COLLEGE OF BUSINESS AND ECONOMICS
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The Impacts of Climate Change on Small Holder's Crop Production in Major Crop Producer Zones in Ethiopia: A Dynamic Panel Data Approach

A RESEARCH SUBMITTED TO ADDIS ABABA UNIVERSITY FACULTY OF BUSINESS AND ECONOMICS IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF A MASTER OF SCIENCE DEGREE IN ECONOMICS SPECIALISATION IN ECONOMICS POLICY ANALYSIS.

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Declaration

I, Lewoye Bantie, declare that this research paper entitled "The Impacts of Climate Change on small Holder's Crop Production in Major Crop Producer Zones in Ethiopia: A Dynamic Panel Data Approach" is my original work submitted for the award of the fulfillment of the requirement for the degree of Master of Science in economics at Addis Ababa University. It has not been presented for the award of any degree or other similar titles in any other institutions of higher learning to the best of my knowledge, and all resources used have been duly acknowledged.

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Date __19/06/2023_____________________

APPROVAL

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This Is To Certify That The Research Thesis Presented By Lewoye Bantie, Titled: **The Impacts of Climate Change on small Holder's Crop Production in Major Crop Producer Zones in Ethiopia: A Dynamic Panel Data Approach** In partial fulfillment of the requirement for the degree of Master of Science (MSc.) in Economics compile with the regulation of the university and confirms to the acceptable standards with the respect to the originality and the quality.

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List of Acronyms

COMTRADE: Commodity Trade

CSA: Central Statistical Agency

DPD: Dynamic Panel Data

GDP: Gross Domestic Product

GMM: Generalized Method of Moments

IMF: International Monetary Fund

NMA: National Methodology Agency

LDCs: Least Developing Countries

MoFEC: Ministry Of Finance and Economic Corporation

NBE: National Bank of Ethiopia

UN: United Nations

USD: United States’ Dollar

WTO: World Trade Organization

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Abstract

The frequency of climatic risks is increasing as a result of climate change. There is a need to assess their impacts on each major crop producer zones in Ethiopia. This paper examined the impacts of climate change on crop production of private peasant holders focusing on cereals, pulse, oilseed, and vegetables in the cases of major selected crop producer zones in Ethiopia. One-step system GMM and Two-step system GMM were used to assess the impacts of climate change on cereal production from the period 2003/04-2021/22 for 21 selected zones from Amhara region, Oromia region, Binishangul Gumuz, SNNP, and Sidama region. We have estimated cereal production, pulse production, oilseed production, and vegetable production. The researcher concluded that lagged total production of cereals, number of private peasant holders, area in hectares, fertilizer, precipitation, Maximum average temperature; relative humidity, and regional dummy variables are the most significant factors that affect the production of cereals in major cereal producer zone in Ethiopia in the case of private peasant holders. Precipitation has adverse effects on cereals, pulse, and oilseed production. At first glance, the study suggested that the private peasant should not only depend on rain-fed cereals, pulse, and oilseed production instead they have to use erratic rainfall as opportunities for building small-sized irrigation dams. Finally, the author suggested that their irrigated land area will be insurance for their rain-fed agriculture if and only if they accumulated heavy rainfall. The author suggested to private peasant holders to use temperature resistance crop types through communicating with the Kebels, Wereda, and Zones base Administrations. The university across each zone has to introduce initiatives across each Woredas by supporting farmers to identify which types of seed they are adopting i.e. improved seed adaptation and traditional seed adaptation.

Keywords: Cereals, Relative Humidity, one-step system GMM, Pulse, private peasant holders

CHAPTER ONE: INTRODUCTION

1.1 Background of the Study

The growing atmospheric concentration of greenhouse gases will significantly affect the Earth's climate in the ensuing decades, according to recent scientific studies. The most recent IPCC Report from the Intergovernmental Panel on Climate Change indicated that the global warming range predicted for 2100 is between 1.2°C and 4.1°C, and for 3000 is between 1.9°C and 5.6°C(Engelbrecht & Monteiro, 2021; Zhongming et al., 2022). Natural climate and environmental systems would be affected by global warming in a variety of ways, including an increase in the frequency of extreme weather events, rising sea levels, a reversal of ocean currents, and modifications to precipitation patterns (Tyler et al., 2007; Upadhyay, 2020). These changes may have an effect on social and economic activities, which might have major repercussions for human welfare for a very long time.

Furthermore, it is doubtful that the effects of climate change on agricultural productivity would be dispersed equally throughout all regions. Because of their disadvantaged geographic situation, increased agricultural dependence on agriculture for economic growth, and limited capacity to adjust to climate change, low-latitude, and underdeveloped nations are anticipated to experience larger agricultural impacts of global warming. In contrast, climatic change will often be advantageous for agricultural productivity in high-latitude areas. A 1.73 percent average yearly improvement in agricultural production is required to sustainably feed and create other agricultural goods for more than 9 billion people by 2050 (Fuglie, 2018). Global agricultural production increased by just 1.12% year on average from 2011 to 2020, which is a sharp deterioration from the average growth rate of 1.99% between 2001 and 2010 (Marcacci et al., 2020; Tian, 2022).

Agriculture continues to dominate Ethiopia's economy. This sector has a huge contribution to the country’s economy. The conventional sector has accounted for roughly 65.0 percent of employment; 37.57 percent of GDP; 72 percent of export and nearly 118 million people of which 80.5 percent of the population relies on agriculture for their livelihoods in 2022 (Zerssa et al., 2021).

However, the sector has been less productive for a long period and the country is not maintained food security. This issue is particularly severe in rural areas of the nation where individual peasant holdings are in desperate need of agricultural land. In Tigray and its neighboring areas of Amhara and Afar, the civil war that began in northern Ethiopia in November 2020 has influenced agricultural output and way of life (Ghebreyohannes et al., 2022).

There are plenty of reasons for the low productivity of agriculture in the country such as poor and traditional agricultural farming technology; fragment and small household farming which is not supported by commercial and large scale farming; losing soil fertility and degradation especially in the higher crop producer region of the country because of overpopulation; ineffective and inefficient agricultural policy; unimproved market structure and linkage and poor institutions (Ghebreyohannes et al., 2022). But the most devastating factor that affects crop production is drought which is resulted from climate change which makes the country depends on food aid in different decades (Marie et al., 2020). In addition, the county's climate is noted for its history of climate extremes including drought and flooding as well as shifting trends in temperature and precipitation patterns. Based on this background, this thesis makes an investigation about the impact of climate change on agricultural crop production of the country.

1.2 Statement of the Problem

Due to its heavy reliance on environmental factors, particularly temperature, precipitation, and soil quality, agriculture is the economic sector that will be most affected by the predicted changes in climate over the coming decades (Tesfaye et al., 2020). Thus, recognizing these effects and the repercussions for the rest of the economy is crucial to map the effects and to build, if required, mitigating environmental and economic policies (Gwambene et al., 2022).

Climate and the environment are inextricably related to the agriculture industry and its productivity (Arora, 2019). The impact of climate change tops all other current worldwide obstacles to food production and the expansion of the agro-based business (Kountios, 2022). Compared to other businesses, the agriculture industry will be more negatively impacted by climate change economically. In addition, the bulk of rural inhabitants in developing nations continues to depend primarily on rained agriculture for their means of subsistence. Food security will be maintained through the maintenance of regular rainy seasons with adequate rainfall and favorable temperatures (Lansbury Hall & Crosby, 2020). Yet, the unpredictable nature of the rainy seasons and the resulting rainfall deficiencies will diminish yield, which may cause food insecurity.

Climate change is gradually emerging as one of the most important local and international environmental policy problems due to its significant potential influence on economic results and its global character (Aryal et al., 2019; Sultan et al., 2019). To create successful national adaptation programs and international climate policy agreements, it is crucial to understand the economic effects of climate change on a particular country. The structure of developing nations' economies, which frequently makes them more vulnerable to climate-related shocks, and the need to ensure the genuine participation of developing nations in climate change agreements make it particularly important to quantify the impact of climate change on the overall economy (Akram et al., 2022).

In regard to this Ethiopia as a developing country is characterized by a high food poverty incidence (Mohammed et al., 2020). Regardless of substantial resources allocated each year to reduce the number of food-insecure households, both chronic and transitory food insecurity problems are continuing in the country at the household level. The country as an agrarian economy largely depends on its agricultural sector to meet its domestic food demand. Nonetheless, this sector is characterized by poor productivity which makes the country's food insufficient (Teshale Woldie et al., 2020).

Most of the research done was specifically specific regions and areas. For instance, Kindu et al. (2022) in Jama Werda, Belay & Mengistu (2021) in Muga watershed in the upper Blue Nile basin, Hawaria et al., (2020) in Arjo Dedessa, Sertse et al. (2021) in Raya Azebo, Warasame et al. (2021) in Somalia region and other researcher. Likewise, regional specific they also only considered one type of agricultural commodity, Bedeke et al. (2019), the impact of climate change on maize producers and smallholder farmers, Chemura et al. (2021) on coffee, Lemessa et al. (2019) on Potato, Emeru (2022) on Teff, Zewdu et al. (2020) on Sorgum, Alemnew & Abera (2020) on Wheat. So, it will be more fruitful and practical to fill the gap by looking at the consequences of climate change on the major crop producers in Zones in Ethiopia.

In addition to the above Gap, the majority of those studies used computational general equilibrium analysis, which has the drawback of not taking into account the temporal impact of climate change on agriculture. Similarly, the Ricardaian approach is based on survey data regarding climate change, which raises the possibility of respondents mis appreciating its importance and necessitating greater awareness. The study's goal is to link climate change to a single, total crop production using pane data analysis to close the knowledge gap, add to the body of knowledge, and inform national policy. Therefore, the study analyzed using the dynamic panel data to examine the impact of climate change on crop production on private peasant crop production in the case of major crop producer zones in Ethiopia.

1.3 Objectives of the Study

1.3.1 General Objective of the Study

The general objective of the study is to determine the effect of climate change on private peasant holders’ crop production in the case of major crop-produce zones in Ethiopia using a dynamic panel data approach.

1.3.2 Specific Objectives of the Study

Specifically, the study is

1. Determine the effect of climate change on smallholder agricultural crop production
2. Compare cereal production and productivity differences across regions.
3. Identify possible adaptation and mitigation strategies suitable for Ethiopian agricultural crop production to climate change.

1.4 Significance of the Study

Using dynamic panel data, this study examined the effects of climate change on Ethiopia’s private peasant holders' crop production in the case of major crop-producing areas. Although it is now commonly acknowledged that climate change will have a significant impact on crop production, it is unclear just how much. Studying the effect of climate change on crop production will therefore enable the government to create effective policies, implement sufficient mitigation and adaptation measures, and assure meaningful participation in international climate change accords. So, the results will provide a clear direction for building policies to adapt to climate change.

Additionally, Planning for development has shown to be difficult when climate changes are present. The study aims to provide cost-effective and simple-to-implement adaptation measures for Ethiopian 10-year development goals. The study's findings would be more significant to farmers who are now losing money due to climate change if they planted drought-resistant crops and kept animals that can adapt to changing weather patterns.

1.5 Scope and Delimitation of the Study

The scope of this study was limited to an empirical analysis of the impact of climate change on agricultural production by using recent panel data from 2003/4 to 2021/22. This was because shifts in the country's overall crop production are frequently impacted by variations in the climatic conditions of temperature, rainfall, and relative humidity. Climate change has just recently been included in Ethiopian policy discussions.

1.6 Organization of the Study

The study was organized as follows. The first chapter discusses the background, statement of the problem and objective of the paper. The second chapter discussed related literature including theoretical and empirical literature on climate change's impact on agricultural productivity. The Third chapter explained the methodology used, data type, source of data, and panel data specifically dynamic panel data used in this study. The other chapter, chapter four discussed on results and discussions of impacts of the impact of climate change on crop production in Ethiopia’s private peasant holders using dynamic panel data. Finally, the fifth chapter demonstrated the study’s conclusions and policy implications.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

This chapter first established theoretical models to access the impact of climate change on crop production using the dynamic panel data that was explained. Next, the author explained the relationship between climate change and agricultural production based on developing and developed countries with special attention to developing countries in general and Ethiopia in particular. After explaining the theoretical part in the first section, the researcher assesses different empirical literature reviews on the impact of climate change on crop production throughout the world with more emphasis on developing countries, sub-Saharan countries, and Ethiopia. In the third portion, the researcher discussed the summary and gap of previous research.

2.1 Theoretical Literature Review

2.1.1 Theories on Climate Change

The idea of global warming, which is also known as the increased greenhouse effect, states that these gases produce a drastic increase in temperature. Through its permeable atmosphere, the Earth's surface receives energy from the sun, some of which is absorbed and some of which is reflected as heat into the atmosphere (Zheng et al., 2020).

The proponents of this hypothesis dispute the idea that the last century's global warming of over 0.70C and the last 30 years of over 0.50C may be attributable to natural processes like recovery from the last Ice Age (Sovacool et al., 2021). According to the computer simulations employed in the theory to assume future GHG levels, the Earth's temperature would continue to rise if the amount of carbon dioxide in the atmosphere doubled. The model also predicts that the tropics will suffer more warming than has been detected by satellites and radiosonde observations as a result of tropospheric warming (Schiermeier, 2019).

According to Muchiri et al. (2019) Bio-thermostat Theory of Climate Change, positive feedback brought on by increased CO2 is balanced out by negative feedback resulting from biological and chemical processes. In addition to increasing plant carbon sequestration, higher temperatures are partly to blame for the rise in atmospheric CO2.

According to the solar variability theory of climate change, the late 20th-century global warming was caused by solar variability, which will also be responsible for most of the global warming in the 21st century regardless of human-made GHG emissions (Frölicher et al., 2023). Periodically, solar flares from the sun's surface explode; sending solar winds a flow of charged particles—out into space. These galactic cosmic rays are influenced by the solar winds that reach the surface of the planet and the atmospheres, which in turn affect cloud formation. According to a landmark work by du Plessis (2018), differences in sea surface temperatures and wind patterns are primarily responsible for changes in cloud formation.

2.1.2 Theories on Impacts of Climate Change on Agricultural Productivity

Climate may have a range of effects on agriculture. Changes in average temperatures, extreme weather events that have a significant impact on soil erosion, changes in pests and diseases, variations in the nutritional value of some foods, variations in the growing season, and variations in sea level and carbon dioxide (CO2) concentration are all significant factors that affect agricultural productivity, and their relationships are not simply linear (Nkongho & George, 2019). Existing research demonstrates that certain climatic factors have thresholds over which crops cannot thrive. For instance, the modeling studies discussed in previous IPCC reports show that agricultural yields in temperate regions are projected to gain from an increase in temperature from mild to medium by 1-3°C, coupled with accompanying CO2 increases and rainfall changes. While in low-latitude locations, a minor temperature increase of 1-2°C is anticipated to have a detrimental influence on key crop yields. Crop production would decline worldwide with warming of over 3°C (IPCC, 2007).

A multitude of theories, including market theories and development theories, serve as a foundation for comprehending the study of climate change and its implications on production or productivity. The growth and development ideas from the Washington Consensus period in the early 1990s emphasized the need to let supply and demand dynamics in the market work on their own. As shown by Krogstrup & Oman (2019), Batten et al. (2020), and Sun et al. (2022), theories advanced by growth experts emphasize the necessity of incorporating climate change into growth models to ensure macroeconomic stability, foster innovation, and creativity, open up the global economy, and promote political stability. The idea places a lot of emphasis on both human and physical geography, which both play important roles in development, in addition to institutions. To achieve a rapidly expanding economy, elements of growth and development that are frequently linked with sustainable and private sector-led growth are interconnected (Jeyacheya & Hampton, 2020; Owojori & Okoro, 2022).

According to Zhou et al. (2020). Ryzhenkov (2022), Models blatantly fail to account for how climate influences productivity, which is what this study's major goal is. Exogenous variables in the model include things like migration patterns, population expansion, capital depreciation, and levels of productivity. The model showed that the impact of climate change on economic growth through lower growth was greater than that of direct level effect, contrary to studies in this field that place more emphasis on the level of growth than the rate of growth (Meyghani et al., 2022).

According to Hundie (2021), enumerative and dynamic techniques are used to analyze how climate change may affect productivity. The enumerative analysis examines implications on a sector-by-sector basis, including the influence on agriculture, the environment, energy, infrastructure, and tourism. To determine the overall change in socioeconomic well-being brought on by changes in climatic circumstances, the consequences are examined. This method focuses solely on one era while largely ignoring the consequences of inter-temporal relationships. The study did not, however, give information on the long-term impact of climatic changes on well-being. The strategy also disregards the principles of horizontal inter-linkages, including effects and sectorial interconnections (Hossain Chowdhury, 2020).

2.1.3 Models of the Impact of Climate Change on Agricultural Productivity

2.1.3.1 Ricardian Model

To examine the long-term effects of climate change on agriculture while taking adaptation into account, the Ricardian technique was created (Hossain et al., 2019). Beginning with the presumption that land rents reflect predicted agricultural production (Su & Chen, 2022)

The Ricardian model accounts for the costs of various options. The Ricardian model, for instance, implies that a farmer would bear the expenses typically associated with cultivating a new crop on his property as the temperature warms. In other words, the farmer will be required to pay for fresh seeds and brand-new machinery tailored to the crop. Yet, the Ricardian model does not account for transition costs. The approach does not account for the transition cost, for instance, if a farmer has crop failures for a year or two while learning about a new crop. The model also does not account for the expense of prematurely decommissioning capital equipment if the farmer decides to switch to a new crop. Costs of transition are unquestionably crucial in industries with significant capital that is difficult to replace. For instance, research on timber (Tun Oo et al., 2020) demonstrates the critical necessity of modeling the transition to accurately reflect how challenging it is to alter the forest supply.

Another possible problem is that the climatic variance that can be seen in different parts of the universe could not be representative of how the climate will vary over time (Nguyen & Scrimgeour, 2021). For instance, the temperature variation across space can be negligible in comparison to the temperature change over the coming century. This explains why a Ricardian model may be difficult to estimate in tiny nations. One cannot determine how a country's climate could affect crops if its variety of climates is minimal. This particular issue is not relevant to our study because the sample has a wide range of climatic variances. The fact that future climates won't resemble any extant climates, meanwhile, may still be accurate. For instance, the climate might become unpredictable, resulting in precipitation occurrences that are now uncommon. The analysis is unable to quantify the effect of such modifications.

The Ricardian model likewise counts on constant pricing. This puts a bias into the study, as claimed by Baylie & Fogarassy (2021), overestimating benefits and underestimating losses. As all farms in the same nation practically face the same pricing, the Ricardian technique, which relies on a cross-section, is unable to fully control prices. As prices are a result of the worldwide market, figuring out price fluctuations is not an easy process. Research that claimed to account for pricing fluctuations was forced to make unfounded assumptions about how climate change will affect global output. If these broad assumptions are incorrect, bias could also be introduced. Yet, even analysts who believe that global warming would have significant agronomic effects expect that greenhouse gases will have little overall influence on the world's food supply (Stojcheska et al. 2019).

2.1.3.2 Panel Model

This method has a few significant differences from the hedonic method. Its estimated parameters are first cleared of the impact of any unobserved time-invariant elements under an additive separability condition. Second, once the county-fixed effects are taken into account, using land values as the dependent variable is no longer practical. This is because land values represent long-term weather averages rather than yearly variations from these averages and such factors do not vary over time (Guntukula, 2020).

