed as a function of pesticide and other control variables. The sign and size of the coefficients are similar in both models. Taking pesticide as an exogenous variable in the NLS model, we observe that pesticide has no significant effect on maize yield.

When we control for the endogeneity of pesticides using 2SNLS, the coefficient becomes statistically significant and positive. The result shows that a 1% increase in pesticide use results in a 0.04% increase in maize yields. The result is consistent with previous studies

(Mutuc et al., 2011; Richard & Chikuvire, 2005; Schreinemachers et al., 2020; Zhang et al., 2015). This indicates that pesticide can improve maize yields by reducing the damage caused by pests, given other factors unchanged.

Table 4. 8 Damage abatement model estimates under exponential specification.

Variables	**NLS**	**2SNLS**
Damage abatement effect (λ) of pesticides, Log	0.0313	0.0388*
	(0.0255)	(0.0215)
No pesticide used (1/0)	0.0474**	0.0455**
	(0.0197)	(0.0194)
Hired Labor (1/0)	0.0460**	0.0461***
	(0.0182)	(0.0193)
Fertilizer use (kg/ha), Log	0.1381***	0.1378***
	(0.0159)	(0.0155)
Farm size (ha), Log	-0.2276***	-0.2309***
	(0.0385)	(0.0338)
Livestock ownership (000's ETB), Log	0.0141***	0.0141***
	(0.0036)	(0.0038)
Mobile phone ownership (1/0)	0.0622***	0.0605***
	(0.0212)	(0.0197)
Household size (numbers)	-0.0009	-0.0010
	(0.0054)	(0.0061)
Education of household head (years)	0.0053**	0.0052**
	(0.0025)	(0.0022)
Age of household head (years)	0.0012	0.0012
	(0.0009)	(0.0009)
Sex of household head (1/0)	0.0021	0.0043
	(0.0422)	(0.0448)
Manure/Compost (1/0)	-0.0081	-0.0064
	(0.0162)	(0.0166)
Medium plot fertility (1/0)	-0.0050	-0.0049
	(0.0176)	(0.0151)

Variables	NLS	2SNLS
Poor plot fertility (1/0)	-0.1905***	-0.1910***
	(0.0463)	(0.0440)
Medium plot slope (1/0)	-0.0008	-0.0002
	(0.0204)	(0.0235)
Steep plot slope (1/0)	-0.1468***	-0.1475***
	(0.0559)	(0.0521)
Medium plot depth (1/0)	0.0174	0.0177
	(0.0251)	(0.0306)
Deep plot depth (1/0)	0.0357	0.0349*
	(0.0230)	(0.0249)
Brown soil type (1/0)	0.0148	0.0142
	(0.0211)	(0.0208)
Red soil type (1/0)	-0.0024	-0.0021
	(0.0547)	(0.0482)
Grey soil type (1/0)	0.0626***	0.0620***
	(0.0195)	(0.0162)
Previous crop maize (1/0)	-0.1951***	-0.1953***
	(0.0228)	(0.0220)
Irrigation (1/0)	-0.0608	-0.0613
	(0.0648)	(0.0647)
Maize-legume Intercropping (1/0)	0.2380***	0.2374***
	(0.0236)	(0.0229)
Crop residue (1/0)	0.0144	0.0149
	(0.0205)	(0.0177)
Plot distance from residence (walking minutes)	-0.0005***	-0.0005***
	(0.0001)	(0.0002)
Distance to extension service (walking minutes)	-0.0004	-0.0004
	(0.0004)	(0.0004)
Household's confidence in extension service (1/0)	0.0407	0.0415
	(0.0423)	(0.0433)

Variables	**NLS**	**2SNLS**
Stress incidence (1/0)	-0.1881***	-0.1875***
	(0.0219)	(0.0201)
Altitude(masl)	-0.0001	-0.0001
	(0.0002)	(0.0002)
Constant	7.3085***	7.3510***
	(0.3826)	(0.3484)
Number of households	1,270	1,270
Number of plots	4,428	4,428
R-squared	0.2177	0.2179

Source: Author's Computation

Notes: Dependent variable is Maize yield in (kg/ha, Log).

Clustered-robust standard errors in parenthesis adjusted for 1270 clusters in household id for NLS regression. Bootstrapped standard errors at household level are used for 2SNLS regression. Kebele fixed effects are included (Appendix A). *** p<0.01, ** p<0.05, *p<0.1, shows significance level at 1%, 5% and 10% respectively.

4.10.4 Marginal Product and Optimal Amount of Pesticides

Using the estimated coefficients and mean values of the other explanatory variables, Table 4.9 presents the marginal product and optimal amount of pesticides. The marginal product of 1 liter of pesticide is 51 kg maize yield, meaning that every additional liter of pesticide increases maize yield by 51 kg. Moreover, the ratio of the value of marginal product to price of pesticide is 1.27 which is above unity, suggesting the underuse of pesticides. This means that value of marginal product of pesticide is above marginal cost and farmers could gain more by increasing pesticide use up to the point where value of marginal product equals marginal cost (i.e., optimal level).The result is consistent with a study from China, which claimed that lack of knowledge and information on pest occurrence resulted in pesticide underuse (Zhang et al., 2015). Moreover, high price of pesticides also discourage farmers from using pesticides because the majority of the farmers in Ethiopia have low economic status.

Based on equation (5), we estimated the optimal value of pesticides to be 8.4 liters which is above the actual value of 3.0 liters used by farmers, implying that farmers are operating at a sub-optimal level. Besides low yield, inefficient pest control has the following negative effects. First since crop pests can migrate across farms, pesticide underuse may put pressure on the neighbouring farmers to increase their pesticide use to achieve effective pest control (Zhang et al., 2015). Second, it may worsen the proliferation of pests as it is associated with the development of pest resistance. Third, it may affect farmers profit by reducing the quality and thus market access of agricultural products. To maximize their profit, farmers need to use 2.8 times higher pesticides than they are currently using. However, in the act of increasing pesticide use, the negative impacts on health and environmental safety needs to be taken into consideration and careful application techniques need to be practiced.

Table 4. 9 Estimated marginal product and optimal amount of pesticides

Exponential damage control specification	**Values**
Marginal product of 1liter of pesticides (kg)	**51**
Actual amount of the of pesticide (liter/ ha)	3.0
Ratio of value of marginal product to pesticide price	1.27
Optimal amount of pesticide (liter/ha)	8.4

Source: Author's Computation

Notes: Though multiple inputs are used in maize production, to ease the expression, we assumed that farmers only used one type of productive input.

CHAPTER FIVE
CONCLUSIONS AND POLICY IMPLICATIONS

For a country like Ethiopia where food insecurity and poverty reduction is the main agenda of the government, improving the productivity of the agricultural sector is of primary importance. One way is through the use of pesticides to combat the problem of pests in agriculture. Although use of pesticides has resulted in an increase in agricultural productivity, there is growing public concern on the negative effects of pesticides on human, environment and the ecosystem. In this study, we used a panel data from 1,270 maize farmers in southern Ethiopia to analyse the productivity effects of pesticides. We employed a production function with damage control specification where pesticides are treated as a damage reducing agent. The production function is estimated using both the NLS and 2SNLS methods to account for the endogeneity of pesticides. Parameters are interpreted as the partial production elasticities of pesticides and other inputs.

Results of NLS show that pesticides have no significant effect on maize productivity. After accounting for the endogeneity of pesticides, the results from the 2SNLS show that pesticide use results in a 0.04% increase in maize output. Moreover, optimal amount of pesticides (8.4 liters) is found to be above the actual amount. This suggests that farmers could benefit financially by increasing investment on pesticides. However, it should be noted that this estimate did not consider the health and environmental costs associated with pesticides. Our results would be an overestimate if these factors are considered. Therefore, the study suggests further analysis on the optimal level of pesticide use from the societal point of view where negative externalities on the society are considered. To minimize the adverse effects of pesticides this study suggests improving and subsidizing pesticide application technologies like spraying and protective equipment and educating farmers about the precautions required in all stages of pesticide handling.

Since pesticide use has a multidimensional effect (i.e. it increases agricultural output but also causes damage to the society and the environment), pest management policies need to balance between the private benefits and social costs of pesticide use. Focusing on either of the two extremes may not bring a desired outcome as both agricultural productivity and environmental conservation are essential for the socio-economic prosperity of the country. Future research may also need to quantify both the social and private benefits as well as costs of pesticides to understand whether pesticides promotion is a worthy investment or not.

REFERENCES

Abang, A., Kouame, C., Abang, M., Hanna, R., & Fotso, A. (2014). Assessing Vegetable farmer knowledge of diseases and insect pests of vegetable and management practices under tropial conditions. *International Journal of Vegetable Science*, *20(3)*(240–253).

Abro, Z. A., Jaleta, M., & Qaim, M. (2017). Yield effects of rust-resistant wheat varieties in Ethiopia. *Food Security*, *9*(6), 1343–1357.

Amare W. Nigatu, Bratveit, M., & Moen, B. E. (2016). Self reported acute pesticide intoxication in Ethiopia. *BMC Public Health*, *16*(575).

Amera, T., & Abate, A. (2008). *An assessment of pesticide use, practices and hazards in the Ethiopian Rift Valley in 2007*.

Arrow, K. ., Chenery, H. ., Minhas, B. ., & Solow, R. . (1961). Capital labour substitution and Economic efficiency. *Review of Economics and Statistics*, *63*, 225–250.

Asfaw, A., Mithofer, D., Lohr, B., & Waibel, H. (2011). *Challenges for economic impact assessment of classical biological control in kenya and Tanzania.* (D. Mithöfer & H. Waibel (eds.); 1st ed.). CABI.

Babcock, B. A., Lichtenberg, E., & Zilberman, D. (1992). Impact of Damage Control and Quality of Output: Estimating Pest Control Effectiveness. *American Journal of Agricultural Econonomics*, *74*, 163–172.

Bhanumurthy, K. . (2002). *Arguing A case for the Cobb-Douglas Production Function, Review of Commerce Studies.*

Blackwell, M., & Pagoulatos, A. (1992). The econometrics of damage control. In *American Journal of Agricultural Economics* (Vol. 74). Oxford University Press on behalf of the Agricultural & Applied Economics Association. https://doi.org/10.2307/1243203. Accessed 19 Jan 2021

Campbell, H. . (1976). Estimating the Marginal Productivity of Agricultural Pesticides: The Case of Tree-Fruit Farms in the Okanagan Valley. *Canadian Journal of Agricultural Economics*. https://doi.org/10.1111/j.1744-7976.1976.tb02812.x. Accessed 02 Feb 2021.