The method may be used to assess the impact of climate change on agricultural land values, even though land values are not the dependent variable. We specifically calculate the impact of temperature and precipitation increases on agricultural earnings. To determine the effect on profitability, we next multiply these estimations by the anticipated changes in the climate.

2.1.3.3 Agronomic-Economic Crop Models

The crop simulation models serve as systems research tools that help to address issues related to the production of crops. They are in reality a straightforward and relevant depiction of a crop. In essence, the knowledge obtained from field-based testing and observations must be reduced using crop simulation models. Moreover, it offers a space for cross-disciplinary cooperation. Moreover, crop simulation models' systems-based approach aids in the resolution of issues related to crop production. The crop models need input data for operational purposes, including but not limited to information on crop type and variety, soil type and features, meteorological data, and agronomic techniques (Devkota et al., 2022).

Crop simulation models are used to assess how crop growth and development, agricultural productivity, and the sustainability of the agricultural production system are affected by soil, climate, and crop management techniques. The cost and time associated with field trials are significantly reduced when crop simulation models are used for agricultural research. This is so that outcomes from one site or season may be extrapolated to results from other locations or seasons. In recent years, the creation of crop simulation models and the use of decision support system methodologies have substantially aided in increasing resource utilization and agricultural production, minimizing the environmental effects caused by agricultural methods, and mapping yield gaps (McNunn et al.,2019)

The theoretical understanding of agriculture and ecology may be enriched by the historical interpretation of functional changes in agroecosystems, and this information can be used to assist well-informed decisions in practical areas like soil, farm, and land management. To strengthen the interpretation of ecological processes, modern trends in ecology studies integrate and complement many approaches, methodologies, and information sources (Sanches et al., 2021). The economic performance and sustainability of the production system are significantly influenced by the biophysical properties of the agroecosystem, particularly the soil texture, and climate.

To predict crop yield responses, crop-simulation models, sometimes referred to as agro-economic models, relies on controlled trials where crops are cultivated in a field or laboratory settings modeling for various probable future climatic conditions and CO2 levels (Badon, 2022). Although additional modifications in the agricultural practices are not permitted across experimental settings, the differences in the variables of interest, such as temperature, precipitation, and CO2 levels, are then attributed to the variations in the results. Following that, the yields are included in economic models that forecast overall crop production, prices, and net income (Walsh et al., 2020).

Numerous applications exist for crop improvement using crop simulation models. The idea of employing models to find desired features or combinations of attributes possibly leading to the definition of crop ideotypes is instantly suggested by their capacity to forecast growth and yield as impacted by growing environment, agronomic techniques, and crop traits (Emran et al., 2019; Young et al., 2021). The genotype by environment interaction, which studies variation in cultivar response to the environment, is another area where models are very useful (Zhang et al., 2020; Champagne et al., 2021). Although there are instances of how models may be used in practice to better crops, plant breeders have not utilized models extensively.

2.1.3.4 Agro-Ecological Zone Models

According to Amin et al. (2022), the agro ecological zoning strategy tries to provide answers to queries regarding the zonation of a region of the soil and climate. The size of the region might be on the scale of a single mountainside or the entire world, depending on the data that is available and the resolution. The goal is to determine the possible uses that the zones in these places may have. Questions about crop suitability or other resource-based land use, appropriate management techniques, and prospective yields are focused on agriculture and natural resources.

The Food and Agricultural Organization of the United Nations established the conceptual and practical framework known as "agroecological zoning" (UN-FAO). Agroecological zones are homogeneous regions with particular combinations of soils, climate, and other topographic characteristics that are important for agricultural output. For every pertinent component of production, the spatial variability within agroecological zones is kept lower than the variability across zones. These regions or zones are used to evaluate the biophysical constraints and possibilities for the production of food and fiber crops at various management levels (Mohapatra et al., 2021).

The two types of agroecological zoning are matrix and cluster. According to Amin et al. (2022), a matrix zonation uses variables that have been categorized into classes or sub-classes to designate zones. Classes may be determined by frequency distributions of the variable range of values or by subject-matter expertise. The variables are intersected to create the zones. In general, more zones with tiny regions are formed when there are more variables. The number of zones formed for the intended purpose may be greatly controlled using the matrix approach (Amin et al., 2022). Using multivariate statistical analysis, the cluster approach divides the world into a predetermined number of zones. Grid cells are "clustered" to create the classes depending on provided values. Contrary to matrix approaches, the quantity of variables does not affect the number of zones created. As a result, this approach can manage many variables without diminishing the size of the zones (Amin et al., 2022).

To assist in implementing land-use plans and enabling measures for land resources, agroecological zoning was introduced (FAO, 1996). Many regional and international studies have verified it for use in agricultural resource evaluations (AMPOFO et al., 2020). By matching the intended land use needs to the characteristics of the natural endowment, an AEZ approach to land use planning helps to protect the quality of natural resources while decreasing degradation (AMPOFO et al.,2020).

Similar to crop simulation models, these models have the drawback that researchers must explicitly account for farmers' adaptability to changing climatic circumstances (Li et al., 2022). To determine the potential production capacity of various agroecological zones, they also employ crop yield simulations (rather than real crop yields). A further issue with the model is that final results cannot be predicted without explicitly modeling all pertinent components. Hence, failing to consider a single important element might significantly impair the model's predictions (Li et al., 2022).

2.1.3.5 Crop Production Model

Production function models often relate inputs to the production process, such as land, labor, money, and entrepreneurial talent, to the outputs of crops or cattle. Individually or as part of an index, such as the Laspeyres Quantity Index, which may combine any physical inputs, these inputs can be used. These models used panel data to predict the link between output (such as tons per hectare) as a function of socio-economic and climate factors in different agro-climatic zones (Sultan et al., 2019).

In this instance, the effects of maximum temperature, lowest temperature, and years with an annual rainfall that was below the mean (thought to be in years) during the time under discussion were also examined. Additionally, According to Ortiz-Bobea (2021), the effects of numerous technological factors such as machinery value, fertilizer usage, pesticide imports, and the proportion of irrigated land used for the production of wheat, grapes, olives, and oranges were also taken into consideration.

Although the production function technique is currently the least popular method for simulating how climate change may affect agricultural outputs, it is empirically sound. The production function technique, according to Ray et al. (2019), gives estimates of the impact of weather on crop yields that do not account for bias resulting from agricultural output characteristics such as soil quality that are beyond the control of farmers. On the other hand, these authors pointed out that one drawback is that production function estimations do not take into account the entire spectrum of adaptation responses that farmers might undertake to maximize their earnings in reaction to changes in the weather. The production function method, which entirely restricts farmer adjustments, is likely to result in estimates of climate change that are skewed to the negative.

The production function technique has the benefit of accounting for farmers' historical responses to changes in meteorological and economic conditions in historical farm-level and aggregated data. However, given that the crop-weather link is limited to a few factors, such as temperature and rainfall, these historical data are unable to adequately predict future plant-climate interactions. Due to the modest fluctuation in historical CO2 values, these models are therefore unable to adequately incorporate the predicted effects of CO2 fertilization on plants (Akpoti et al., 2019).

Castillo et al (2020) established the relationship between economic and meteorological factors and coffee output in Veracruz, Mexico. The model demonstrated that temperature was the most important climatic component for coffee output and that, given the model's prediction of a 34% decrease in yield; coffee cultivation may not be economically sustainable for producers. The seasonal variation of climatic variables, mean seasonal precipitation, and mean seasonal temperature were all employed in the model. In addition, economic factors like state and international coffee prices, a producer price index for coffee's raw materials, national and American coffee stocks, and the state's real minimum wage were taken into account as proxies for the cost of the labor used to produce coffee.

2.1.3.6 General Equilibrium Model

To evaluate the effects of climate change on agriculture, relationships across many sectors of the economy must be evaluated since they may be directly or indirectly impacted by climate change. The depiction of relationships between agriculture and other economic sectors is well-suited for CGE models. The introduction of land allocation for various uses presents a hurdle when treating agricultural policy within the CGE framework. Using the CGE framework, two basic techniques have been utilized to evaluate the effects of climate change on agriculture. Creating an integrated assessment model, which combines a CGE model with a partial equilibrium agricultural land use model, is the first strategy. The second strategy is to enhance the CGE framework's internal land modeling.

Among the two methods, increasing the functional form inside the CGE framework through a constant elasticity of transformation function is the more popular and straightforward way to include endogenous land use allocation in a CGE model. Early research of this kind typically ignored spatial relationships and the biophysical properties of the land, seeing the land as homogeneous. Several researchers employed a constant elasticity of substitution (CES) aggregator function to discriminate between various land uses to get around this issue. Palatnik and Roson (2009) employed a dynamic multi-regional CGE model with 17 industries in eight areas, where the PRC and India together constitute a region, as an example of this sort of study.

A long-standing tradition in economics that dates back to the nineteenth century is general equilibrium analysis. The interwar period saw the development of general equilibrium modeling, which was encouraged by developments in mathematics and computers since the 1960s. Next, we discuss the global growth of three significant model families: overlapping generations (OLG) models, computable general equilibrium (CGE) models, and macroeconomic GEMs.

Outside macroeconomics, the CGE model family focuses on problems with resource allocation across various supply sectors, relative pricing of commodities and inputs of production, and welfare levels of various income groups. CGE models have their origins in economy-wide planning models, which were created during the 1950s and 1970s. In nations where the government has a significant role in setting sector prices and quantities, planning models integrate macroeconomic (and notably fiscal) policy analysis with aggregate and sector-level budgeting and planning. Multi-sector planning models that integrated the budget, the balance of payments, and national accounts were based on social accounting matrices. A binding foreign resource limitation was incorporated into several planning models for developing nations using two-gap models.

2.1.4 Climate Change Overview and its Impact on Crop Production in Ethiopia

Development and climate change are closely related: Years of development work might be jeopardized by the dangers of global warming, especially in the world's poorest areas. Therefore, it is crucial to make sure that development initiatives increase the ability of their recipients to combat climate change. Making ensuring that the same developments do not result in excessive greenhouse gas emissions is also crucial.

Due to their limited capacity for adaptation, persons in poverty are particularly impacted by climate change. All types of development initiatives have the potential to improve or impair those capabilities. They simultaneously have the power to favorably or negatively affect greenhouse gas emissions, which are the primary contributor to climate change. Therefore, it is crucial to assess how development initiatives may affect the capacity for adaptation and climate change to develop ways to better projects in the face of climate change, mitigation is necessary.

No part of the world or nation is immune to its effects, yet the degree of susceptibility varies greatly. The specific effects of climate change will depend on the climate variance and change in its experiences as well as its geographical, social, cultural, economic, and political situation.. Ethiopia, like many other nations in sub-Saharan Africa, is experiencing climate change. These, according to the United Nations Development Programme (UNDP, 2010), are anticipated to have long-term effects on its food supply.

Ethiopia, like many other tropical and subtropical nations, has experienced severe climatic disasters. The most vulnerable sector is the agriculture sector, which accounts for around 37.57% of the GDP in 2021, more than three fourth of the labor force, and foreign exchange revenues. The agricultural subsectors most impacted by climatic variability are specifically crop and livestock agriculture, which together accounted for more than 80% of the agricultural value added (NBE, 2022).

Ethiopia is one of the most susceptible nations to climate change and unpredictability because it relies on natural resources and rain-fed agriculture, as well as its lack of adaptive capacity to deal with these anticipated changes. Inadequate road infrastructure in drought-prone areas, poor institutional frameworks, a lack of knowledge, low health care coverage, a high population growth rate, and low economic development are only a few of the problems. In addition to rainfall unpredictability and rising temperatures, Ethiopia has regularly suffered severe occurrences including droughts and floods, which hurt livelihoods.

Due to the majority of farmers in Ethiopia being small-scale subsistence farmers who are still largely reliant on rainfall (only 1% of all cultivated land is irrigated), agriculture is the country's industry that is most sensitive to the effects of climate change. The industry uses low-intensive technology, and access to financial or technical assistance is limited. Furthermore, with a 34% GDP contribution, the agricultural sector is vital to Ethiopia's economy. As of 2018, smallholder farming households were responsible for over 85% of all employment and around 95% of the nation's agricultural output. According to estimates, 75% of Ethiopia's export commodity value which includes important exports like coffee and livestock comes from the agricultural sector. Risks associated with the climate are made more vulnerable by limited water storage capacity.

Many of Ethiopia's small-holder farmers cultivate "long cycle" crops, which are slow-maturing, high-yielding, and rely on two rainy seasons to reach harvest, making them even more susceptible to variations in seasonal rainfall. Most plots are less than half a hectare, which is insufficient to maintain household food security, much alone provide enough money. Due to this, households are less able to invest in better farming methods that can boost climate resilience. Due to persistent droughts and growing desertification brought on by land use constraints, a considerable amount of arable land has been lost, making the nation more and more reliant on food aid. Warmer temperatures may temporarily boost agricultural productivity in some regions (highlands and high plateaus), but prolonged high temperatures will cause heat stress and crop failure. If the current decrease in average annual rainfall levels for primary agricultural zones persists until the middle of the next century, Ethiopia is predicted to lose more than 6% of its yearly agricultural production. Growing seasons may be shortened and soil erosion may rise as a result of rising temperatures and changing rainfall patterns. These possibilities might also change where and how often pests appear.

The agriculture industry is strongly reliant on surface and groundwater supplies, which are susceptible to localized land use and are anticipated to undergo declining recharge and quality due to decreased precipitation in certain locations and increased evaporation. In increasingly dry regions, a predicted trend of decreasing rainfall might have an impact on agriculture and water quality. A rise in pests and illnesses that are destructive to yield production and quality may also be brought on by rising temperatures and the potential for waterlogging of fields. Further soil erosion and soil fertility loss will result from changes in the seasonality of precipitation. Climate warming might accelerate soil erosion by 40–70% by 2050.

2.1.5 Theoretical Framework and Econometrics Model of the Study

The model uses the production function as a deterministic one related to the output level. There was different researcher that studied the impact of climate change on crop production. For instance, Ketema & Negeso (2020) used Real agricultural growth domestic product as the dependent variable and labor force, mean annual temperature, rainfall, agricultural land as the independent variable; Zaied & Cheikh (2017) in Tunisia studied agricultural crop production and climate variables for 1979-2011 using time series approach; Attiaoui & Boufateh (2019), Panel regional data from 1975 to 2014 and found that climate change affects negatively the cereal output in Tunisia; Guntukula and Goyar (2020) in India using a panel data approach from 19956-2015 and they found that the average minimum temperature has a significant unfavorable effect on maize yield in the country.

The stochastic production function of the crop production for the zone (i) for the year (t), Yit, is represented as follows:

$$Y_{it} = f(X_{it}; \beta) + \varepsilon_{it} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.1)$$

Where it ε is the stochastic term with mean, E (ε_{it})=0, and variance V=σ^2, β is the production term variables to be estimated. The estimation of the equation $f(X_{it}; \beta)$ provides the effects of the independent variables on the mean crop production, E$(Y_{it}) =$. The explanatory variables, X_{it} will be used in the model will include a constant, rainfall (precipitation), relative humidity, number of holders, the area covered in a hectare, fertilizer used in quintals, annual maximum mean temperature, and annual minimum temperature.

Generally, our econometrics model is based on Kelbore (2012), Mano & Nhemachena (2007), Bozzola (2014), Nkonde (2014), Zaied & Cheikh (2017), Attiaoui & Boufateh (2019), Saei et al. (2019), Guntukula & Goyar (2020) and Ketema & Negeso (2020) as follows:

$lnY_{ijt} =$
$\beta_0 + \beta_1 \ln(Perci_{ijt}) + \beta_2 \ln(HH_{ijt}) + \beta_3(\ln\mathrm{ACH}_{ijt}) + \beta_4(lnFrt_{ijt}) + \beta_5(lnMinimumAMT_{ijt}) + \beta_6(lnRH_{ijt}) + \beta_7(lnMaximumAMT_{ijt}) + Dummy(region) + \alpha_i + u_i$ ………………………………
(2.2)

Where $lnY_{ijt}$the natural logarithm of annual crop production for zone j is, $lnPerci_{ijt}$ is the natural logarithm of mean annual precipitation for zone j, HH is the total number of holders of the crop in zone j and time t, ACH is the total area covered in a hectare in zone j and at time t, Frt is the total amount of fertilizer in quintal used in zone j at time t, minimumAMT is the mean minimum annual temperature in zone j at time t, maximuAMT is the mean maximum annual temperature in zone j at time RH is the relative humidity in zone j at time t and dummy (region) is the zone in which regions is located, α_i is the crop production item-specific fixed effect, U_{it} ~N (0, σ^2) is the random term, α_i and u_{it} are independently and identically distributed.

2.2 Empirical Literature Review

2.2.1 World Level

According to a study by Zhang et al. (2017), the yields of wheat, maize, and rice in China are predicted to decline by 18.26 ± 12.13, 45.10 ± 11.55, and 36.25 ± 10.75% until 2100 due to the effectr of climate change. Since the turn of the century, extreme weather events have increased in frequency in the Netherlands, having a substantial impact on wheat output (Powell & Reinhard, 2016). The severity of the decline in wheat output was dictated by the week in which the extreme weather event occurred (Stevanović et al., 2016).

Research by Schlenke & Roberts (2009), investigated the impact of climate change on crop productivity (corn, soybean, and cotton) in the USA by using the Hadley III model, and they incorporated the Slowest warming scenario and rapid warming scenario and they found that the yield can increases when the temperature level was 29–32 ◦C. whereas the yield was decreasing when the temperature level was different from this level temperature by 30-46 percent by 2100.

Guntukula (2020) in India also investigated the impact of climate change on Indian Agriculture using a timer series data over 58 years period (1961-2017) for seven important crops, including rice, wheat, pulses, rapeseeds and mustard, cotton, sugarcane, and peanuts. Guntukula (2020) found that rainfall and maximum and minimum temperatures have a considerable impact on main crop yields, although the extent of the impact differs across the crops tested. In addition, he also concluded that Except for pulses, an increase in rainfall harms food crops; however, it has a favorable impact on non-food crops during the research. Furthermore, he argued that all crops, except rice, are positively impacted by the average maximum temperature.

2.2.2 Africa Level

Climate change concerns are of great concern to policymakers and the academic community because of the close connection between agriculture, poverty, and climate change. At the continental level, it has been calculated that the overall impact of climate change on the agricultural industry is greater than 10%. At the continental level, expected variations in temperature, precipitation, atmospheric carbon content, and severe events are expected to have a significant impact on plant growth and yields, agricultural output, animal production, and water availability. Depending on height and other variables, the effects of climate change differ amongst nations. While sub-humid nations like some areas of Mali, Burkina Faso, and Ghana are anticipated to suffer from decreased rainfall, countries like Mauritania, Mali, and Niger are anticipated to profit from longer growing seasons brought on by climate change.

Downing (1992) studied the effects of climate change on food security in three African countries including Zimbabwe, Kenya, and Senegal, and concluded that high temperatures and increased rainfall in Kenya's highlands would enhance potential food production. However, as yields continue to decline due to a lack of rainfall, people from socioeconomically disadvantaged groups in semi-arid areas, in particular, would face significant challenges. Additionally, he stated that a temperature increase of 20C would result in a one-third reduction in Zimbabwe's core agriculture and a major reduction in Senegal's rain-fed agriculture's carrying capacity.

Nhemachena et al. (2020) studied the impact of climate change impacts on the water and agriculture sectors in Southern Africa. The researcher found that the majority of Southern Africa is predicted to see decreased rainfall, rising temperatures, and high variability, with significant decreases in the region's drier and marginal western regions. In addition, they analyzed that the performance of agriculture and its contribution to regional and national development goals were significantly impacted by these effects. The researcher also argued that the agricultural production of the area is predicted to decline by 15% to 50%, which would increase the region's food insecurity. Nhemachena et al. (2020) recommended that the task is to manage water and energy resources effectively and sustainably while simultaneously lowering environmental impact to maximize production on the already available arable land.

Lokonon et al. (2019) studied the economic impact of climate change in West Africa by using a bio-economic approach model through assessing the potential influence on land usage and agricultural production in two typical concentration routes along with three socio-economic scenarios, and it is calibrated using data from the base year 2004. Their finding implied that crop kinds and current future circumstances may influence land use change. In addition, they analyzed that crop output, paddy rice, oilseeds, sugarcane, cocoa, coffee, and sesame production might typically decrease under both mild and hard climate conditions. Additionally, they analyzed that increasing food yields by twofold by 2050 could help to lessen the adverse effects of mild climate change overall.

Schilling et al. (2020), studied in North Africa and their findings implied that all countries were vulnerable to severe temperature rises and a significant risk of drought due to climate change. Specifically, they found that due to its great sensitivity to climate change, Algeria is the country most at risk. They argue that climate change and rapid population expansion in North Africa are extremely likely to exacerbate the region's already precarious water supply situation. Finally, they suggested that the so-called Arab Spring has demonstrated that the population's unfulfilled basic requirements for food and water are a contributing factor to social unrest.

Tadesse et al. (2019), studied production limitations, and an analysis of the demand-supply chain for wheat. Their finding indicated that in 2013, Sub-Saharan African countries used 25 million tons of wheat overall, of which 17.5 million tons were imported for USD 6 billion. In contrast, during the same year, the region produced just 7.3 million tonnes of wheat in an area of 2.9 million hectares. The region's poor production (2t/ha) was mostly caused by biotic and abiotic stressors that are becoming more intense and frequent as a result of climate change, including yellow rust, stem rust, septoria, and fusarium.

2.2.3 Ethiopia (Country) Level

There aren't plenty of publications on the effects of climate change on agricultural productivity in Ethiopia from Zonal Perspectives. The few publications that have been published thus far employ CGE methodology, and the majority of them reflect a general equilibrium model which is not based on yearly time series data. In this context, Solomon et al. (2021), Gebreegziabher et al. (2016), Ferede et al. (2013) and Robinson et al. (2013) use Country SAM whereas Borgomeo et al. (2018), Holden et al. (2005), Tekle, & Simane (2014), and Berhanu (2016) used Village SAM explain the effect of climate change on agricultural productivity without specifying the effect on each agricultural outputs. The other shortage of the previous research was most of them were simulated based on one Social Accounting Matrix without identifying the yearly trend of each agricultural productivity.

Whereas a study by Assefa et al. (2008), Deressa et al. (2008) examined only the perception of small-scale farmers and pastoralists in the most vulnerable parts of the country. According to the result by Assefa et al. (2008), and Deressa et al. (2008), due to their over-reliance on natural resources for their livelihoods and good fortune with a variety of sources of income, families led by women and those with low levels of education were found to be the ones most affected by climate change. Both of them also demonstrated how various regions are impacted by climate change. Finally, they suggested that lowlands that are neither arid nor semi-arid are less sensitive to climate change, whereas regions with arid, semi-arid, and dry sub-humid lowlands are more vulnerable.

A study by Aragie (2013) analyzed the effects of climate change on agricultural production and estimated the output that is lost as a result by using data from the country and area to conduct a time series econometrics analysis. According to the researcher, between 1991 and 2008, Ethiopia lost a total of more than 13 percent of its present agricultural output. Aragie suggested that Ethiopia would lose, on average, more than 6% of its yearly agricultural production if the pace of drop in the average annual rainfall continues over the next few decades. Variability in rainfall has a significant influence on poverty. Thus, even if it is expensive, addressing climate change and adapting to it may help the nation's economy flourish and combat poverty.

Singh (2019), studied the impact of climate change on agricultural crop productivity in the Metu area using descriptive statistics for the year 2018/19. According to the researcher, the region's agricultural output is negatively impacted by climate change. The availability of livestock feed, the impact on animal health, growth, and reproduction, the reduction of crop quality and quantity, changes in distribution rates, contraction of pastoral zones, expansion of tropical dry forests, and expansion of desertification are just a few of the ways that the changing climate has an impact on agricultural productivity and production. Finally, the researcher suggested that to prevent the negative effects of climate change, cooperation between the state and local communities is essential, as the study both practically and conceptually supports.

In addition, research by Solomon et al. (2021), found that at the national level, the agricultural output will suffer over the next 40 years, with the severity increasing throughout that time. In addition, their results indicated that teff, maize, and sorghum production will all decrease by 25 percent, 21 percent, and 25.2 percent, respectively, compared to the base period by 2050. And also, 31.1 percent of the agricultural GDP will be lost as a result of climate change by 2050. They also concluded that poor rural households are more impacted by climate change in terms of income and consumption than urban-rural non-farming households. Finally, they argued that the decline in agricultural output won't affect all agroecological zones equally, and it won't be entirely bad.

Sertse et al. (2021) studied the farm households' perceptions and adaptation strategies to climate change risks and their determinants of a vulnerable farming community of Raya Azebo district using a multi-stage sampling approach from a sample of 397 farm households from the study using descriptive and interferential statistics. According to the result, the most widely used adaptation strategies were reported to be crop diversification (99%) and water management techniques (78%). In contrast, the least widely used adaptation strategies were reported to be the use of improved seed (27%), tree planting (26%), mixed farming (12%), and home farm practices (3%). The researcher recommended that increasing rural families' access to different institution-led services (such as loans, advice, and climate information) will boost their capacity for adaptation and livelihood resilience.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

The objective of the study was to determine the impacts of climate change on major crop producer zones of Ethiopia in the case of private peasant holders' crop producers. Therefore, this chapter set out the methodology which uses to achieve the study objectives. The chapter also focused on the research design used in the study and the theoretical framework adopted. The section also presented model specifications. Lastly, the section mentioned the data type, source, and data analysis.

3.2 Research Design

Research design encompasses the methodology and procedures that were employed to conduct the study. The study adopted a diagnostic research design to determine the effect of climate change on crop production because the study seeks to analyze the frequency with which climatic variables occur and their effect on crop production. Quantitative panel data series data pertinent to each variable was used to answer the research questions and objectives as stated in chapter one. The study used annual data for the period 2003/04-2021/22 for all the variables. Dynamic panel data regression analysis was used to measure the relationship between the variables, the direction, and the magnitude of change.

3.3 Description of the Variable

Annual Crop Production ($\boldsymbol{lnY_{jt}}$): It is the total amount of crop production (cereals, pulse, oilseed, and vegetables) in zones in the yearly period in quintals.

Mean Annual Rainfall (ln$\left(\text{precipitation}_{\boldsymbol{ijt}}\right)$: Mean rainfall (mm) is the arithmetically averaged total amount of precipitation recorded during a year for each selected zones.

Number of Holders$\left(\boldsymbol{ln}(\boldsymbol{HH_{ijt}}\right)$: It is the total number of agricultural household i who produced a certain type of crop in zone j at a time t.

Area Covered in Hectare (lnACH$_{\boldsymbol{ijt}}$): It is the total land arable area covered by a certain crop at zone j in time t.

Fertilizer $\left(\boldsymbol{lnFrt_{ijt}}\right)$: it is the total amount of fertilizer in quintals used by a crop in a year.

Mean Annual Maximum Temperature ($lnAMT_{ijt}$): The mean maximum annual temperature refers to the average of the maximum temperatures of a year, taking the mean average of the hottest month of the year in zone j at a certain year.

Mean Annual Miniminium Temperature ($lnAMT_{ijt}$): The mean annual temperature refers minimum temperatures of a year, taking the mean average of the coldest month in zone j at a certain year.

Relartive Humidity ($lnRH_{ijt}$): The quantity of water vapour in an air-water combination relative to the maximum amount is known as relative humidity (RH). RH is a comparison between the saturation humidity ratio at a specific temperature (dry-bulb) in zone j in a given year and the humidity ratio of a specific water-air combination.

3.4 Data

The study used secondary data to examine how climate change has affected the production of Ethiopian private peasant holders in major crop-producer zones. The Ethiopian National Metrology Agency (NMA) and the Central Statistical Agency (CSA) of Ethiopia provided the datasets. The sources mentioned above were used to compile an annual panel series of data on net crop production, land input available for each crop production, the weight of fertilizer used, annual minimum average temperature, annual maximum average, relative humidity, and annual average precipitation for each zone was collected. The study's time frame, measured in terms of the Gregorian calendar, ranges from 2003/04-2021/22. The information was gathered based on the dataset's accessibility and the variables' applicability to the investigation. The researcher was only limited to 2003/04-2021/22 due to the availability of data on crop production before 2003/04.

3.4.1 Crop Production Data

The study used the yield data for four major crops in the country's agricultural production which accounts for more than 90 percent of crop production in the country namely cereals, pulses, oilseeds, and vegetables. The crop prodction data were obtained from the agricultural sample surveys conducted by the Central Statistical Agency (CSA) of Ethiopia starting from the period 2003/04. To maintain, the zonal level reporting units for the years from 2003/04, the total production for each zonal classification is based on the 1995 EPRDF zonal classifications from each region.

Thus the study covers 21 zones located in five administrative regions as of the current administrative classification of the country. Namely, the study focused on seven zones from the Amhara region such as East Gojjam, West Gojjam, North Gondar, South Gondar, North Wollo, South Wollo, and North Shewa; five regions from Oromia regional state namely West Wollega, East Wollega, Jimma, West Shewa, Arsi, West Arsi, and South West Shewa; five zones from SNNP namely, Gurage, Woilata, Keffa, Gammogofa, and Silitie; one from Simada region Sidama zone in the previous administration and lastly one zone Metekel from Binishangul Gumuz.

The above-mentioned Zones was selected because for instance during the 2021/22 period, in the Amhara region, the total crop production was 112,528,693.08 quintal and from this, the above 7 zones crop production was 101,350,573 which was 90.07 percent of the region total crop production. From the Oromia region, 175,542,709.96 quintals were produced, and from this 131,875,519 quintals which was 75.12 percent of the total production in the region. From the Binishangul Gumuz region during 2021/22, 7,097,770.88 quintal was produced and out of this 4,220,555.17 quintal was produced in the Metekel region which accounts for 59.46 percent of the total production in the region. From the SNNP region, 26,529,237.41 quintals were produced and from this, the above 5 selected zone produced 19,973,330 quintals was produced which accounts for 75 percent of the total production. Lastly, the Sidama region which produced 2,643,012.56 quintals was included in the study. Totally during the 2021/22 period in the country 327,903,521.41 quintal crop was produced. Out of this, the selected zone 260,062,989.73 quintal crop was produced which accounts for 79.31%.

For the study, the Tigray region was not included because data was not available during 2021/22 and the war in the northern part of the war has affected the crop production in the country as a result of this the researcher will not include it in the study. The other regions and zones were not included in the study since they are not major crop production areas.

3.4.2 Rainfall Data and Climate Change Data

A panel data series of rainfall data for 21 stations across five regions of Ethiopia, namely Amhara, Oromia, SNNPR, Binishangul Gumuz, and Sidama was used to collect data on mean minimum temperature, mean maximum temperature, mean annual precipitation, and relative humidity. Missing values for the climate change-related variables at the station level were interpolated using a moving average method, as the moving average better approximates the series than regressing the rainfall climate change series variables (mean minimum temperature, mean maximum temperature, mean annual precipitation, and relative humidity) of the nearby station on the station for which missing data are reported.

3.5 Method of Data Analysis

Tools for descriptive and econometric analysis were employed in this investigation. Crop production, yearly mean minimum and maximum temperatures, and annual mean rainfall are all described using descriptive statistics like mean, standard deviation, and minimum and maximum values. The study examines how explanatory factors affect the dependent variable using Arellano bond GMM dynamic panel model estimation.

It is predicated on the idea that the instrumental variables method does not fully use all of the data present in the sample. We may create more effective estimates of the dynamic panel data model by doing this in the context of the Generalised Method of Moments (GMM). Arellano-Bover/Blundell-Bond (Arellano and Bover 1995; Blundell and Bond 1998) and Arellano-Bond (Arellano and Bond 1991) dynamic panel estimators are becoming more and more common in this situation. Both of these are general estimators created for scenarios with 1) "small T, large N" panels, or few periods and many individuals, 2) a linear functional relationship, 3) one left-side variable that is dynamic, depending on its past realisations, 4) independent variables that are not strictly exogenous, meaning they are correlated with past and possibly current realisations of the left-side variable, and 5) a linear functional relationship. Arellano-Bond estimation, also known as difference GMM, employs the generalized method of moments (GMM) (Hansen 1982) to convert all regressors in the beginning. The fact that the estimators use instrumental variable approaches and that the Sargan-Hansen test findings must be evaluated when they are used is another factor in the researcher's decision to use dynamic panel data.

3.6 Specification and Estimation Procedure

The advantage of panel data is that they enable the researcher to better grasp the dynamics of adjustment. Many econometric connections are dynamic. According to Baltagi (2005), Sul (2019), Tsionas (2019), and Parker (2020), these dynamic relationships are characterised by the inclusion of a lagged dependent variable among the regressors. The overall structure of an autoregressive model of order of p with extra regressor xit might be defined as follows for a dynamic panel data approach (Baltagi, 2005):

$$Y_{it} = \theta_1 Y_{it-1} + \cdots + \theta_p Y_{it-p} + X'_{it}\beta + \alpha_i + \varepsilon_{it}; t = 1, \dots, T, i = 1, \dots, N \quad \dots\dots\dots\dots\dots (3.1)$$

The basic formulation of equation (4) simplifies to a first-order model in our situation, where i is a time-invariant individual effect whose treatment may be constant or random, and ijt is a disturbance term considered to be uncorrelated with Xit. In a dynamic model, the reverse is true since it will rely on i regardless of how we treat the latter, in contrast to a static panel data model where choosing between fixed or random effects produces a consistent and efficient estimate (Verbeek, 2004). A within estimator applied to a first-order autoregressive model yields consistent estimates only when the number of periods *T* is very large (Green, 2003). (Arellano & Bond, 1991), introduced a two-step procedure based on differencing and instrumenting which is a consistent and efficient estimator. The first step consists of differencing the dynamic equation to remove the individual effects (α_i). Cameron & Trivedi (2005) wrote the first step of the procedure as:

$$\Delta Y_{it} = \theta_1 \Delta Y_{it-1} + \cdots + \theta_p \Delta Y_{it-p} + \Delta X'_{it}\beta + \Delta\varepsilon_{it} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3.2)$$

Δ is the first-order differential equation expressing the change of the dependent variable by the effect of its lagged value and exogenous regressors. In this regard, we assume that ε_{it} is serially uncorrelated, otherwise, estimators are inconsistent. The second step deals with instrumental variable (IV) estimation of the first differenced (FD) model that uses appropriate lags of the dependent variable as instruments. According to (Drukker, 2008), these couple of steps does lead to consistent parameter estimates. The fixed or random effects panel data estimators are not appropriate even for the FD equation. In contrast to a static model, ordinary least squares on the FD data produce inconsistent estimates because the regressor ΔY_{it-1} is correlated with the error $\Delta\varepsilon_{it}$, even if the ε_{it} are serially uncorrelated. For serially uncorrelated ε_{it}, the FD model error term

$\Delta\varepsilon_{it} = \varepsilon_{it} - \varepsilon_{it-1}$ correlates with $\Delta Y_{it-1} = Y_{it-1} - Y_{it-2}$ because Y_{it-1} depends on ε_{it-1}. However, $\Delta\varepsilon_{it}$ is uncorrelated with ΔY_{it-k} for $k \geq 2$, opening up the possibility of IV estimation using lagged variables as instruments (Cameron & Trivedi, 2005).

Depending on the previous justifications, our equation to be estimated can be specified in the levels and first differenced forms.

$$lnY_{ijt} = \beta_0 + \beta_1 \ln(Perci_{ijt}) + \beta_2 \ln(HH_{ijt}) + \beta_3 ln(\mathrm{ACH}_{ijt}) + \beta_4 ln(Frt_{ijt}) + \beta_5 ln(MinimumAMT_{ijt}) + \beta_6 ln(RH_{ijt}) + \beta_7 ln(MaximumAMT_{ijt}) + Dummy(region) + \alpha_i + u_i \ldots\ldots\ldots\ldots\ldots\ldots (3.3)$$

$$\Delta lnY_{ijt} = \beta_{1\Delta} Y_{ijt-1} + \beta_2 \Delta\ln(Perci_{ijt}) + \beta_{3\Delta} \ln(HH_{ijt}) + \beta_{4\Delta} ln(\mathrm{AH}_{ijt}) + \beta_{5\Delta} ln(Frt_{ijt}) + \beta_6 \Delta ln(MinimumAMT_{ijt}) + \beta_7 \Delta ln\left(RH_{ijt_{ijt}}\right) + \beta_8 \Delta(MaximumAMT_{ijt}) + \Delta u_i \ldots\ldots\ldots\ldots\ldots\ldots (3.4)$$

All variables are in natural logarithms. Using the latest version of Arellano/Bond GMM estimation, equation (3.3) is first estimated to determine the determinants of crop production. Since the Arellano-Bond method generates several instruments (for large T) leading to potentially poor performance of asymptotic results (when the number of groups is small), we have employed the least possible number of instruments. The Stata/SE 13.0 computer software was employed for estimation.

3.7 Econometrics estimation procedures

3.7.1 **Serial Correlation**

For consistent estimation of dynamic models, the GMM estimators require that the error term (ε_{it}) be serially uncorrelated (Stata13, 2013). Specifically, if ε_{it} are serially uncorrelated, then $\Delta\varepsilon_{it}$ are correlated with $\Delta\varepsilon_{it-1}$ because $\mathrm{Cov}(\Delta\varepsilon_{it}, \Delta\varepsilon_{it-1}) = \mathrm{Cov}(\varepsilon_{it} - \varepsilon_{it-1}, \varepsilon_{it-1} - \varepsilon_{ijt-2}) = -\mathrm{var}(\varepsilon_{it-1}) \neq 0$. Conversely, $\Delta\varepsilon_{it}$ will not be correlated with $\Delta\varepsilon_{it-k}$ for all $k \geq 2$. A test of whether $\Delta\varepsilon_{it}$ is correlated with $\Delta\varepsilon_{it-k}$ for $k \geq 2$ can be performed by using the Arellano-Bond tests for serial correlation (Roodman, 2006). According to the literature, it is not always true that the model is flawed if the null hypothesis of no serial correlation at order one in the first-differenced errors is rejected. Higher order rejection of the null hypothesis instead suggests that the moment conditions given by Drukker (2008), Gebreyesus (2011), Roodman (2006), Cameron & Trivedi (2005), and Stata13 (2013) are invalid.