Carlson, G. . (1977). Long-Run Productivity of Insecticides. *American Journal of Agricultural Economics*, *59*, 543–548.

Carpentier, A., & Weaver, R. (1997). Damage Control Productivity: why Econometrics matters. In *American Journal of Agricultural Economics* (Vol. 79). Oxford University Press on behalf of the

Agricultural & Applied Economics Association. https://doi.org/10.2307/1243942. Acccessed 21 Apr 2021.

Carrasco- Tauber, C., & Moffitt, L. J. (1992). Damage Control Econometrics: Functional Specification and Pesticide Productivity. *American Journal of Agricultural Economics*, *74*(1), 158–162.

Central Statistical Agency (CSA). (2018). *Area and Production of Major Crops(Private Peasant Holding, Meher Season)*.

Colman, D., & Young, T. (1989). *Principles of agricultural economics: Markets and Prices in less developed countries.* Cambridge University Press (CUP).

Cramer, H. . (1967). *Plant Protection and World Crop Production* (Vol. 5, Issue 1). Cambridge University Press.

Damte, T., & Tabor, G. (2015). Small-scale vegetable producers' perception of pests and pesticide uses in east Shewa zone. *Ethiopian Interntional Journal of Pest Management*, *61*, 1–8.

Damtie, M., & Bayou, M. (2008). *Overview of Environmental Impact Assessment in Ethiopia* (N. Benequista (ed.)). MELCA Mahiber.

Demissie, G., Tefera, T., & Tadesse, A. (2008). Importance of husk covering on field infestation of maize by Sitophilus zeamais Motsch (Coleoptera: Curculionidea) at Bako, Western Ethiopia. *African Journal of Biotechnology*, *7*(20), 3777–3782.

Deribe, E., Rosseland, B. O. Borgstrom, R., Salbu, B., Gebremariam, Z. Dadebo, E., Norli, H. R., Eklo, O., & M. (2011). Bioaccumulation of persistent organic pollutants in fish species from Lake Koka, Ethiopia: The influence of lipid content and trophic position. *Science of the Total Environment*, 410–411, 136–145.

Dorosh, P., & Minten, B. (2020). *Ethiopia's Agrifood System Past Trends, Present Challenges, and Future Scenarios*. https://lccn.loc.gov/2020007433. Accessed 26 Feb 2021.

EEA/ EEPRI. (2002). *Annual Report on the Ethiopian Economy*.

Emama, B., Mohammed, H., & Mohammed, S. (2015). *A situational analysis of agricultural production and marketing, and natural resource management systems in the Ethiopian highlands*.

EPA(Environmental Protection Agency). (2004). *Environmental Impact Assessment Guidline on Pestcides In: The Federal Democratic Republic of Ethiopia*.

EPA. (2004). *Environmental Impact Assessment Guideline on Pesticides, Addis Ababa, Ethiopia*.

FAO(Food and Agricultural Organization of the United Nations). (2020). *Pesticides Use*. http://www.fao.org/faostat/en/#data/RP. Accessed 21 Oct 2021.

FAO. (2017). *Food and Agriculture Organization Corporate Statistical Database (FAOSTAT).Statistical databases and data-sets of the Food and Agriculture Organization of the United Nations.* http://faostat.fao.org/default.aspx.Accessed 25 Nov 2021.

FAO, & WHO. (2019). *Global situation of pesticide management in agriculture and public health*.

FDRE(Federal Democratic Republic of Ethiopia. (1995). *Proclamation of the Ethiopian constitution No. 1/95)*.

FDRE. (2009, December). Apiculture Resource Development and Protection Proclamation No.660/2009. *Federal Negarit Gazeta*, 5117.

FDRE. (2010). Pesticide registration and control proclamation No.674/2010. *Federal Negarit Gazeta*.

Fikadu, Z. (2020). Pesticides use, practice and its effect on honeybee in Ethiopia: a review. *International Journal of Tropical Insect Science*, *40*(3), 473–481.

Gebremichael, S., Birhanu, T., & Tessema, D. A. (2013). Analysis of organochlorine pesticide residues in human and cow's milk in the towns of Asendabo, Serbo and Jimma in South-Western Ethiopia. *Chemosphere*, *90*(5), 1652–1657.

Gesesew, H. A., Woldemichael, K., Massa, D., & Mwanri, L. (2016). Farmers knowledge, attitudes, practices and health problems associated with pesticide use in rural irrigation villages, Southwest Ethiopia. *PLoS ONE*, *11*(9), 1–13.

Getachew, A., & Degu, T. (2019). *Adoption of Technologies and Crop Productivity in Ethiopia: The Role of Agricultural Information* (Vol. 4, Issue 1).

Gizachew, A. (2011). *Pesticide use in Ethiopia.*

Gogo, E., Saidi, M., Itulya, F., Martin, T., & Ngouajio, M. (2014). Eco-Friendly Nets and Floating Row Covers Reduce Pest Infestation and Improve Tomato (Solanum lycopersicum L.) Yields for Smallholder Farmers in Kenya. *Agronomy*, *4*(1), 1–12.

Gollin, D., Michael, M., & Derek, B. (2005). Technology adoption in intensive post-green revolution systems. *American Journal of Agricultural Economics*, *87*(5), 1310–1316.