3.7.2 Over identifying Restrictions

Under the immediate conditions provided by dynamic panel data (DPD) models, a large number of devices are employed to estimate a small number of parameters. Therefore, it is necessary to assess the overall validity of these over-identifying limitations. The conventional GMM test, commonly referred to as the Sargan (1958) test of over-identifying restrictions, performs that procedure (Bowsher, 2002). However, only a homoskedastic error term in the Sargan test exhibits an asymptotic chi-squared distribution (Stata13, 2013). As a result, it was found by (Bowsher, 2002) that the Sargan test lacked power in panels of dimensions often employed in empirical investigations. The test (create a test statistic) fails fully when robust standard errors are provided.

According to Arellano and Bond (1991), a one-step Sargan test tends to over-reject valid instruments whereas a two-step test tends to under-reject weak instruments when heteroskedasticity is present. Over-identifying limits in both models aren't valid for one-step estimate but are highly valid for two-step estimation. Utilising an enhanced variation of Roodman's (2006) system GMM estimators is one possibility. It is possible to perform the Hansen (1982) J test of over-identifying restrictions when strong standard errors are provided.

3.7.3 Heteroskedasticity

The default GMM estimators produce homoskedastic standard errors when estimating DPD models. However, some writers (Cameron & Trivedi, 2005; Drukker, 2008; Stata13, 2013) strongly advise that robust standard errors must be used to account for heteroskedasticity. To determine whether heteroskedasticity occurs, the residuals Breusch and Pagan (1980) test was run. The test's central notion is based on an auxiliary regression of squared residuals against explanatory factors, including the constant. The desired statistic is obtained by multiplying N(T-1) times R2 of the auxiliary regression by an asymptotic chi-squared distribution with degrees of freedom equal to the number of regressors (Verbeek, 2004).

3.7.4 Endogeneity

In the crop production model, climate-related factors were an exogenous variable (Bergstrand, 1985). Despite these efforts, there is theoretical and empirical support for the idea that agricultural output is being impacted by climate change (Batra, 2014; Ram & Prasad, 2007; Rahman, 2009). As a result, the paradigm allows for both positive and negative causality. Regression results using an exogenous climate change treatment might be misleading if this is the case. Endogeneity should thus not be disregarded in equations (3.4). The lagged levels and starting differences of the endogenous variables are used in the GMM setup as instruments to account for these potential issues.

CHAPTER FOUR

DATA ANALYSIS, RESULTS, AND DISCUSSION

4.1.Over view of Crop Production and Climate Change in Ethiopia

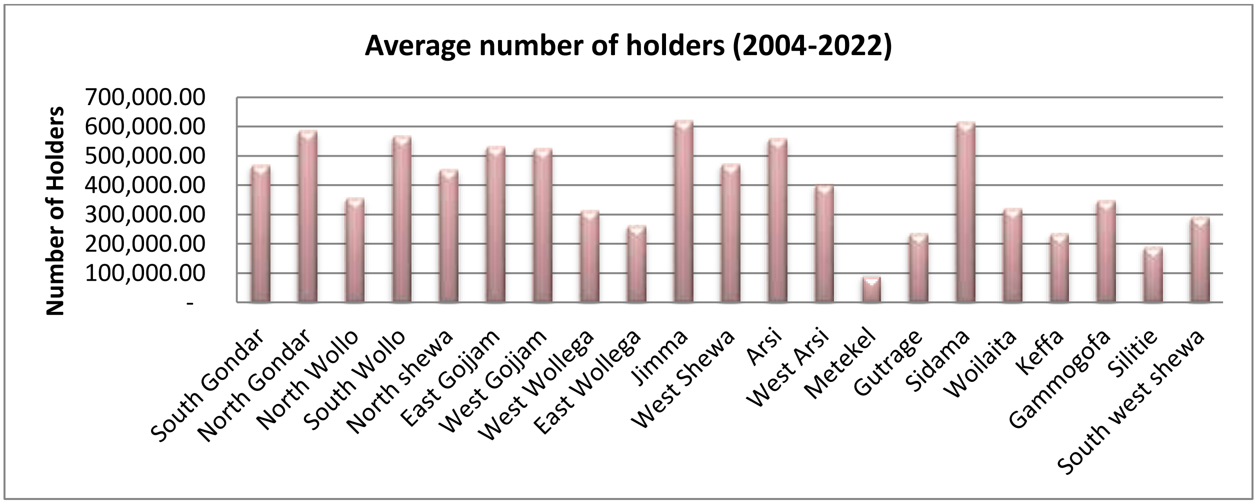
4.1.1 Overview of Crop Production in Selected Major Crop Producer Areas

4.1.1.1 Overview of Cereals Production in Selected Major Crop Producer Areas

Figure 4.1 below shows the average number of holders in major crop producer zones, in Ethiopia for the periods between 2004 to 2022. As the data shows Sidama, Jimma, north Gonder, south Wollo, Arsi, east Gojjam, and west Gojjam, have a large number of farmers in the production of cereals. Hence, in each area above 500 thousand farmers, while the other zones such as Metekel, siltie, and Keffa zones have a small number of farmers in cereal production (for more see figure 4.1).

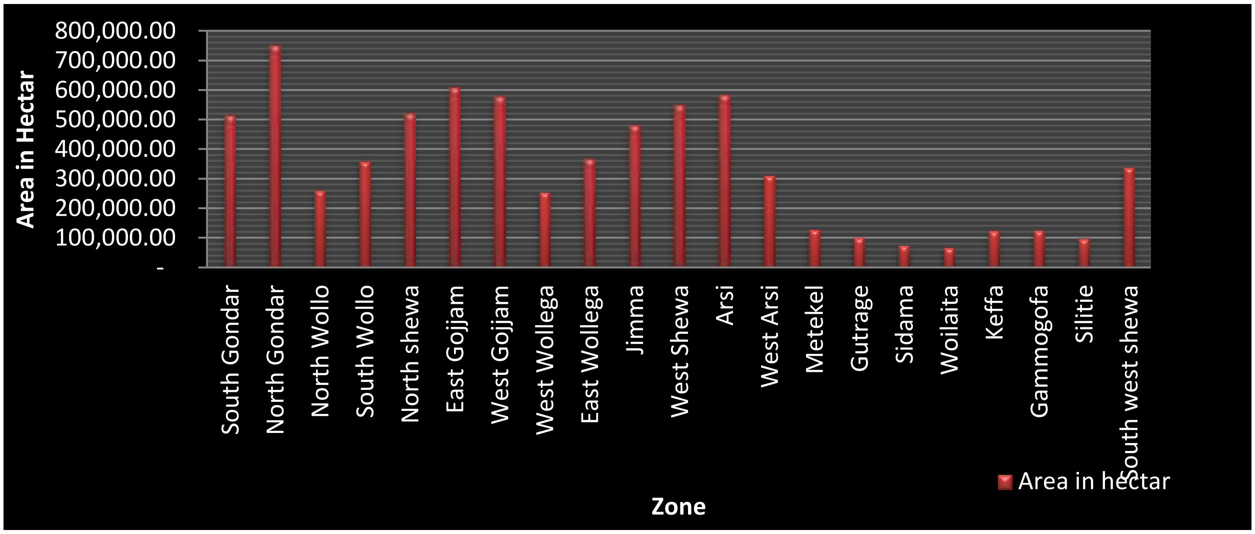
In addition to this figure 4.2 clearly indicates the areal coverage's of cereal production, in which, north Gonder, east Gojjam, Arsi, west Gojjam, and west Showa have a large portion of hectare of land for the production of cereals, while Welkite, Sidama, silte, Gurage, Metekel, keffa as well as gamogofa have a small hectare of lands belongs to the production of cereals (see figure 4.2)

Figure 4.1: Average Number of Holders of Cereals from 2004-2022



Source: Authors Computation Using Data From CSA (2022)

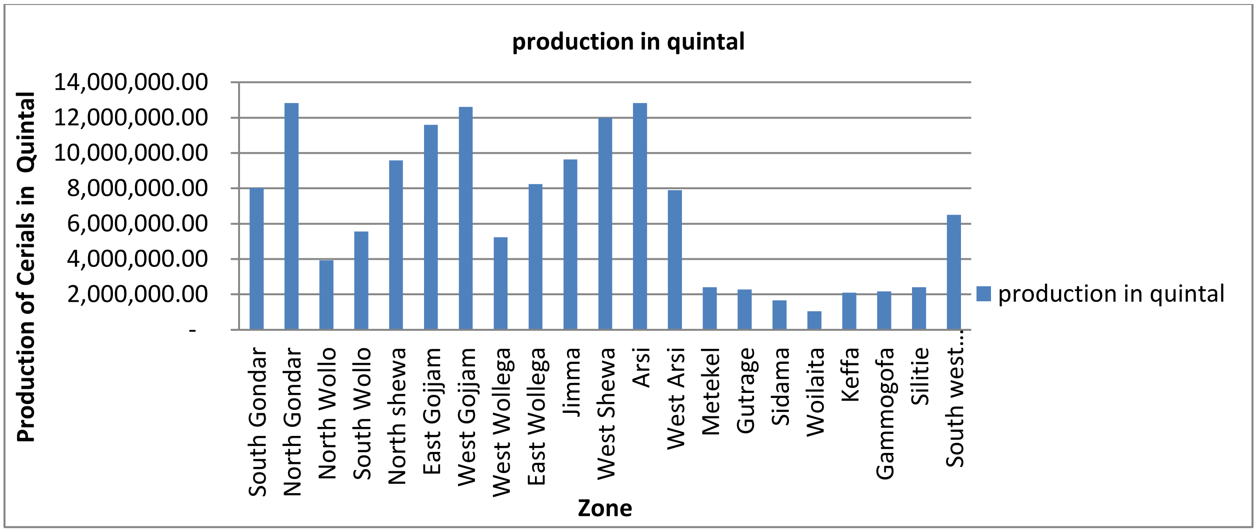
Figure 4. 2: Area in Hectare for cereals for Selected Major Producer zones



Source: Authors Computation Using Data From CSA (2022)

Figure 4.3 shows the production of cereals in different cereal producers' areas, as per the graph below, high cereal producer zones are North Gonder, Arsi, West Gojam, West Shewa as well as East Gojjam, hence, such zones produce 10 million quintals of cereals from the period 2004 to 2022 on average. Also, North Shewa, Jimma, South Gonder, West Arsi, and East Wollega produce cereals from 6 million up to 10 million quintals on average. While, wolkita, Sidama, Gurage, mettekel, keffa, gamogofa, and silite zones are low cereal producers (see Figure 4.3).

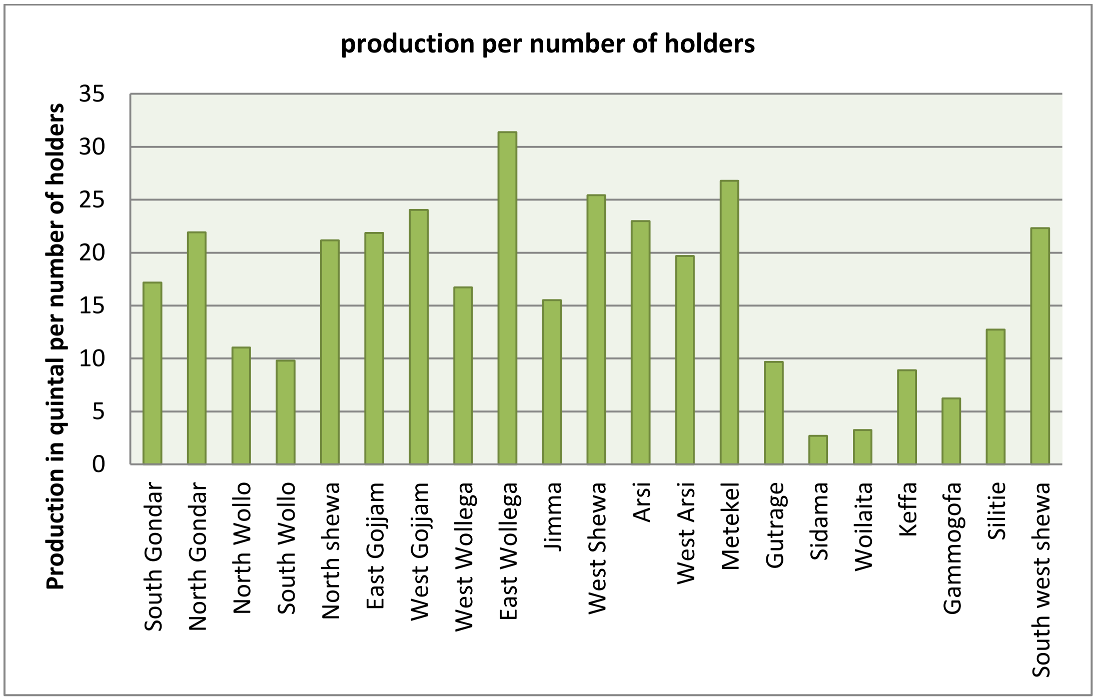
Figure 4.3: Production in Quintal of Cereals on Average Under study (2004-2022)



Source: Authors Computation Using Data From CSA (2022)

The production of cereals per number of holders/farmers is discussed in Figure 4.4 below, in which east wollega, metekel, west Shewa, Arsi, Southwest Shewa, west gojjam, north Gonder, north show, and east gojjam zones on average are high in the production of cereals per number of farmers, in which area the production of cereals per quintal is greater than 20 on average per holders or farmers. While, on average Sidama, Wolkite, Gamogofa, Keffa, Gurage, and Silte zones are low production of cereals in quintals per number of holders or farmers (for more see figure 4.4).

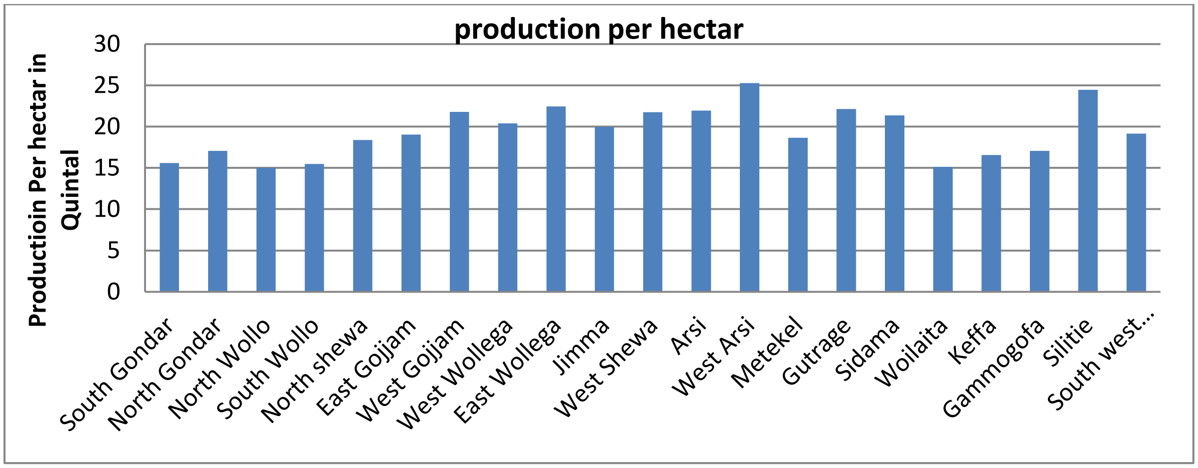
Figure 4.4 Production of Cereals Per number of Holders



Source: Authors Computation Using Data From CSA (2022)

The production of cereals per hectare is discussed in Figure 4.5 below, in which West Arsi, Siltie, East wollega, Gurage, Sidama, west gojjam, and west wollega, zones on average are high in the production of cereals per hectare, in which area the production of cereals per hectare is greater than 20 quintals on average per hectare (for more see figure 4.5).

Figure 4. 5: Production per Hectar of Cereals in Major Producer Zones on Average from 2004-2022

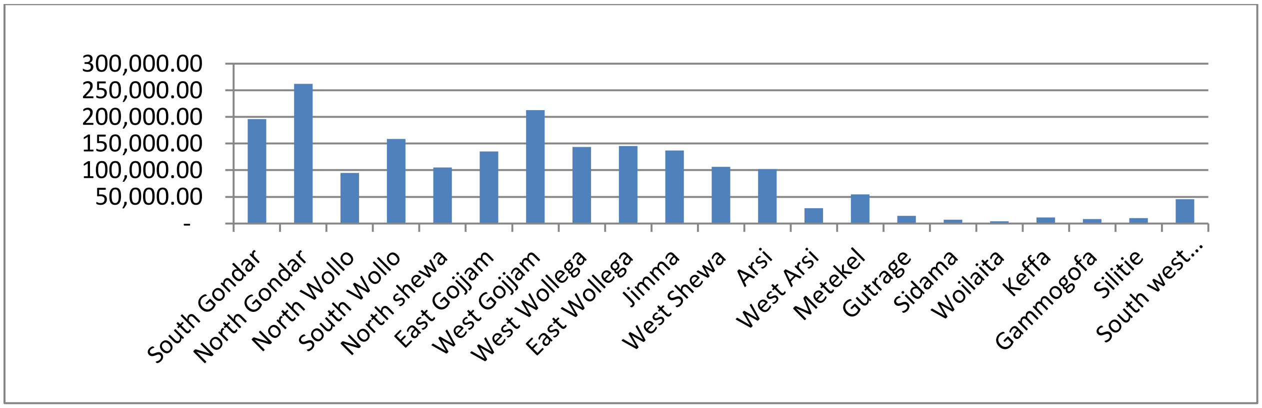


Source: Authors Computation Using Data From CSA (2022)

4.1.1.2 Overview of Oilseed Production in Selected Major Crop Producer Areas

Figure 4.6 below shows the average number of holders in major crop producer zones, in Ethiopia for the periods between 2004 to 2022. As the data shows North Gonder, West Gojjam , and South Gondar have a large number of farmers in the production of cereals. Hence, in each area above 200 thousand farmers, while the other zones such as West Wollega, East Wollega, East Gojjam, North Shewa ,South Wollo, Jimma, West Shewa and Arsi have a medium number of farmers in oilseed prodction production (for more see figure 4.1). The remaining zones, North Wollo, West Arsi, Metekel, Gurage, Woilaita, Gamogofa and South West Shewa have the smallest number of farmers.

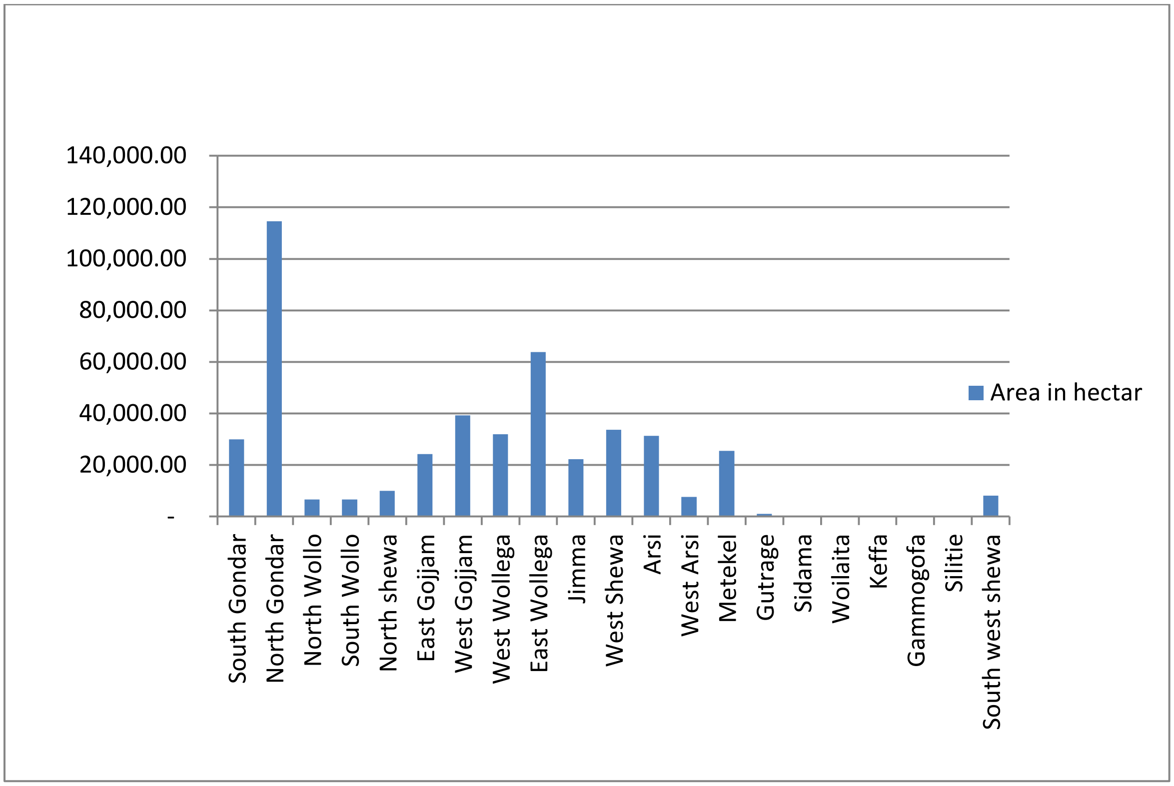
Figure 4.6: Average Number of Holders for Oilseed Production



Source: Authors Computation Using Data From CSA (2022)

In addition to this figure 4.7 clearly indicates the areal coverage's of oilseed production, in which, North Gonder has a large portion of area in hectare and secondly East Gojjam, West Gojjam, East Wollega, West Wollega, West Shewa and South Gonder have medium portion of hectare of land for the production of oilseed, while Gurage, Woilaita, Sidama, silte, , Metekel, keffa as well as gamogofa have a small hectare of lands belongs to the production of oilseed (see figure 4.7)

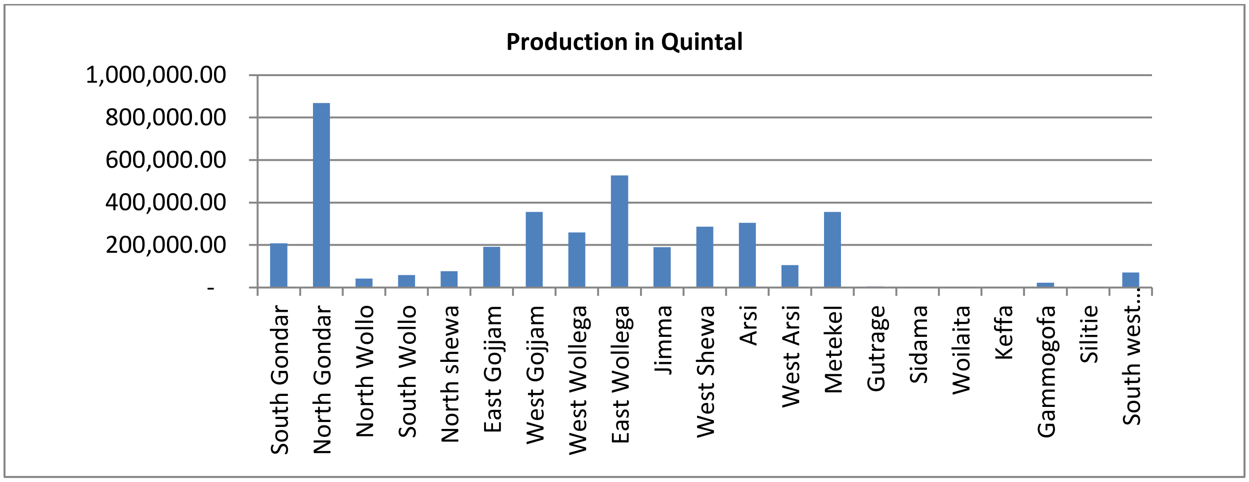
Figure 4. 7: Average Area in Hectares for the Production of Oilseed (2004-2022)



Source: Authors Computation Using Data From CSA (2022)

Figure 4.8 shows the production of oilseed in different oilseed producers' areas, as per the graph below, high cereal producer zones are North Gonder, East Wollga, West Wollega, Metekel, West Gojjam as well as East Gojjam, hence, such zones produce 200 thousand quintals of oilseed from the period 2004 to 2022 on average. Also, North Shewa, Jimma, West Arsi, and East produce cereals from up to 200 thousand quintals on average. While, Wolkita, Sidama, Gurage, mettekel, keffa, gamogofa, and silite zones are low oilseed producers (see Figure 4.8).

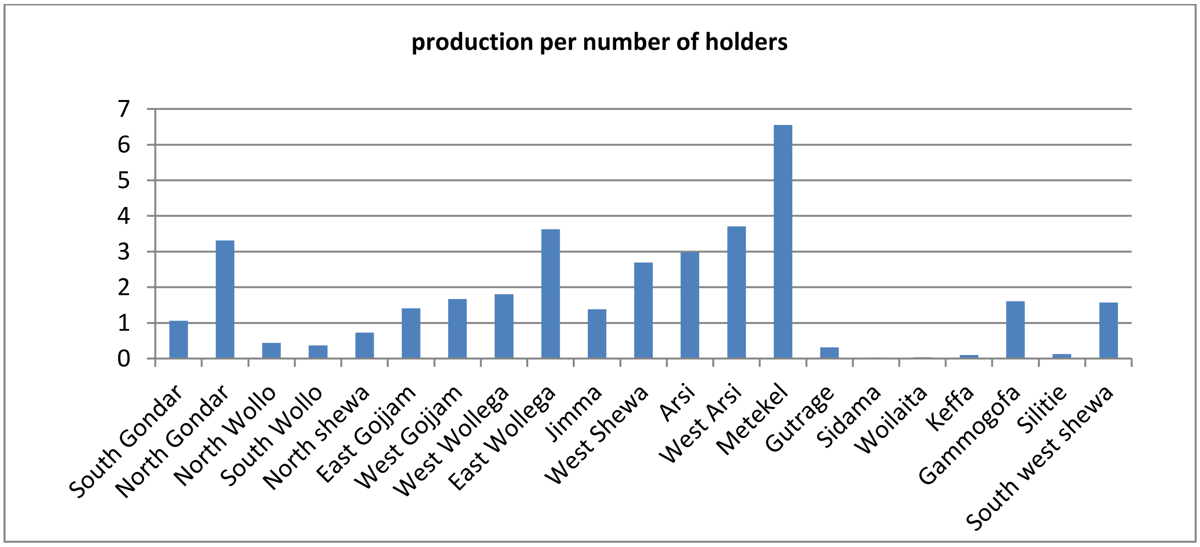
Figure 4.8: Average Production of Oilseed in Quintal from 2004-2022



Source: Authors Computation Using Data From CSA (2022)

The production of Oilseed per number of holders/farmers is discussed in Figure 4.9 below, in which east wollega, metekel, west Shewa, Arsi, Southwest Shewa, west gojjam, north Gonder, north show and east gojjam zones on average are high in the production of oilseed per number of farmers, in which area the production of oilseed per quintal is greater than 3 on average per holders or farmers. While, on average Sidama, wolkite, gamogofa, keffa, gurage, and silte zones are low production of cereals in quintals per number of holders or farmers (for more see figure 4.9).

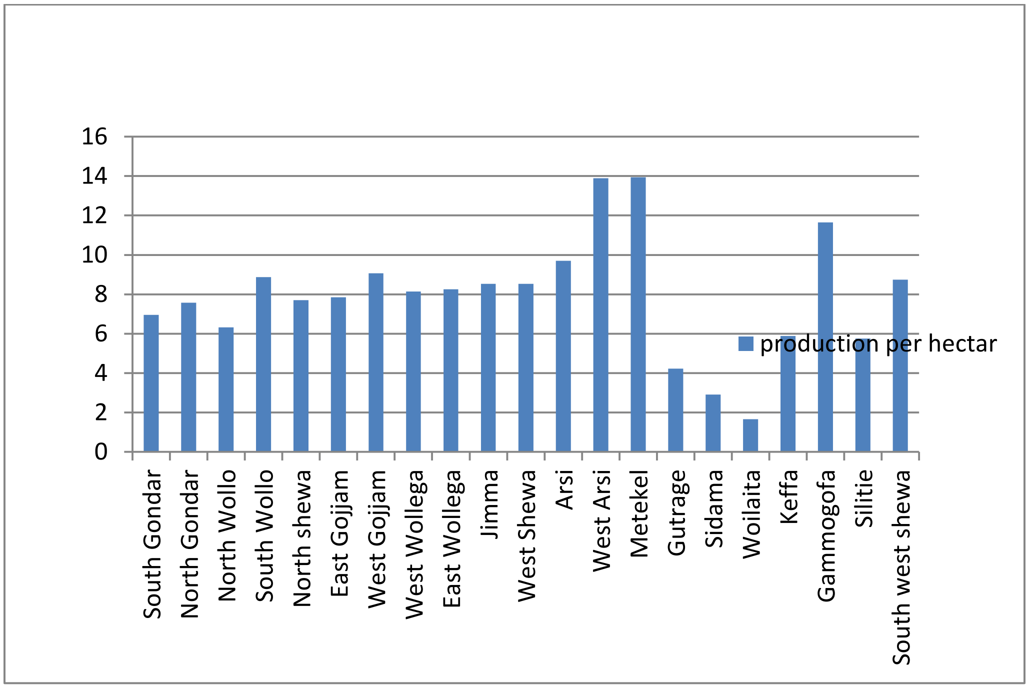
Figure 4.9: Average Production per Number of Holder for Oilseed from 2004-2022



Source: Authors Computation Using Data From CSA (2022)

The production of oilseed per hectare is discussed in Figure 4.10 below, in which West Arsi, Metekel and GamoGofa zones on average are high in the production of oilseed per hectare, in which area the production of oilseed per hectare is greater than 1 quintals on average per hectare (for more see figure 4.10). On the other hand, South Gonder, North Gonder, South Wollo, East Gojjam, West Gojjam, West Wollga and East Wollge on average have medium production of oilseed per hectare. The remaining Zones Gurage, Sidama, Woilaita and Silitie have the lowest average production per hectar (see figure 4.10).

Figure 4:10 Average Production per Hectares for Oilseed Production from 2004-2022

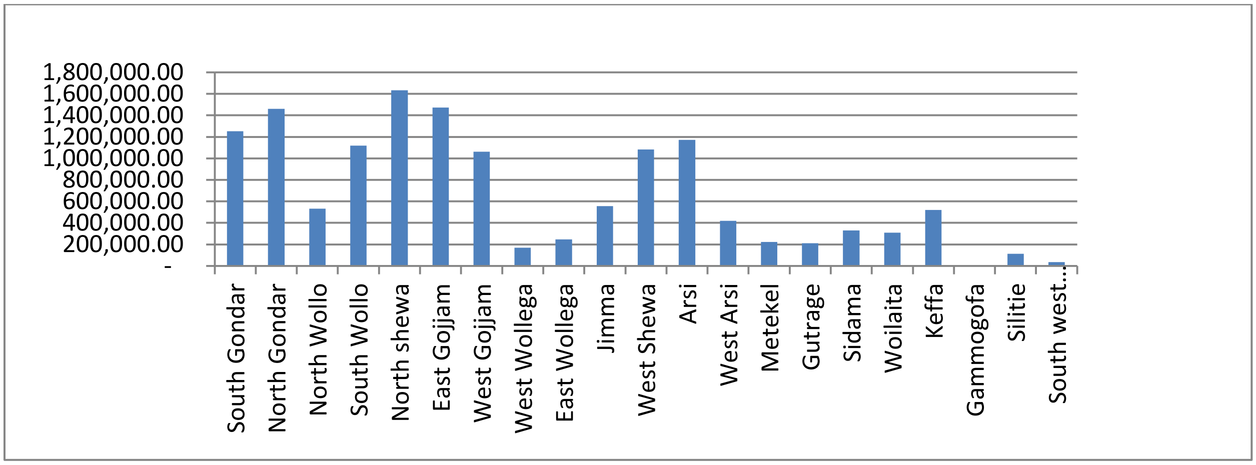


Source: Authors Computation Using Data From CSA (2022)

4.1.1.3 Overview of pulse Production in Selected Major Crop Producer Areas

Figure 4.11 shows the production of pulse in different pulse producers' areas, as per the graph below, high pulse producer zones are North Gonder, North Shewa, West Gojjam, East Gojjam, South Gonder hence, such zones produce one million quintals of pulse from the period 2004 to 2022 on average. Also, North Wollo, Jimma, West Arsi, and Keffa produce pulse from 400 thousand up to 600 thousand quintals on average. While, Wolkita, Sidama, Gurage, mettekel, gamogofa, and silite zones are low oilseed producers (see Figure 4.11).

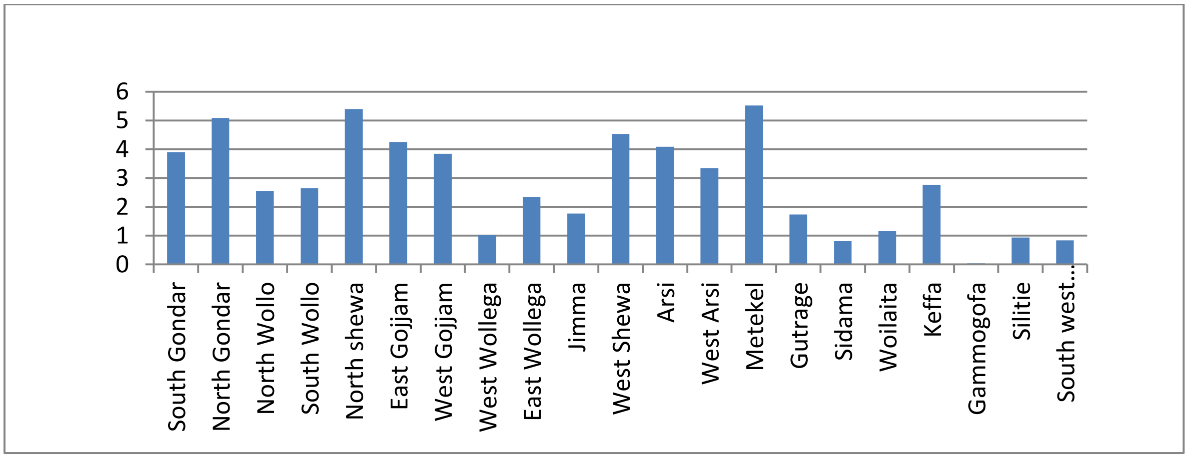
Figure 4.11: Average Production of pulse in Quintal from 2004-2022



Source: Authors Computation Using Data From CSA (2022)

The production of pulse per number of holders/farmers is discussed in Figure 4.9 below, in which east wollega, metekel, west Shewa, Arsi, Southwest Shewa, west gojjam, north Gonder, north show and east gojjam zones on average are high in the production of oilseed per number of farmers, in which area the production of oilseed per quintal is greater than 3 on average per holders or farmers. While, on average Sidama, wolkite, gamogofa, keffa, gurage, and silte zones are low production of cereals in quintals per number of holders or farmers (for more see figure 4.9).

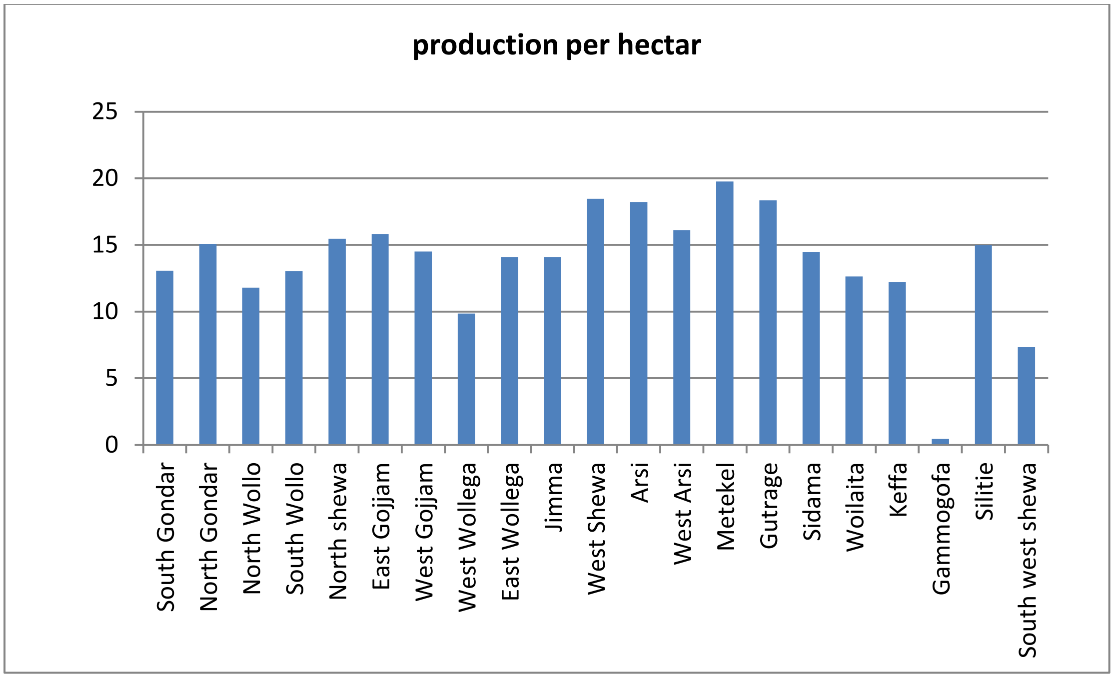
Figure 4.12: Average Production Per number of Holders of Pulse from 2004-2022



Source: Authors Computation Using Data From CSA (2022)

The production of pulse per number of holders/farmers is discussed in Figure 4.13 below, in which all most all zones have on average similar production per hectare (yield). While, on average gamogofa zones has low production of pulse in quintals per number of holders or farmers (for more see figure 4.13).