Greene, W. H. (2012). *Econometric Analysis. 7th Edition, Pearson Education, Inc., New York.*

https://www.pearson.com/us/higher-education/program/Greene Econometric-Analysis-8th - Edition/PGM334862.html. Accessed 21 Dec 2021.

Grovermann, C., Schreinemachers, P., & Berger, T. (2013). Quantifying pesticide overuse from farmer and societal points of view: An application to Thailand. *Crop Protection*, *53*, 161–168.

Gujarati, D. N., & Porter, D. C. (2009). *Basic Econometrics* (A. E. Hilbert (ed.)). Douglas Reiner.

Hausman, J. A. (1978). Specification Tests in Econometrics. *Econometrica*, *46*, 1251–1271.

Headley, J. . (1968). Estimating the Productivity of Agricultural Pesticides. *American Journal of Agricultural Economics*, *50*, 13–23.

Hertel, T. W. (2015). The challenges of sustainably feeding a growing planet. *Food Security*, *7*(2), 185–198. https://doi.org/10.1007/s12571-015-0440-2. Acessed 18 Feb 2021.

Hicks, B. (2013). Agricultural pesticides and human health. *The Journal of Geoscience Education*, *In: National Association of Geoscience Teachers*. https://serc.carleton.edu/NAGTWorkshops/health/case_studies/pesticides.html

Huang, J., Hu, R., Scott, R., & Fangbin, Q. (2002). Transgenic Varieties and Productivity of Smallholder Cotton Farmers in China. *Australian Journal of Agricultural and Resource Economics, 46Transgen*(3), 367–387.

Huang, J., Qiao, F., Zhang, L., & Rozelle, S. (2001). *Farm Pesticides, Rice Production, and Human Health in China*.

IUPAC (The International Union of Pure and Applied Chemistry). (2010). *History of pesticide use*. http://agrochemicals.iupac.org/index.php?. Accessed 23 May 2021.

Jansen, H. ., & Dubois, M. (2014). Gobal Pesticide Governance by disclosure: Prior informed Consent and the Rotterdam Convension. *Transparency in Environmental Governance: Critical Perspectives*, 107–131.

Jha, R. K., & Regmi, A. P. (2009). Pesticide productivity and vegetable farming in Nepal. *Environmental Valuation: In South Asia*, *43*, 115–140.

Kalayou, H., & Amare, A. (2015). Assessment of pesticide use, practice and environmental effects on the small holder farmers in the north Shoa zone of Amhara national regional state of Ethiopia. *Journal of Agriculture and Environmental Sciences*, *2*, 16–24.

Kassie, M., Teklewold, H., Marenya, P., Jaleta, M., & Erenstein, O. (2015). Production Risks and Food Security under Alternative Technology Choices in Malawi: Application of a Multinomial

Endogenous Switching Regression. *Journal of Agricultural Economics*, *66*(3), 640–659.

Kassie, M., Wossen, T., Groote, H. De, Tefera, T., Sevgan, S., & Balew, S. (2020). Economic impacts of fall armyworm and its management strategies : evidence from southern Ethiopia. *European Review of Agricultural Economics*, 1–29.

Katerrega, E. (2012). Economic Analysis of Strengthening the governance of pesticide management in Uganda's Agricultural Sector. *International Jornal of Development and Sustainability*, *1(2)*, 527–544.

Keno, T., Azmach, G., Wegary, D., Worku, M., Tadesse, B., Wolde, L., Deressa, T., B.Abebe, Chibsa, T., & Suresh, L. M. (2018). Major biotic maize production stresses in Ethiopia and their management through host resistance. *African Journal of Agricultural Research*, *13*(21).

Kim, H. . (1992). The Translog Production Function and Variable Returns to Scale. *The Review of Economics and Statistics*, *74*(3), 546–553.

Krugman, P. (1994). *Defining and measuring Productivity: The Age of Diminishing Expectations*.

Kumbhakar, S. C., & Lovell, C. A. K. (2000). Stochastic Frontier Analysis. In *Stochastic Frontier Analysis*. Cambridge University Press. https://doi.org/10.1017/cbo9781139174411. Accessed 21 Jan 2021.

Kumela, T., Mendesil, E., Enchalew, B., Kassie, M., & Tefera, T. (2019). Effect of the Push-Pull Cropping System on Maize Yield, Stem Borer Infestation and Farmers' Perception. *Agronomy*.

Lah, K. (2011). *Effects of pesticides on human health. In: Toxipedia*. http://www.toxipedia.org/display/toxipe%0Adia/Effects+of+Pesticides+on+Human+%0AHealth . Accessed 25 Oct 2021.

Lansink, A. O., & Carpentier, A. . (2001). Damage Control Productivity: An Input Damage Abatement Approach. *Journal of Agricultural Economics*, *52*(3), 11–22.

Lichtenberg, E., & Zilberman, D. (1986). The Econometrics of Damage Control: Why Specification Matters. *American Journal of Agricultural Economics*, *68*(2), 261–273. https://doi.org/10.2307/1241427. Accessed 19 Nov 2021.

Loha, K. M., Lamoree, M., Weiss, J. M., & de Boer, J. (2018). Import, disposal, and health impacts of pesticides in the East Africa Rift(EAR) zone: A review on management and policy analysis. In *Crop Protection* (Vol. 112, pp. 322–331). Elsevier Ltd.

Macharia, I. (2015). *Pesticides and Health in Vegetable Production in Kenya. BioMed Research*

International. http://dx.doi.org/10.1155/2015/241516.. Accessed 21 Dec 2021.

Matthews, G. (2006). *Pesticides: Health, Safety and the Environment*.

Mekonnen, Y., & Agonafir, T. (2002). Effects of pesticide applications on respiratory health of Ethiopian farm workers. *International Journal of Occupational and Environmental Health*, *8*(1), 35–40.

Mekonnen, Y., & Ejigu, D. (2005). Plasma cholinesterase level of Ethiopian farm workers exposed to chemical pesticide. *Occupational Medicine*, *55*(6), 504–505.

Mengistie, B. (2016). Policy-practice Nexus: pesticide registration, distribution and use in Ethiopia. *SM Journal of Environmental Toxicology, 2,* 1–13.

Mengistie, B., Mol, A., Oosterveer, P., & B, S. (2014). Information, motivation and resources: the missing elements in agricultural pesticide policy implementation in Ethiopia. *Journal of Sustainable Agriculture*, *13*, 240–256.

Mengistie, B., Mol, A. P. J., & Oosterveer, P. (2016). Environmental Governance of Pesticides in Ethiopian Vegetable and Cut Flower Production. In *Ambio*. http://edepot.wur.nl/391632. Accessed 22 Oct 2021.

Mengistie, B. T., Mol, A. P. J., & Oosterveer, P. (2017). Pesticide use practices among smallholder vegetable farmers in Ethiopian Central Rift Valley. *Environment, Development and Sustainability*, *19*(1), 301–324.

MOA. (2013). *National Pesticide Management Strategies in Ethiopia.*

MoFED. (2010). *Growth and Transformation Plan (GTP) 2010/11–2014/15*.

Murray, A. (2016). *Partial versus Total Factor Productivity: Assessing Resource Use in Natural Resource Industries in Canada*.

Mutuc, M. E., Rejesus, R. M., & Jose M. Yorobe, J. (2011). Yields, Insecticide Productivity, and Bt Corn: Evidence from Damage Abatement Models in the Philippines. *AgBioForum*, *14*(2), 35–46.

Negatu, B., Kromhout, H., Mekonnen, Y., & Vermeulen, R. (2016). Use of chemical pesticides in Ethiopia: A cross-sectional comparative study Onknowledge, attitude and practice of farmers and farm workers in three farming systems. *Annals of Occupational Hygiene, 60*(5), 551–566.

Norwood, F. B., & Marra, M. C. (2003). Pesticide Productivity: Of Bugs and Biases. *Journal of Agricultural and Resource Economics*, *28*(3), 596–610.

Ntow, W. . (2008). *The use and fate of pesticides in vegetable-based agroecosystems in Ghana.* https://edepot.wur.nl/1586. Accessed 23 Dec 2021

Oerke, E. . (2006). Crop Losses to Pests. *Journal of Agricultural Science, 144*, 31–43.

Oerke, E. ., Dehne, H., Schonbeck, F., & Weber, A. (1996). Crop Production and Crop Protection: Estimated Losses in Major Food and Cash Crops,. *The Journal of Agricultural Science*, *127*(1), 137–137.

PAN-UK. (2006). *Hazardous pesticides and health impacts in Africa: Food and fairness Briefing No.6*. www.pesticideinfo.org. Accessed 15 Oct 2021.

Pemsl, D., Waibel, H., & Gutierrez, A. P. (2005). Why do some bt-cotton farmers in China continue to use high levels of pesticides? *International Journal of Agricultural Sustainability*, *3*(1), 44–56.

Pérez-Lucas, G., Vela, N., Aatik, A. El, & Navarro, S. (2018). *Environmental Risk of Groundwater Pollution by Pesticide Leaching through the Soil Profile*. https://doi.org/10.5772/intechopen.82418. Accessed 22 Dec 2021.

PHRD. (2015). *List of Registered Pesticides as of June 2015.*

Pimentel, D. (2005). *Environmental and economic costs of the application of pesticides primarily in the United States.* https://doi.org/10.1007/s10668-005-7314-2. Accessed 25 May 2021.

Popp, J. (2011). Cost-Benefit analysis of crop protection measures. *Journal of Consumer Protection and Food Safety*, *6(suppleme*(105–112).

Popp, J., Pető, K., & Nagy, J. (2013). Pesticide productivity and food security. A review. *Agronomy for Sustainable Development*, *33*(1), 243–255.

Praneetvatakul, S., Kuwattanasiri, D., & Waibel, H. (2002). The productivity of pesticide use in rice production in Thailand: A damage control approach.

Pratt, C. F., Constantine, K. L., & Murphy, S. T. (2017). Economic impacts of invasive alien species on African smallholder livelihoods. In *Global Food Security* (Vol. 14, pp. 31–37). Elsevier B.V. https://doi.org/10.1016/j.gfs.2017.01.011. Accessed 21 Jan 2021.

Rao, A., & Morimoto, R. (2020). *An analysis of the use of chemical pesticides and their impact on yields, farm income and agricultural sustainability: the case for smallholder farmers in Ethiopia.* (No. 234).

Richard, F., & Chikuvire, T. . (2005). Farm Level Pesticide Use and Productivity in Smallholder

Cotton Production in Zimbabwe: The Case of Gokwe Communal Area Farmers. *Journal of Sustainable Development in Africa*, *7*(2), 12.