Figure 4:13: Average Production per hectares

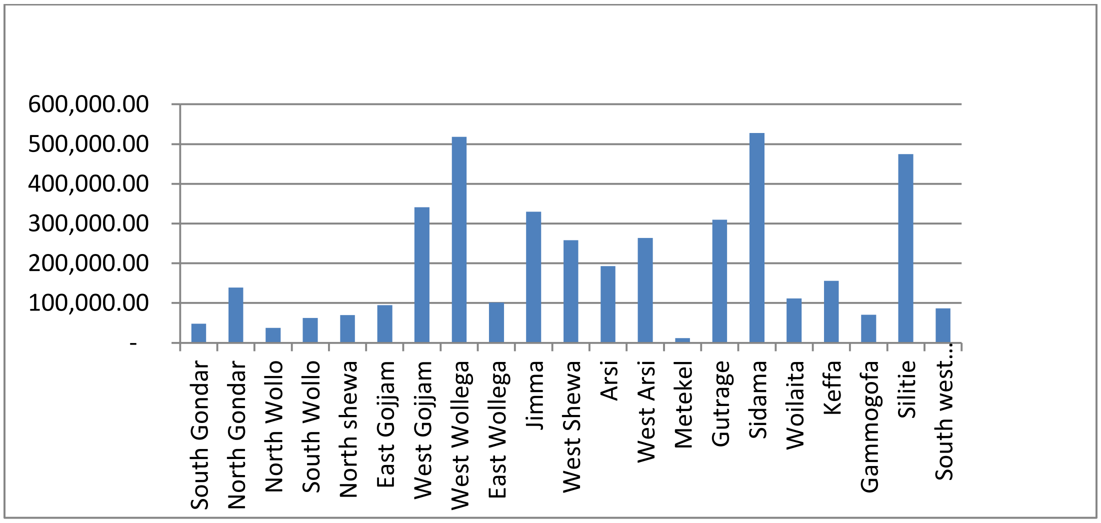


Source: Authors Computation Using Data From CSA (2022)

4.1.1.4 Overview of Vegetable Production in Selected Major Crop Producer Areas

Figure 4.14 and 4.15 below shows the average number of holders in major crop producer zones, in Ethiopia for the periods between 2004 to 2022. As the data shown in Figure 4.14 clearly indicates the areal coverages of vegetable production, in which, Sidama, west wellega, and Siltie are large vegetable producer areas/zones, while Metekel, north wollo, south Gonder, gamogofa, south wollo, wolita, north Shewa, as well as east Gojjam zones, belongs to low production of vegetables (see figure 4.2).

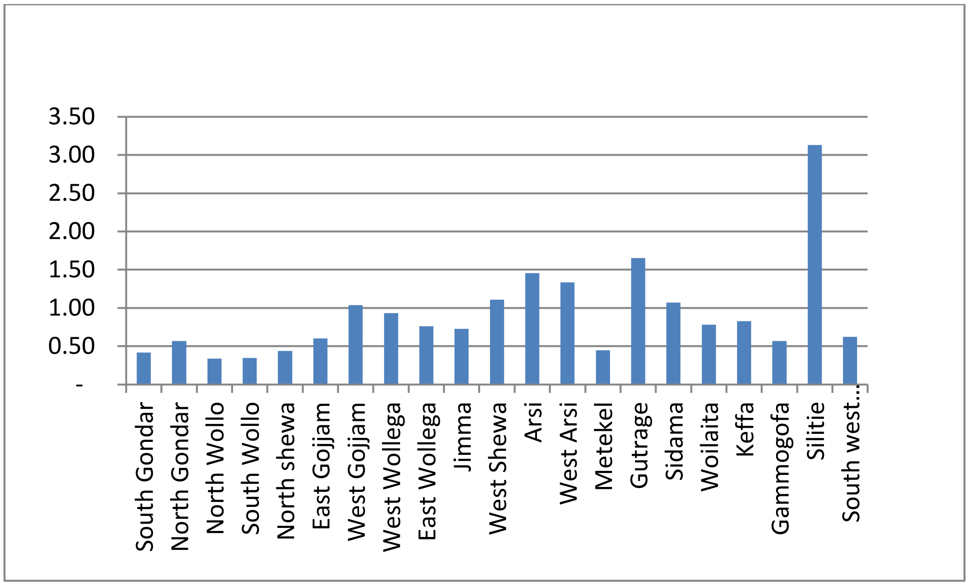
Figure 4.14: Average Production of Vegetable in Quintal from 2004-2022



Author's Computations Using CSA (2022)

Figure 4.15 below shows the average number of holders in major vegetable producer zones, in Ethiopia for the periods between 2004 to 2022. As the data shows Silte, Gurage, Arsi, west Arsi, and Sidama zones are relatively a large number of farmers in the production of Vegetables (for more see figure 4.15).

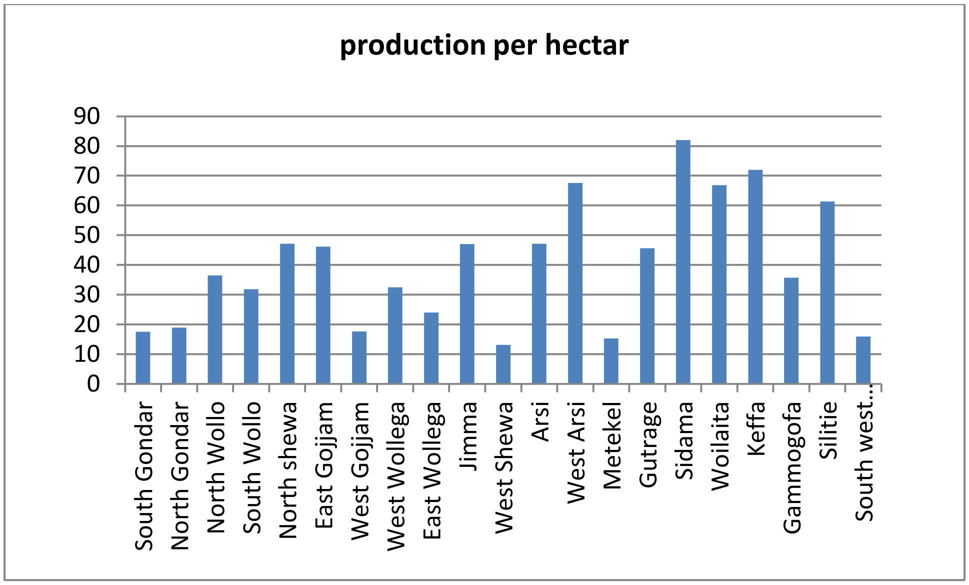
Figure4. 15: Average Production Per Number of Holders from 2004-2022



Author's Computations Using CSA (2022)

The production of vegetables per hectare is discussed in Figure 4.16 below, in which Sidama, keffa, west Arsi, wolita, siltie, Arsi, jimma, north Shewa, and east gojjam zones are relatively on average high in the production of vegetables per hectare, in which area the production of vegetable per hectare is greater than 40 quintals on average per hectare (for more see figure 4.16).

Figure 4.16: Average Vegetable Production Per hectare from 2004-2022



Author's Computations Using CSA (2022)

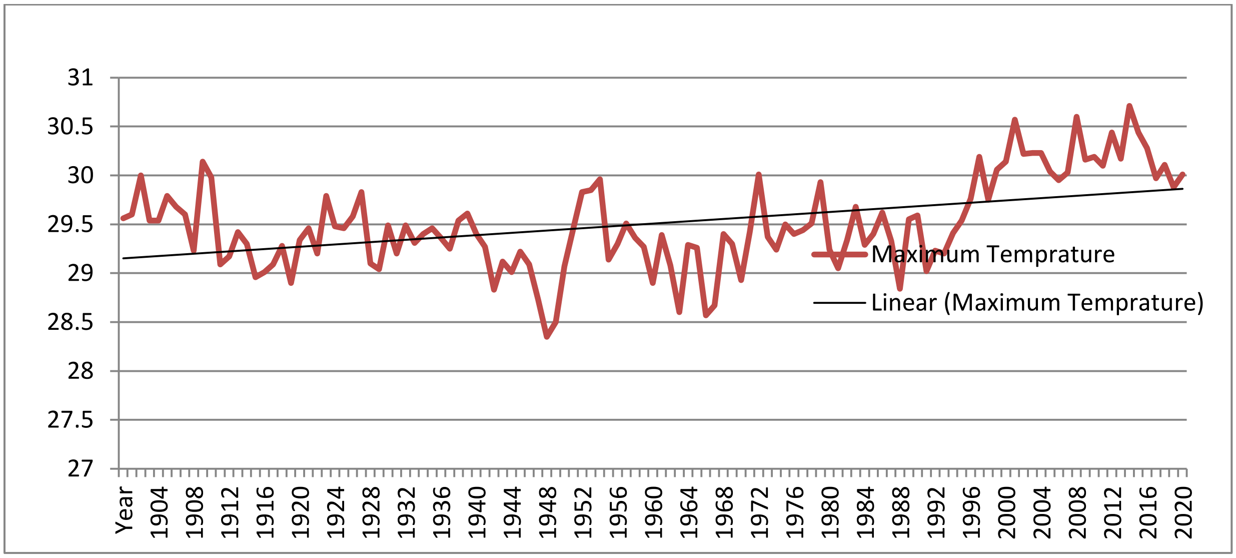
4.1.2 Overview of Climate Change In Ethiopia

Ethiopia is one of the most susceptible countries to climate change and unpredictability because it relies on natural resources and rain-fed agriculture, as well as its lack of adaptive capacity to deal with these anticipated changes. Inadequate road infrastructure in drought-prone areas, poor institutional frameworks, a lack of knowledge, low health care coverage, a high population growth rate, and low economic development are only a few of the problems. In addition to rainfall unpredictability and rising temperatures, Ethiopia has regularly suffered severe occurrences including droughts and floods, which have a negative impact on livelihoods. Soil erosion, deforestation, repeated droughts, desertification, land degradation, loss of biodiversity, and species extinction are the main environmental issues.

From the figure below the level of maximum temperature is increasing from year to year. From the beginning year 1900 to 1948, the level of growth rate maximum temperature in the country was decreasing even if there were shocks during the period. For instance, it was increasing from 1990 to 1902 and then reached a maximum in 1908. From 1908 onwards, the level has been tending to decline and it reached the maximum temperature until the year 1997. From 1908 the level of temperature up to 1948, the growth rate of maximum temperature declined this is because the country was not affected by global warming, and the world maximum temperature also during this period was minimal compared to pre-1908 and post-1948. The other reason is that during that time, deforestation, population growth, and other devastating factors that resulted in higher temperatures were minimal or had no effect.

Reaching the minimum in 1948, the level of maximum temperature tends to increase at an increasing rate until 1954 and then tends to decline at an increasing rate and reached the minimum in 1966. From the result, the shocked and unpredictable maximum temperature has a tremendous effect on agricultural activities in general and crop production in particular. Starting from 1966 up to 1972, the growth rate of maximum temperature on average was positive. i.e. it also tends to increase from time to time. Starting from 1972 to 1988, the growth rate of maximum temperature was negative. During this period the Derg government tried to decrease the maximum temperature through a policy of forest recovery and plantation policy in the country. And then from 1988 till 2014, the growth rate of maximum temperature tends to increase at a faster rate since global warming in the world and overgrazing, population density, Carbon emission, and deforestation were the factors that caused the growth rate of the maximum temperature tends to increase at an alarming rate. Generally, as we can see from the figure below, the linear maximum temperature line is increase from the origin to the final period (1900-2021). So we can understand that the maximum temperature on average during the period has been increasing from time to time and this adversely affects crop production and in turn results in drought which affected the poor and developing country which depends on their on life primarily on agricultural production.

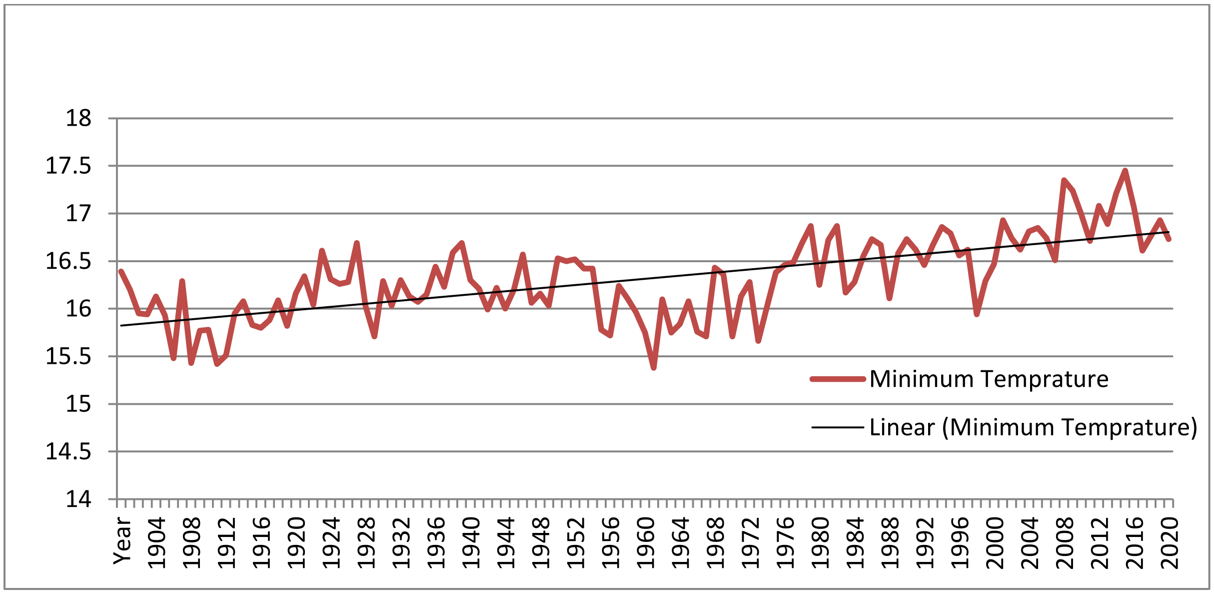
Figure 4.17: Trends of Maximum Temperature



Source: Author Computation Based on World Climate Catalogue (2023)

Regarding the trend of minimum temperature, the trend starting from 1900 to 1912, was decreasing at an increasing rate. Starting from 1912 to 1927, the growth of minimum temperature increases at an increasing rate. Even if the minimum temperature in the country during this time interval was increasing it has both positive and negative effects. The positive effect was moderate temperature is important for the growth of different types of crops whereas the negative effect was increasing the minimum level of temperature beyond the normal rate is an indication of the increasing rate of overall country temperatures during the period.

Figure4. 18: Trend of Minimum Temperature in Ethiopia from 1900 to 2021

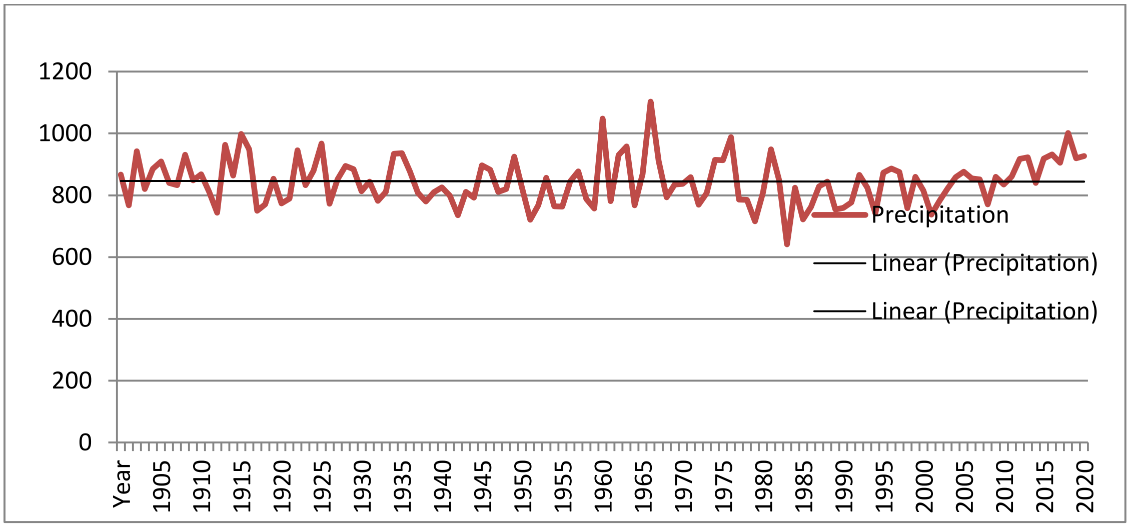


Source: Author Computation Based on World Climate Catalogue (2023)

When we come to the trends from the period 1927 to 1938, on average the trend of the minimum temperature declined at the beginning and then increases and reached the maximum in 1938. From the period 1938 to 1960, the growth rate of minimum temperature was negative. Starting from 1960 to 1973, on average the growth rate of minimum temperature was constant even if it had ups and downs during that time interval. Starting from 1973 onwards the level of minimum temperature tends to increase until 1979 and then from 1979 to 1994, the growth rate of minimum temperature was stagnant on average even if there were ups and downs during that period. From 1994 up to 2000, the growth rate of minimum temperature declined and then tends to increase from 2000 until 2015. Starting from 2015, the growth rate of minimum temperature tends to decline. In addition from the result below of the straight line, we can understand that the growth rate of minimum temperature on average was increasing with shocks in different periods.

Regarding the level of precipitation, it was increasing at from 1900 to 1910 and then tends to decline until 1912. From 1912 to 1915, the level of precipitations was increasing and then tends to decline until 1917. From 1917 onwards the level of precipitation was increasing until 1925. From 1925 to 1942 on average the growth rate of precipitation was negative which was the combined effect of increasing maximum temperature and increasing rate of minimum temperature which tends to decline the level of precipitation during the period.

Figure 4:19: Trend of Precipitation from the period 1900 to 2021



Source: Author Computation Based on World Climate Catalogue (2023)

When we come to the period from 1942 until 1949, the growth rate of precipitations was positive meaning that the level of rainfall during the period was increased and in reverse the level of temperature declined during that period. Onwards from 1949 till 1958, the level of precipitation declined which was caused by higher temperature, deforestation, and global warming during that period. From 1958, onwards the level of precipitation on average grew at a positive rate and then tends to grow at a negative rate from 1958 to 1983. During this period as a result of the shortage of rainfall in the country, there was drought and famine. From 1983 onwards, the growth rate of precipitation was positive however compared to the decades the volume of rainfall was decreasing even if the growth rate was positive. From the result on average, we can understand that the level of precipitations under the period 1900 to 2021, was declined.

4.2 Regression Diagnostics Test Results

4.2.1 Panel unit root test

Even though the unit root test is commonly thought of as a time series phenomenon, checking stationarity for panel data sets offers more power and advantages than the time series stationary test. In empirical analysis, non-stationary data is frequently seen as a challenge. Working with non-stationary variables might lead to erroneous regression findings that are useless for further inference. Because Hadri LM (2000) and Im–Pesaran–Shin (2003) unit root tests are valid when the number of periods (years in this study) is small and the number of persons (countries in this study) is big, these two tests were utilized in this study. The Hadri LM test allows for non-normality and is based on within estimate. Im-Pesaran-Shin (IPS) test is more general than LM and it is based on the combination of independent Dickey-Fuller tests besides IPS allowing heteroskedasticity, serial correlation, and non-normality.

Table 4.1: Panel unit root test

Variables	Harris-Tzavalis unit-root		Levin-Lin-Chu unit-root	
	t-statistics	P	t-statistics	P
ln(TP_quintal)cereals	0.0954	0.000	-6.1063	0.000
ln(TP_quintal)pulse	0.0096	0.000	-10.0229	0.000
ln(TP_quintal)oilseed	0.0314	0.000	-4.8550	0.000
ln(TP_quintal) vegetable	0.345	0.000	-3.2152	0.000
ln(NH_{jt}) cereals	-0.0986	0.000	-10.9645	0.000
ln(NH_{jt}) pulse	-0.0318	0.000	-11.6211	0.000
ln(NH_{jt}) oilseed	-0.0453	0.000	-10.2061	0.000
ln(NH_{jt}) vegetable	-0.567	0.000	-8.4533	0.000
ln(AH_{tj}) cereals	0.0018	0.000	-8.2186	0.000
ln(AH_{tj}) pulse	-0.0318	0.000	-10.7934	0.000
ln(AH_{tj}) oilseed	0.0069	0.000	-7.7344	0.000
ln(AH_{tj}) vegetable	0.0078	0.000	-12.1279	0.000
ln($Fertlizer_{tj}$) cereals	0.2116	0.000	-7.4566	0.000
ln($Fertlizer_{tj}$) pulse	0.1155	0.000	-5.7843	0.000
ln($Fertlizer_{tj}$) oilseed	0.2605	0.000	-8.0540	0.000
ln($Fertlizer_{tj}$) vegetable	0.123	0.000	-4.4561	0.000
ln($percpitation_{tj}$)	-0.0368	0.030	-12.4275	0.000
ln($TMPmin_{tj}$)	-0.0627	0.115	-6.9675	0.000
ln($TMPmax_{tj}$)	-0.0927	0.141	-4.7513	0.000
ln(RELHUM)	-0.1733	0.053	-8.3890	0.000

Source: Authors computation using stata 13 from the CSA(2023), NMA (2023

According to the above table result, we reject the null hypothesis and conclude that all variables are stationary.