Ríos-González, A., Jansen, K., & Javier Sánchez-Pérez, H. (2013). Pesticide risk perceptions and the differences between farmers and extensionists: Towards a knowledge-in-context model. *Environmental Research*, *124*, 43–53.

Rola, A. C., & Pingali, P. . (1993). *Pesticides, rice productivity, and farmer's health- an economic assessment.* (A. Rola & P. L. Pingali (eds.)). International Rice Research Institute.

Ruttan, V. (2002). Productivity Growth in World Agriculture: Sources and Constraints. *Journal of Economic Perspectives, 16*(4), 161–184.

Schreinemachers, P., H.P.CHEN, T. T. ., Nguyen, B. B., L. Bouapao, S., Gautam, N. T. Le, T.Pinn, P. V., & Srinivasan, R. (2017). Too much to handle? Pesticide dependence of smallholder vegetable farmers in Southeast Asia. *Science of the Total Environment*, *593–594*, 470–477.

Schreinemachers, P, & Tipraqsa, P. (2012). *Agricultural pesticides and land use intensification in high, middle and low income countries. 37*(6), 617–626.

Schreinemachers, Pepijn, Grovermann, C., Praneetvatakul, S., Heng, P., Nguyen, T. T. L., Buntong, B., Le, N. T., & Pinn, T. (2020). How much is too much? Quantifying pesticide overuse in vegetable production in Southeast Asia. *Journal of Cleaner Production*, *244*, 1–23.

Semreab, E. (2018). *The Determinants of Agricultural Technology Adoption And it's impact on Teff productivity in the case of Amhara and Oromia National Regional State*. Addis Ababa University.

Sentayehu, F., & Tibebu, H. (2016). *Effects of Herbicide Application in Wheat Crops and on Honeybee Populations in Ethiopia*.

Sexton, S. S., Lei, Z., & Zilberman, D. (2007). The economics of pesticides and pest control. *International Review of Environmental and Resource Economics*, *1*(3), 271–326.

Sheahan, M., Barrett, C. B., & Goldvale, C. (2017). *The unintended consequences of agricultural input intensification: Human health implications of pesticide use in Sub-Saharan Africa*.

Sickles, R. C., & Zelenyuk, V. (2019). Measurement of productivity and efficiency: Theory and practice. In *Measurement of Productivity and Efficiency: Theory and Practice*. Cambridge University Press. https://doi.org/10.1017/9781139565981. Accessed 17 May 2021.

Skevas, T, Stefanou, S. ., & Lansink, O. . (2013). Do farmers internalize environmental spillovers of pesticides in prodction? *Journal of Agricultural Economics, 64(3)*, 624–640.

Skevas, Theodoros, Stefanou, S. E., & Lansink, A. O. (2012). Can economic incentives encourage actual reductions in pesticide use and environmental spillovers? *Agricultural Economics*, *43*(3), 267–276.

StataCorp. (2015). *Stata 14 Base Reference Manual*. College Station, TX: Stata Press.

Sun, S., Zhang, C., & Hu, R. (2020). Determinants and overuse of pesticides in grain production: A comparison of rice, maize and wheat in China. *China Agricultural Economic Review*, *12*(2), 367–379.

Tadesse, A. (2016). *Stewardship towards responsible management of pesticides, the case of Ethiopian agriculture.* Swedish University of Agricultural Sciences.

Tamiru, S., Minten, B., Alemu, D., & Bachewe, F. (2017). The Rapid Expansion of herbicide use in smallholder agriculture in Ethiopia: Patterns, drivers and implications. *The European Journal of Development Research Volume*, *29*, 628–647.

Tefera, B. N., & Kim, Y.-D. (2019). Ethnobotanical study of medicinal plants in the Hawassa Zuria District, Sidama zone, Southern Ethiopia. *Journal of Ethnobiology and Ethnomedicine*, *15*(25).

Teklu, B. M. (2016). *Environmental risk assessment of pesticides in Ethiopia: a case of surface water systems*.

Tilahun, B., & Hussen, A. (2014). Assessment of Pesticide Use, Practice and Risk in Gedeo and Borena Zones; Ethiopia. *International Journal of Environment*, *3*(3), 201–209.

Tinyami, E. ., Wook, C. ., Shendeh, T. ., Eko, E. ., & Afoh, C. . (2014). Small-scale tomato cultivators’ perception on pesticides usage and practices in Buea Cameroon. *Health Science Research, 6*. http;//dx.doi.org/10.4236/health.2014.621333. Accessed 14 Dec 2021.

UNDP (2017). Taxes on Pesticides and Chemical fertilizers. *Financing Solutions for Sustainable Development*.

Wang, J., Chu, M., & Ma, Y. (2018). Measuring rice farmer’s pesticide overuse practice and the determinants: A statistical analysis based on data collected in Jiangsu and Anhui provinces of China. *Sustainability (Switzerland)*, *10*(3), 1–17.

WHO. (2019). *Exposure to highly hazardous pesticides: A major public health concern*.

Wilson, C., & Tisdell, C. (2001). Why farmers continue to use pesticides despite environmental, health and sustainability costs. *Ecological Economics*, *39*(3), 449–462.