4.3 Estimation Results

Equations from chapter three in the model specification procedure are estimated by the technique of the generalized method of moments. For the sake of comparison, we fit the models using one-step system GMM and two-step system GMM estimators with robust standard errors.

4.3.1 Estimation Result for Cereals Production

Looking at the findings shown in Table 4.2 below, we applied both a 1-step system GMM and a 2-step system GMM to execute the dynamic panel data model estimate with preset variables. Dynamic Panel data provides the benefit of being able to control measurement errors, unobserved panel heterogeneity, omitted variable bias, and endogeneity of the lagged dependent variable (Biresselioglu et al., 2016; Gulcemal, 2021). The researcher choose the system GMM after comparing the data because, in addition to the difference GMM, it has a smaller bias and greater efficiency than all the other estimators (Soto, 2007; Jung & Kwon, 2007; Bun & Windmeijer, 2010; Jung et al., 2015; Biresselioglu et al., 2016; Gulcemal, 2021).

From the result below, the Hansen J test shows a case of no over-identifying restrictions as shown in the table below since the value is greater than 0.05 and less than 0.9 (Roodman, 2007). This suggests that the entire model seems to be valid in the present context. The AR (1) term is found to be significant with a p-value of 0.010 for one-step system GMM and 0.013 for two-step system GMM. Whereas AR (2) term is found to be insignificant with a p-value of 0.611 for the one-step system GMM result and 0.328 for the two-step system GMM result. This implies the presence of a negative first-order autocorrelation though does imply consistency in the results. From the diagnostic result, failure to reject the null hypothesis of no second-order serial correlation implies that the original error term is not serially correlated and the moment conditions are correctly specified (that is the p values of AR(2) are greater than 0.05).

The below table shows that lagged total production of cereals, number of private peasant holders, the area in hectares, fertilizer, precipitation, Maximum average temperature, relative humidity, and regional dummy variables are the most significant factors that affect the production of cereals in major cereal producer zone in Ethiopia in the case of private peasant holders. The coefficient of lagged cereals production is positive and statistically significant at a 1 percent level, indicating an autoregressive level of cereals production. Since the lagged value has a considerable significant effect, we understand that the dynamic specification of the model overwhelms the static panel data. Based on the two-step results, for instance, a one percent increase in cereal production of the previous year boosts current production by about 0.106 percent, ceteris paribus. This is because last year's production was used as seed for the current year. As a result of this increasing the level of previous cereals production have a considerable effect on current year production by increasing the accumulated seed for current year farm for each zone.

Likewise, the number of private peasant holders has a positive and significant effect on cereal production. The concept behind this demonstrated a higher number of private peasants. According to the report by UN FAO (2021), smallholder farmer produces 80 percent of the world's food, and increasing the level of private smallholder farmer will result in increasing the production level of cereals in each zone. In absolute terms, when the number of private peasant holders increases by one percent, other things remain unchanged; the total production of cereals of zones grows by some 0.142 percent. The other control variable that determines the total production of cereals is the Area covered by cereals in hectares. Treated as a proxy for total production of cereals, the area in hectares has a positive and significant effect on the total production of cereals. For every one percent increase in the Area covered by cereals in a hectare, production of cereals tends to boost by 0.432 percent, ceteris paribus. The fertilizer variable has also positive and significant determinants of cereals production. Other things remain constant; increasing the level of fertilizer used by 1 percent resulted in increasing the level of cereals production by 0.202 percent.

The precipitation variable carries a negative sign with a statistically significant effect on total cereals production. For every one percent increase in the precipitation, production of cereals tends to decline by 0.055 percent, ceteris paribus. Intuitively it would mean that high rainfall could reduce production through for instance damage from oxygen deficit as a consequence of soil waterlogging after heavy rain; bending of the stem; loss of soil nutrients; and plant anchorage failure since the topography of the major producer of cereals is found in highland topography of Ethiopia which are adversely affected by heavy erosion and heavy summer rainfall. For instance, Beillouin et al. (2018) demonstrated that excessive rainfall can adversely affect maize yields in the USA in proportions similar to extreme drought. These impacts may become more frequent in the future given the expected increase in the frequency of extreme precipitation events.

Regarding the temperature variable, the minimum average temperature has a negative and insignificant effect on cereals production. The maximum average temperature has a negative and significant effect on cereals production. For every one percent increase in the maximum temperature, production of cereals tends to decline by 0.532 percent, ceteris paribus. Variations in climate models can partly explain the co-occurrence of climate variables unfavorable to the production of cereals. For instance, comparing recent major droughts in Ethiopia, similar preceding high air temperature and soil water anomalies were observed preceding 2006, 2010, and 2021 droughts in Ethiopia. Yet, the area under droughts and factors aggravating the effect of the drought is distinct: severe soil drying caused by preceding rainfall deficits and high evaporative demand before summer in 2022, and high evapotranspiration linked to extremely warm and sunny conditions in spring in 2020 reduced the level of the growth rate of cereals production in the major producer zones in the country.

Relative Humidity has a positive and significant effect on crop production in a one-step system GMM result. This is because relative humidity (RH) directly influences the water relations of plants and indirectly affects leaf growth, photosynthesis, pollination, the occurrence of diseases, and finally economic yield. Relative humidity has an indirect effect on photosynthesis. When relative humidity is low, transpiration occurs and the plant experiences water deficiencies. Water deficits cause partial or full closure of stomata and increase mesophyll resistance blocking the entry of carbon dioxide. Even if relative humidity has a positive relationship with crop production very high relative humidity and very low relative humidity (extreme) hurt cereals production. On plant leaves, high RH encourages the rapid germination of fungus spores. Crops produced using irrigation produce less than those planted with the same quantity of water from rainfall when exposed to the same amount of solar radiation. This is because irrigation has minimal effect on the dry environment, which independently inhibits crop development.

Regarding region dummy variables, where Dregion1 is zones found in the Amhara region, Dregion2 is zones located in the Binishangul Gumuz region, Dregion3 is zones in the Oromia region, Dregion4 is zones placed in SNNP and Dregion5 is Sidama region which is a base category since it produces least cereal production through the study. From the result in the table below, we can argue that there is a huge crop production gap among regions. From the result Zones found in Binishangul Gumuz followed by Oromia and Amhara regions have the greatest potential to produce cereals.

Table 4.2: Regression result of the cereals production equation

Dependent variable: Natural logarithm of the total cereal production in quintal

Regressors	One-step system GMM result			Two-step system GMM		
	Coeff.	Standard error	P- value	coeff	Standard error.	p-value
ln(l.TP_quintal)	0.0726***	0.025	0.004	0.070***	0.106	0.000
ln(NH$_{jt}$)	0.194***	0.057	0.001	0.142**	0.071	0.047
ln(AH$_{tj}$)	0.344**	0.411	0.000	0.432***	0.102	0.000
ln(Fertlizer$_{tj}$)	0.215***	0.019	0.000	0.202***	0.014	0.000
ln(percpitation$_{tj}$)	-0.059**	0.029	0.045	-0.055***	0.020	0.006
ln(TMPmin$_{tj}$)	-0.010	0.447	0.822	-0.044	0.071	0.538
ln(TMPmax$_{tj}$)	-0.544***	0.142	0.000	-0.532**	0.171	0.037
ln(RELHUM)	0.144***	0.041	0.001	0.102*	0.054	0.063
Dregion1	0.710***	0.121	0.000	0.566***	0.168	0.001
Dregio3	0.740***	0.121	0.000	0.611***	0.148	0.000
Dregion2	0.822***	0.174	0.000	0.765***	0.135	0.000
Dregion4	0.504***	0.110	0.000	0.442***	0.072	0.000
Constant	4.117**	0.844	0.000	3.897***	0.617**	0.000
Hansen Test of Overid. Restrictions	chi2(14) =16.44 Pr > chi2 = 0.287			chi2(14) =16.44 Pr > chi2 = 0.287		
Arellano-Bond Test for Autocorrelation	AR (1): z = -2.59 Pr > z = 0.010			AR (1): z = -2.47 Pr > z = 0.013		
	AR (2): z = 0.51 Pr > z = 0.611			AR (2): z = 0.98 Pr > z = 0.328		
No of observation	21 zone*19 years =399 Observations					

Note *, **, and *** represents significance at the 10%, 5%, and 1% level respectively
Source: Authors computation using stata 13.1 from the CSA(2023), NMA (2023)

4.3.2 Estimation Result for Pulse Production

Finding the right instruments for period t in the equations is the first step to be taken into account in this method. In general, the assumption that the instruments are exogenous is critical to the validity of GMM. The Hansen J test results in a scenario where there are no over-identifying limitations, as indicated in the table below. Since the value is greater than 0.05. The study suggests that the entire model seems to be valid in the present context. The AR (1) term is found to be significant with a p-value of 0.004 for the one-step system GMM and 0.033 for the two-step system. Whereas AR (2) term is found to be insignificant with a p-value of 0.647 for the one-step system GMM model and 0.601 for the two-step system GMM. This implies the presence of a negative first-order autocorrelation though does imply consistency in the results.

Area covered by pulse, fertilizer, precipitation, minimum average temperature, maximum average temperature, relative humidity, and regional dummy were significant factors affecting the production of pulses in selected major pulse producer zones. The remaining variable's lag of pulse production was an insignificant factor.

The number of private peasant holders of the pulse has a significant and adverse effect on pulse production. For every one percent increase in the private peasant holders, production of pulse tends to decline by 0.069 percent, ceteris paribus. It would mean that increasing the smallholders have a higher tendency of reducing the annual pulse production. Increasing the level of smallholders causes the shortage of land and this in return reduces the mass production of the pulse. If a household has two-hectare arable land of pulse and in the coming year he gives half one-hectare arable land to his incoming son with the new family, it automatically reduces pulse production through the substitution effect of pulse arable land by other crops. In addition increasing number of holders automatically exacerbates soil erosion; severe degradation and this in turn decrease the level of pulse production in Ethiopia. Our findings related to the number of peasant holders and pulse production variables are also in line with previous empirical studies. Among those studies of particular interest include Hordofa et al. (2008), Neelakantam & Naidu (2016), Amenu & Mamo (2021), and Nagy et al. (2020).

Area in hectare has a positive and significant effect on pulse production. For every one percent increase in the arable land for the pulse in a hectare, production of pulse tends to increase by

1.117 percent, ceteris paribus. Our finding is in line with Merga & Haji (2019), Naik & Nethrayini (2019), and Siddiq et al. (2019). The fertilizer variable has also positive and significant determinants of pulse production. Other things remain constant; increasing the level of fertilizer used by 1 percent resulted in increasing the level of pulse production by 0.801 percent. Previous researchers Galpottage (2020), Yadav et al. (2019), and Kenngott (2021) also found that increasing the level of fertilizer improved pulse production.

Regarding the climate change variables, precipitation has a significant and negative effect on pulse production. Based on the two-step system GMM result, a one percent increase in precipitation decrease pulse production by about 0.042 percent ceteris paribus. This is since erratic and unpredictable rainfall during the sowing stage and early vegetative growth stage and the flowering stage of pulses resulted in damage to pulse production. The other supporting reason is erratic rainfall resulted in flooding and soil erosion which in turn reduce the fertility of the soil. Our findings related to precipitation variables are also in line with previous empirical studies. Among those studies of particular interest include Potts et al. (2006), Robertson et al. (2009), Thomey et al. (2011), and Mar et al. (2018).

Mean minimum Temperature has a significant and positive effect on pulse production. Based on the two-step system GMM result, a one percent increase in mean minimum temperature resulted in increasing pulse production by about 0.310 percent ceteris paribus. Increasing the moderate temperature can increase the rate of reproductive development, which shortens the time for photosynthesis to contribute to fruit or seed production. Previous researchers such as Hancke et al. (2008), Basu et al. (2016), Dubey et al.(2011), and Pandiselvam et al.(2022).

The other determining variable that affects pulse production is maximum temperature, other things remain constant, a one percent increase in the level of maximum temperature resulted in decreasing the level of pulse production by 0.507 percent. This is since the maximum and elevated temperature on pulse production is determined to have a highly significant effect due to the global warming pressure. Due to high temperatures at every stage of pulse producer zones, pulse production is increasing at decreasing rate even if the number of holders are increasing from time to time. High temperature considerably influences the oilseed by affecting several physiological injuries like leaf abscission, leaf scorching, senescence, and root and shoot growth limitation that subsequently leads to a reduction in yield. Moreover, the impact of high temperature affects photosynthetic membranes followed by ion leakage, enlargement of grana stacks, and aberrant stacking. By down-regulating particular genes in carbohydrate metabolism, high temperature alters the activities of carbon metabolic enzymes, starch accumulation, and sucrose production.

Relative humidity has a significant and positive effect on pulse production. Other things remain constant; increasing the level of relative humidity by 1 percent resulted in 0.142 percent, ceteris paribus. This is since relative humidity of 40-60% is suitable for most of the crop plants. Very few crops like pulse can perform well when relative humidity is 80% and above. As a result, increasing the level of relative humidity automatically improved the total production of pulse in the country. Our findings related to relative humidity variables are also in line with previous empirical studies. Among those studies of particular interest include Peyrous (1990), Xu et al. (2019), Boudhan et al. (2019), and Vatansever et al. (2020).

Regarding region dummy variables, where Dregion1 is zones found in the Amhara region, Dregion2 is zones located in the Binishangul Gumuz region, Dregion3 is zones in the Oromia region, Dregion4 is zones placed in SNNP and Dregion5 is Zidama region which is a base category since it produces least cereal production through the study. From the result in the table below, we can argue that there is a huge crop production gap among regions. From the result Zones found in the Amhara region followed by Oromia and Binishangul Gumuz regions have the greatest potential to produce a pulse.

Table 4.3: Regression result of the pulse production equation

Dependent variable: Natural logarithm of the total pulse production in quintal						
Regressors	One-step system GMM result			Two-step system GMM		
	Coeff.	Standard error	P- value	coeff	Standard error.	p-value
ln(l.TP_quintal)	-0.007	0.015	0.632	-0.027	0.017	0.119
ln(NH_{jt})	-0.044**	0.011	0.023	-0.069**	0.029	0.018
ln(AH_{tj})	1.117***	0.052	0.000	1.091***	0.028	0.000
ln($Fertlizer_{tj}$)	0.912***	0.020	0.000	0.801***	0.006	0.000
ln($percpitation_{tj}$)	-0.050**	0.030	0.031	-0.042**	0.018	0.023
ln($TMPmin_{tj}$)	0.274**	0.115	0.017	0.310***	0.120	0.010
ln($TMPmax_{tj}$)	-0.535***	0.141	0.001	-0.507***	0.181	0.005
ln(RELHUM)	0.142***	0.053	0.008	0.132***	0.042	0.002
Dregion1	0.657***	0.160	0.000	0.671***	0.116	0.000
Dregio3	0.509***	0.179	0.005	0.524***	0.107	0.000
Dregion2	0.384**	0.153	0.012	0.496**	0.229	0.031
Dregion4	0.383***	0.077	0.000	0.483***	0.132	0.000
Constant	2.631***	0.398	0.001	3.541***	1.056**	0.001
Hansen Test of Overid. Restrictions	chi2(14) = 12.66 Prob > chi2 = 0.554			chi2(29) = 14.30 Prob > chi2 = 0.990		
Arellano-Bond Test for Autocorrelation	AR (1): z = -2.92 Pr > z = 0.004 AR (2): 0.46 Pr > z = 0.647			AR (1): z = -2.13 Pr > z = 0.033 AR (2): z = 0.52 Pr > z = 0.601		
No of observation	21 zone*19 years =399 Observations					

Note *, **, and *** represents significance at the 10%, 5%, and 1% level respectively
Source: Authors computation using stata 15.1 from the CSA(2023), NMA (2023)

4.3.3 Estimation Result for Oilseed Production

Since the value is greater than 0.05. The researcher suggests that the entire model seems to be valid in the present context. The AR (1) term is found to be significant with a p-value of 0.002

for the one-step system GMM model and 0.001 for the model two-step system. Whereas AR (2) term is found to be insignificant with a p-value of 0.320 for one-step system GMM and two-step system GMM 0.378. This implies the presence of a negative first-order autocorrelation though does not imply inconsistency in the results.

From the table below, the number of private peasant holders, the area in hectares, precipitation, average annual maximum temperature, relative humidity, and regional dummy were significant variables that determine the oilseed production. The remaining variables lag of oilseed production; fertilizer and average minimum temperature are insignificant variables.

The number of holders has a significant and positive effect on oilseed production. For every one percent increase in the number of holders of oilseed, production of oilseed tends to increase by 0.550 percent, ceteris paribus. This is because to get more income, private peasant tends to shift from consumption-based crops to commercial-based crop which in turn increases the production of oilseed. Our findings related to the number of holders variables are also in line with previous empirical studies. Among those studies of particular interest include Ukolova & Dashieva (2022), Bastron et al. (2021), and Piras et al. (2021). Area in hectare has a positive and significant effect on oilseed production. For every one percent increase in the arable land for oilseed in a hectare, production of oilseed tends to increase by 0.573 percent, ceteris paribus. Our finding is in line with Lundin (2021), Némethová & Vilinová (2022), and Yilmaz & Avkiran (2020). Fertilizer has not significant effect on oilseed production however it has a positive relationship.

Regarding the climate change variables, precipitation has a negative and significant effect on oilseed production. For every one percent increase in precipitation, production of oilseed tends to decrease by 0.435 percent from the two-step system GMM as described in the table below, ceteris paribus. At a certain level, the amount of precipitation during the rainy season might yield a negative impact on oilseed development. This is since heavy erratic and variable rainfall in Kiremit and Meher season rainfall led to crop damage in certain zones in Ethiopia.

The other determining variable that affects oilseed production is maximum temperature, other things remain constant, a one percent increase in the level of maximum temperature resulted in decreasing the level of oilseed production by 0.875 percent. This is due to the fact that the maximum and elevated temperature on oilseed production is determined to have a highly significant effect due to the global warming pressure. Due to high temperatures at every stage of oilseed producer zones, oilseed production is increasing at decreasing rate even if the number of holders is increasing from time to time. High temperatures have a significant impact on crops by causing physiological damage such leaf abscission, leaf burning, senescence, and restricted root and shoot development, which ultimately reduces output. High temperatures also have an influence on photosynthetic membranes, grana stack growth, ion leakage, and aberrant stacking. High temperatures change the activities of carbon metabolic enzymes, starch accumulation, and sucrose synthesis through down-regulating certain genes involved in carbohydrate metabolism.