Wooldridge, J. M. (2002). *Econometric Analysis of Cross Section and Panel Data* (Issue 4). The MIT Press. https://doi.org/10.1007/s12053-016-9491-2. Accessed 01 June 2021

Wu,Y.,Xi, X., Tang, X., Luo, D., Gu, B., Lam, S. K., Vitousek, P. M., & Chen, D. (2018). Policy distortions, farm size, and the overuse of agricultural chemicals in China. *Proceedings of the National Academy of Sciences of the United States of America*, *115*(27), 7010–7015.

Yohannes, Y. B., Ikenaka, Y., Nakayama, S. M., Saengtienchai, A. Watanabe, K., & Ishizuka, M. (2013). Organochlorine pesticides and heavy metals in fish from Lake Awassa; Ethiopia: Insights from stable isotope analysis. *Chemosphere*, *91*(6), 857–863.

Zhang, C., Guanming, S., Shen, J., & Hu, R. F. (2015). Productivity effect and overuse of pesticide in crop production in China. *Journal of Integrative Agriculture*, *14*(9), 1903–1910.

Zhang, C., Hu, R., Shi, G., Jin, Y., Robson, M. G., & Huang, X. (2015). Overuse or underuse ? An observation of pesticide use in China. *Science of the Total Environment*, *538*(December 2019), 1–6.

Zhu, W., & Wang, R. (2021). Impact of farm size on intensity of pesticide use: Evidence from China. *Science of the Total Environment*, *753*. https://doi.org/10.1016/j.scitotenv.2020.141696. Accessed 11 May 2021.

APPENDIX

Appendix A: Pesticide use model and pesticide productivity regression

Variables	**Pesticide Use**	**NLS**	**2SNLS**
Pesticide price (ETB/liter)	-0.0023***	-	-
	(0.0002)		
Pest control extension service (1/0)	0.0591***	-	-
	(0.0134)		
Age of the household head (years)	-0.0010	0.0012	0.0012
	(0.0007)	(0.0009)	(0.0009)
Sex of the household head (1/0)	0.0691**	0.0021	0.0043
	(0.0323)	(0.0422)	(0.0448)
Education of the Household head (years)	-0.0015	0.0053**	0.0052**
	(0.0019)	(0.0025)	(0.0022)
Household size (numbers)	-0.0037	-0.0009	-0.0010
	(0.0039)	(0.0054)	(0.0061)
Mobile phone ownership (1/0)	-0.0528***	0.0622***	0.0605***
	(0.0170)	(0.0212)	(0.0197)
Manure / Compost (1/0)	0.0551***	-0.0081	-0.0064
	(0.0122)	(0.0162)	(0.0166)
Farm size (ha), Log	-0.1166***	-0.2276***	-0.2309***
	(0.0244)	(0.0385)	(0.0338)
Stress incidence (1/0)	0.0130	-0.1881***	-0.1875***
	(0.0117)	(0.0219)	(0.0201)
Livestock ownership (000's ETB), Log	0.0011	0.0141***	0.0141***
	(0.0022)	(0.0036)	(0.0038)
Damage abatement effect (λ) of pesticides (liter/ha), Log	-	0.0313	0.0388*
		(0.0255)	(0.0215)

Variables	Pesticide Use	NLS	2SNLS
Battese Pesticide	-	0.0474**	0.0455**
		(0.0197)	(0.0194)
Hired Labour (1/0)	-	0.0460**	0.0461***
		(0.0182)	(0.0193)
Fertilizer use (kg/ha), Log	-	0.1381***	0.1378***
		(0.0159)	(0.0155)
Medium plot fertility (1/0)	-	-0.0008	-0.0002
		(0.0204)	(0.0235)
Poor plot fertility (1/0)	-	-0.1468***	-0.1475***
		(0.0559)	(0.0521)
Medium plot slope (1/0)	-	0.0174	0.0177
		(0.0251)	(0.0306)
Deep plot slope (1/0)	-	0.0357	0.0349*
		(0.0230)	(0.0249)
Brown soil type (1/0)	-	0.0148	0.0142
		(0.0211)	(0.0208)
Red soil type (1/0)	-	-0.0024	-0.0021
		(0.0547)	(0.0482)
Grey soil type (1/0)	-	0.0626***	0.0620***
		(0.0195)	(0.0162)
Previous crop maize (1/0)	-	-0.1951***	-0.1953***
		(0.0228)	(0.0220)
Irrigation (1/0)	-	-0.0608	-0.0613
		(0.0648)	(0.0647)
Intercropping (1/0)	-	0.2380***	0.2374***
		(0.0236)	(0.0229)
Crop Residue (1/0)	-	0.0144	0.0149
		(0.0205)	(0.0177)
Plot distance from residence (walking minutes)	-	-0.0005***	-0.0005***
		(0.0001)	(0.0002)

Variables	Pesticide Use	NLS	2SNLS
Distance to extension service (walking minutes)	-	-0.0004	-0.0004
		(0.0004)	(0.0004)
Household's confidence in extension service (1/0)	-	0.0407	0.0415
		(0.0423)	(0.0433)
Altitude(masl)	-	-0.0001	-0.0001
		(0.0002)	(0.0002)
Kebele 2 (1/0)	-0.1197***	0.3232***	0.3191***
	(0.0409)	(0.0645)	(0.0728)
Kebele 3 (1/0)	-0.0057	0.4113***	0.4102***
	(0.0785)	(0.1049)	(0.0976)
Kebele 4 (1/0)	-0.1533***	0.3500***	0.3454***
	(0.0545)	(0.0739)	(0.0745)
Kebele 5 (1/0)	-0.1408***	0.4041***	0.4002***
	(0.0439)	(0.0704)	(0.0724)
Kebele 6 (1/0)	-0.1615***	0.4220***	0.4184***
	(0.0439)	(0.0673)	(0.0790)
Kebele 7 (1/0)	-0.1069**	0.3123***	0.3077***
	(0.0422)	(0.0698)	(0.0845)
Kebele 8 (1/0)	-0.0318	0.2718***	0.2688***
	(0.0426)	(0.0739)	(0.0807)
Kebele 9 (1/0)	-0.0481	0.2928***	0.2917***
	(0.0425)	(0.0691)	(0.0758)
Kebele 10 (1/0)	-0.1243***	0.2256***	0.2213***
	(0.0453)	(0.0757)	(0.0766)
Kebele 11 (1/0)	0.0291	0.2413***	0.2349***
	(0.0612)	(0.0841)	(0.0897)
Kebele 12 (1/0)	-0.1529***	0.2721***	0.2682***
	(0.0409)	(0.0680)	(0.0676)
Kebele 13 (1/0)	0.1237**	0.1880***	0.1842**
	(0.0490)	(0.0692)	(0.0800)

Variables	Pesticide Use	NLS	2SNLS
Kebele 14 (1/0)	-0.1509***	0.1975***	0.1935**
	(0.0428)	(0.0707)	(0.0757)
Kebele 15 (1/0)	-0.1436***	0.3119***	0.3071***
	(0.0452)	(0.0705)	(0.0804)
Kebele 16 (1/0)	-0.0885*	0.1211*	0.1196
	(0.0485)	(0.0728)	(0.0830)
Kebele 17 (1/0)	0.0576	0.2804***	0.2780***
	(0.0475)	(0.0806)	(0.0882)
Kebele 18 (1/0)	-0.0889**	0.2325***	0.2298***
	(0.0419)	(0.0689)	(0.0745)
Constant	1.7896***	7.3085***	7.3510***
	(0.0860)	(0.3826)	(0.3484)
Number of plots	4,428	4,428	4,428
Number of households	1,270	1,270	1,270
R-squared	0.0935	0.2177	0.2179

Source: Author's Computation

Clustered-robust standard errors in parenthesis adjusted for 1270 clusters in household id for NLS regression. Bootstrapped standard errors at household level are used for 2SNLS regression. Kebele fixed effects are included. *** p<0.01, ** p<0.05, *p<0.1, shows significance level at 1%, 5% and 10% respectively.

Appendix B: Econometric Diagnostic tests

Table B1: Multicollinearity Test

Variance inflation factor	VIF	1/VIF
Kebele 18 (1/0)	3.101	.323
Kebele 6 (1/0)	3.044	.329
Kebele 2 (1/0)	2.988	.335
Kebele 16 (1/0)	2.874	.348
Kebele 5 (1/0)	2.828	.354
Kebele 15 (1/0)	2.807	.356
Kebele 12 (1/0)	2.661	.376
Kebele 14 (1/0)	2.311	.433
Kebele 8 (1/0)	2.272	.44
Kebele 13 (1/0)	2.229	.449
Kebele 9 (1/0)	2.209	.453
Kebele 10 (1/0)	2.209	.453
Kebele 7 (1/0)	2.149	.465
Deep plot depth (1/0)	2.081	.481
Kebele 17 (1/0)	2.038	.491
Medium plot depth (1/0)	1.929	.518
Previous season crop was maize (1/0)	1.831	.546
Education of household head (years)	1.763	.567
Kebele 11 (1/0)	1.681	.595
Kebele 14 (1/0)	1.679	.595
Age of household head (years)	1.64	.61
Altitude (masl)	1.568	.638
Intercropping (1/0)	1.519	.658
Farm size (ha), Log	1.414	.707
Grey soil type (1/0)	1.403	.713
Kebele 3 (1/0)	1.383	.723
Mobile phone ownership (1/0)	1.375	.727
Brown soil type (1/0)	1.297	.771
Crop residue (1/0)	1.281	.78

Variance inflation factor	**VIF**	**1/VIF**
Hired labor (1/0)	1.258	.795
Plot distance (numbers)	1.256	.796
Household size (numbers)	1.232	.812
Fertilizer use (kg/ha), Log	1.197	.835
No pesticide used (1/0)	1.184	.845
Medium plot fertility (1/0)	1.173	.852
Manure/Compost (1/0)	1.169	.856
Red soil type (1/0)	1.137	.88
Livestock ownership (000's ETB), Log	1.127	.887
Sex of household head (1/0)	1.122	.891
Stress incidence (1/0)	1.107	.903
Distance to extension office (walking minutes)	1.106	.904
Damage abatement effect of pesticides (liter/ha), Log	1.1	.909
Confidence in extension service (1/0)	1.083	.924
Irrigation (1/0)	1.074	.931
Poor plot fertility (1/0)	1.068	.937
Mean VIF	1.732	

Table B2: Heteroskedasticity Test

Breusch-Pagan / Cook-Weisberg Test for Heteroskedasticity
Ho: Constant variance
Variables: fitted values of Maize yield, Log
chi2(1) = 248.14
Prob > chi2 = 0.0000