Relative humidity has a significant and positive effect on oilseed production. Other things remain constant, for every one percent increase in the level of relative humidity, it boosts the level of oilseed production by 0.587 percent. This is due to the fact that when abundant humidity is available and other factors of the environment are favorable there will be rapid cell division and enlargement and it favors the vegetative phase of growth of oilseed.

Regarding region dummy variables, where Dregion1 is zones found in the Amhara region, Dregion2 is zones located in the Binishangul Gumuz region, Dregion3 is zones in the Oromia region, Dregion4 is zones placed in SNNP and Dregion5 is Zidama region which is a base category since it produces least oilseed production through the study. From the result in the table below, we can argue that there is a huge crop production gap among regions. From the result Zones found in the Binishangul Gumuz region followed by Amhara and Oromia regions have the greatest potential to produce oilseed.

Table 4. 4: Regression Result of Oilseed Production Equation

Dependent variable: Natural logarithm of the total oilseed production in quintal						
Regressors	One-step system GMM result			Two-step system GMM		
	Coeff.	Standard error	P- value	coeff	Standard error.	p-value
ln(l.TP_quintal)	0.004	0.027	0.878	0.003	0.012	0.788
ln(NH_{jt})	0.550***	0.189	0.004	0.465***	0.148	0.002
ln(AH_{tj})	0.629***	0.087	0.000	0.573***	0.090	0.000
ln($Fertlizer_{tj}$)	0.061	0.020	0.137	0.073	0.048	0.133
ln($percpitation_{tj}$)	-0.470***	0.071	0.000	-0.435***	0.108	0.000
ln($TMPmin_{tj}$)	-0.002	0.235	0.990	-0.317*	0.183	0.082
ln($TMPmax_{tj}$)	-0.967***	0.264	0.000	-0.875***	0.342	0.004
ln(RELHUM)	0.601***	0.183	0.001	0.587***	0.142	0.000
Dregion1	0.454***	0.065	0.001	0.422***	0.052	0.006
Dregio3	0.450**	0.216	0.038	0.418**	0.175	0.017
Dregion2	1.571***	0.294	0.000	1.208***	0.257	0.000
Dregion4	-1.380***	0.213	0.000	-1.207***	0.155	0.000
Constant	-7.370***	1.722	0.000	-4.261***	1.574**	0.007
Hansen Test of Overid. Restrictions	chi2(14)=15.89 Prob >chi2 =0.320			chi2(29) = 15.82 Prob > chi2 = 0.378		
Arellano-Bond Test for Autocorrelation	AR (1): z = -3.06 Pr > z = 0.002			AR (1): z = -3.25 Pr > z = 0.001		
	AR (2): z = -0.14 Pr > z = 0.892			AR (2): z = 0.32 Pr > z = 0.749		
No of observation	21 zone*19 years =399 Observations					

Note *, **, and *** represents significance at the 10%, 5%, and 1% level respectively
Source: Authors computation using stata 15.1 from the CSA (2023), NMA (2023)

4.3.4 Estimation Result for Vegetable Production

From the result below, the Hansen J test shows a case of no over-identifying restrictions as shown in the table below. The researcher suggests that the entire model seems to be valid in the present context. The AR (1) term is found to be significant with a p-value of 0.001 for one-step system GMM and 0.002 for two-step system GMM. Whereas AR (2) term is found to be insignificant with a p-value of 216 for the one-step system GMM and 0.840 for the model two-step system. This implies the presence of a negative first-order autocorrelation though does not imply inconsistency in the results.

From the result in the below table, the number of holders, area in hectares, fertilizer in quintals, precipitation, maximum temperature, relative humidity, and regional dummy except SNNP region were significant variables that affect the production of vegetables. Whereas the remaining variables like a lag of vegetable production, average minimum temperature, and relative humidity have insignificant effects on the production of vegetables.

Regarding the non-climate variables that affect the production of vegetables, the number of private peasant holders of vegetables has a positive and significant effect on vegetable production. Other things remain constant, every one percent increase in the number of private peasant holders of vegetables will boost the total vegetable production in the zones. The area in hectare covered by vegetables also has a positive and significant effect on vegetable production. Increasing the level of arable land for vegetable production by one percent will boost the total vegetable production by 0.553 percent, ceteris paribus. Fertilizer has also a positive and significant effect on vegetable production. For every one percent increase in the level of fertilizer, vegetable production will be increased by 0.113 percent, given other things remain constant.

Table 4.5: Regression Result of Vegetable Production Equation

Dependent variable: Natural logarithm of the total Vegetable production in quintal

Regressors	One-step system GMM result			Two-step system GMM		
	Coeff.	Standard error	P- value	coeff	Standard error.	p-value
ln(l.TP_quintal)	0.014	0.037	0.707	0.071***	0.095	0.457
ln(NH_{jt})	0.592***	0.120	0.000	0.635**	0.187	0.001
ln(AH_{tj})	0.563***	0.061	0.000	0.553***	0.104	0.000
ln($Fertlizer_{tj}$)	0.119***	0.040	0.003	0.113**	0.049	0.028
ln($percpitation_{tj}$)	0.075**	0.021	0.038	0.046**	0.108	0.0470
ln($TMPmin_{tj}$)	-0.517	0.490	0.457	-0.280	0.510	0.583
ln($TMPmax_{tj}$)	-0.730***	0.240	0.002	-0.591***	0.236	0.009
ln(RELHUM)	-0.520***	0.085	0.001	-0.471***	0.109	0.000
Dregion1	-0.724***	0.070	0.000	-0.647***	0.170	0.000
Dregio3	-0.472***	0.067	0.000	-0.410***	0.114	0.000
Dregion2	-0.573**	0.224	0.011	-0.565**	0.284	0.047
Dregion4	-0.059	0.113	0.602	0.185	0.375	0.621
Constant	2.250	1.454	0.122	0.945	2.612	0.717
Hansen Test of Overid. Restrictions	chi2(10) = 14.64 Prob > chi2 = 0.146			chi2(10) = 14.64 Prob > chi2 = 0.146		
Arellano-Bond Test for Autocorrelation	AR (1): z = -3.27 Pr > z = 0.001			AR (1): z = -3.16 Pr > z = 0.002		
	AR (2): z = -1.24 Pr > z = 0.216			AR (2): z = -0.20 Pr > z = 0.840		
No of observation	21 zone*19 years =399 Observations					

Note *, **, and *** represents significance at the 10%, 5%, and 1% level respectively
Source: Authors computation using stata 15.1 from the CSA(2023), NMA (2023)

Regarding climate change variables, precipitation has a positive and significant effect on vegetable production. Rainfall is important for the growth and development of vegetables as it provides the necessary water for plant growth and reproduction through their production stage. Increasing the level of precipitation will increase the growth of vegetables and reproduce them within a short period. Our findings related to precipitation variables are also in line with previous empirical studies. Among those studies of particular interest include Veron et al. (2015), Kyei-Mensah et al. (2019), and Yang et al. (2020).

Having discussed the effect of precipitation, we now proceed to deal with the effect of maximum temperature alone. Maximum temperature has a negative and significant effect on vegetable production. Other things remain constant, for every one percent increase in the level of average maximum temperature, it decreases the level of vegetable production by 0.591 percent. This is because high temperatures can accelerate chlorophyll breakdown, resulting in early yellowing, and hasten the softness, wilting, and dehydration of vegetables (Salunkhe et al., 1974; Liu et al., 2021). During the curing process, some veggies might gain from being exposed to high heat (Calín-Sánchez et al., 2020; Li et al., 2021).

Relative humidity has a significant and negative effect on vegetable production. For every one percent increase in the level of relative humidity, it decreases the level of vegetable production by 0.471 percent, ceteris paribus. This is since Plants' ability to open the stomata on the undersides of their leaves is influenced by relative humidity levels. Stomata allow plants to transpire, or "breathe." A plant may shut its stomata to stop water loss when the temperature is high. Additionally, the stomata serve as a cooling system. The plant progressively suffocates on water vapor and its own transpired gases when the surrounding temperature is too high for it and it shuts its stomata for an extended period to preserve water. Compared to other crops, the level of relative humidity for vegetable production has a negative effect due to the problems like foliar and root infections, sluggish drying of the growth medium, plant stress, and loss of quality are frequently happened in vegetable crops. As a result, more pesticides are required to combat disease, and vegetables often grow slowly and laxly, making them less appealing.

Relative humidity has a significant and negative effect on vegetable production. For every one percent increase in the level of relative humidity, it decreases the level of vegetable production by 0.471 percent, ceteris paribus. This is since Plants' ability to open the stomata on the undersides of their leaves is influenced by relative humidity levels. Stomata enable plants to transpire, or "breathe." When the temperature is high, a plant may close its stomata to prevent water loss. The stomata also function as a cooling system. When the ambient temperature is too high for the plant, it closes its stomata for a lengthy period of time in order to save water, eventually suffocating on water vapour and its own transpired gases. Vegetable crops commonly experience issues such foliar and root infections, slow drying of the growing medium, plant stress, and loss of quality, which has a detrimental impact on relative humidity levels compared to other crops. Therefore, more pesticides are needed to fight illness, and vegetables frequently grow slowly and laxly, making them more difficult to harvest.

Figure 4.20: The effect of high relative humidity on vegetable quality

Regarding region dummy variables, where Dregion1 is zones found in the Amhara region, Dregion2 is zones located in the Binishangul Gumuz region, Dregion3 is zones in the Oromia region, Dregion 4 is zones placed in SNNP and Dregion5 is Zidama region which is a base category since it produces least oilseed production through the study. From the result in the table above we can argue that there is a huge crop production gap among regions. From the result Zones found in the Sidama region followed by SNNP and Oromia region have the greatest potential to produce vegetables.

CHAPTER FIVE

CONCLUSION AND IMPLICATIONS

5.1 Conclusion

The frequency of climatic risks is increasing as a result of climate change. There is a need to assess their impacts on each major crop producer zones in Ethiopia. This paper assessed the impacts of climate change on crop production of private peasant holders focusing on cereals, pulse, oilseed, and vegetables in the cases of major selected crop producer zones in Ethiopia. One-step system GMM and Two-step system GMM were used to assess the impacts of climate change on cereal production from the period 2003/04-2021/22 for 21 selected zones from Amhara region, Oromia region, Binishangul Gumuz, SNNP, and Sidama region. We have estimated cereal production, pulse production, oilseed production, and vegetable production.

The researcher concluded that lagged total production of cereals, number of private peasant holders, area in hectares, fertilizer, precipitation, Maximum average temperature; relative humidity, and regional dummy variables are the most significant factors that affect the production of cereals in major cereal producer zone in Ethiopia in the case of private peasant holders.

The researcher concluded that last year's production was used as seed for the current year. As a result of this increasing the level of previous cereals production have a considerable effect on current year production by increasing the accumulated seed for current year farm for each zone.

The precipitation variable carries a negative sign with a statistically significant effect on total cereals production. For every one percent increase in the precipitation, production of cereals tends to decline by 0.055 percent, ceteris paribus. The researcher concluded that high rainfall could reduce production through for instance damage from oxygen deficit as a consequence of soil waterlogging after heavy rain; bending of the stem; loss of soil nutrients; and plant anchorage failure since the topography of the major producer of cereals is found in highland topography of Ethiopia which are adversely affected by heavy erosion and heavy summer rainfall.

The maximum average temperature has a negative and significant effect on cereals production. The area under droughts and factors aggravating the effect of the drought is distinct: severe soil drying caused by preceding rainfall deficits and high evaporative demand before summer in 2022, and high evapotranspiration linked to extremely warm and sunny conditions in spring in 2020 reduced the level of the growth rate of cereals production in the major producer zones in the country. Relative Humidity has a positive and significant effect on crop production in a one-step system GMM result. Crops produced using irrigation produce less than those planted with the same quantity of water from rainfall when exposed to the same amount of sun radiation. The researcher concluded that this is because irrigation has minimal effect on the dry environment, which independently inhibits crop development.

Area covered by pulse, fertilizer, precipitation, minimum average temperature, maximum average temperature, relative humidity, and regional dummy were significant factors affecting the production of pulses in selected major pulse producer zones. The remaining variables' lag of pulse production was an insignificant factor.

Precipitation has a significant and negative effect on pulse production. The researcher concluded that erratic and unpredictable rainfall during the sowing stage and early vegetative growth stage and the flowering stage of pulses resulted in damage to pulse production. The other supporting reason is erratic rainfall resulted in flooding and soil erosion which in turn reduce the fertility of the soil. The maximum and elevated temperature on pulse production is determined to have a highly significant effect due to the global warming pressure. The researcher concluded that due to high temperatures at every stage of pulse producer zones, pulse production is increasing at decreasing rate even if the number of holders are increasing from time to time. Relative humidity has a significant and positive effect on pulse production. As a result, increasing the level of relative humidity automatically improved the total production of pulse in the country.

The number of private peasant holders, the area in a hectare, precipitation, average annual maximum temperature, relative humidity, and regional dummy were significant variables that determine the oilseed production. The remaining variables lag of oilseed production; fertilizer and average minimum temperature are insignificant variables.

Precipitation has a negative and significant effect on oilseed production. The researcher concluded that at a certain level, the amount of precipitation during the rainy season might yield a negative impact on oilseed development. This is since heavy erratic and variable rainfall in Kiremit and Meher season rainfall led to crop damage in certain zones in Ethiopia. The maximum and elevated temperature on oilseed production is determined to have a highly significant effect due to the global warming pressure. The researcher concluded that the impact of high temperature affects photosynthetic membranes followed by ion leakage, enlargement of grana stacks, and aberrant stacking. Relative humidity has a significant and positive effect on oilseed production. This is because when abundant humidity is available and other factors of the environment are favorable there will be rapid cell division and enlargement and it favors the vegetative phase of growth of oilseed.

The number of holders, area in hectares, fertilizer in quintals, precipitation, maximum temperature, relative humidity, and regional dummy except SNNP region were significant variables that affect the production of vegetables. Whereas the remaining variables like a lag of vegetable production, average minimum temperature, and relative humidity have insignificant effects on the production of vegetables.

Precipitation has a positive and significant effect on vegetable production. Rainfall is important for the growth and development of vegetables as it provides the necessary water for plant growth and reproduction through their production stage. Maximum temperature has a negative and significant effect on vegetable production. This is because high temperatures can accelerate chlorophyll breakdown, resulting in early yellowing, and hasten the softness, wilting, and dehydration. Relative humidity has a significant and negative effect on vegetable production. This is since Plants' ability to open the stomata on the undersides of their leaves is influenced by relative humidity levels. Compared to other crops, the level of relative humidity for vegetable production has a negative effect due to the problems like foliar and root infections, sluggish drying of the growth medium, plant stress, and loss of quality are frequently happened in vegetable crops. As a result, more pesticides are required to combat disease, and vegetables often grow slowly and laxly, making them less appealing. Relative humidity has a significant and negative effect on vegetable production. Compared to other crops, the level of relative humidity for vegetable production has a negative effect due to the problems like foliar and root infections, sluggish drying of the growth medium, plant stress, and loss of quality are frequently happened in vegetable crops. As a result, more pesticides are required to combat disease, and vegetables often grow slowly and laxly, making them less appealing.

5.2 Policy Implications

The overall implication of the paper lies in the type of measures that should be applied to promote crop production in Ethiopia. The policy implications associated with the finding of the impact of climate change on Crop production in the case of Major Private Peasant holders. If climate change variables are negatively affected crop production, the implication seems that we have to find a reduction mechanism, and if it is positively related we have to find sustainable implication that increases crop production. With such a standpoint, the following specific measures are suggested for private peasant holders, researchers, government officials, each respective zone, each region, and the country as a whole.

1. Precipitation has adverse effects on cereals, pulse, and oilseed production. At first glance, the study suggested that the private peasant should not only depend on rain-fed cereals, pulse, and oilseed production instead they have to use erratic rainfall as opportunities for building small-sized irrigation dams. Finally, the author suggested that their irrigated land area will be insurance for their rain-fed agriculture if and only if they accumulated heavy rainfall.
2. Maximum Temperature harms crop production in general. The author recommended the Ministry of Agriculture and the current government increases the level of forest coverage from 15.12 percent to 50 percent at least. Even though the current government has targeted to boost forest coverage by planting billions of trees every year starting from 2019, the weak enforcement of regulations on growing, as well as lax implementation of forest policy, has also contributed to deforestation and increasing the rate of temperature. If the first year it sleeps, the second year it creeps and the third year it leaps deforestation will be severe in the country. The author suggested to private peasant holders to use temperature resistance crop types through communicating with the Kebels, Wereda, and Zones base Administrations. The university across each zone has to introduce initiatives

across each Woredas by supporting farmers to identify which types of seed they are adopting i.e. improved seed adaptation and traditional seed adaptation.

3. Thus, the government should intensify adaptation and mitigation measures that have been implemented at a small scale in some parts of the country such as irrigation and water harvesting schemes, introducing climate change resilient crop varieties, implementing suitable settlement and re-settlement policies, creating awareness on adjusting planting and harvesting periods and introducing appropriate land use rights. The currently undergoing land management and water shading activities in some parts of the country need to continue sustainably and holistically.
4. Ethiopia's government ought to take a more active part in promoting adaptations. The 10-year plan has already taken steps to establish a strategy to address the impact of climate change in the years 2020/2021 to 2029/2030. However, because the effects of climate change will be more severe, the government must establish a longer-term strategy for an adaptation mechanism before the worst has happened.
5. Regarding the fertilizer level, the government has to set policies for private peasant holders at the micro level to use organic fertilizer and has to make a fair and equitable distribution of fertilizers across each zones without political differences. The government has to follow strict procedures for the distribution of inorganic fertilizers across each zone. Finally, the government has to put direction for a project of import substitution fertilizer.
6. Future studies need to consider identifying specific adaptation interventions for each of the crop types of the country. This chapter further recommends much wider research in the area, especially concerning the long-run impacts based on agro ecological zone across the country, as the knowledge about the macro-micro impacts of climate change in Ethiopia is limited.

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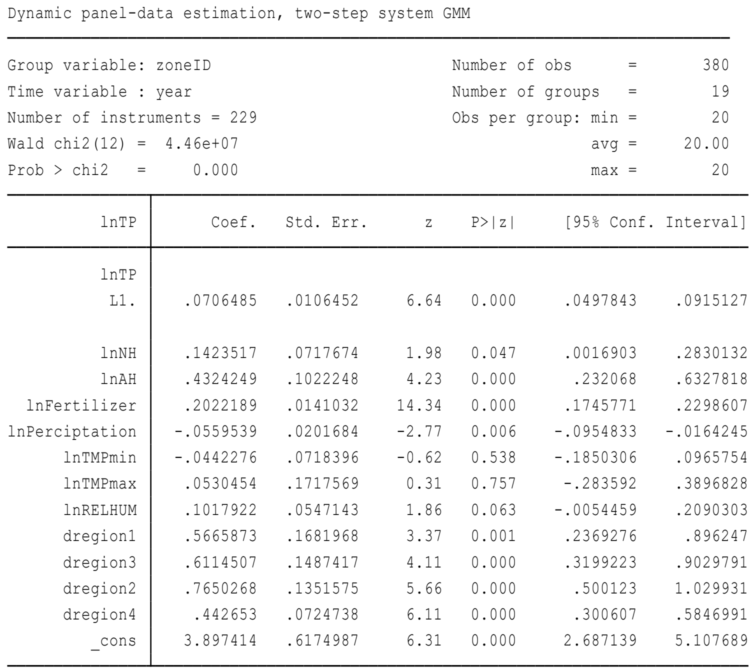
APPENDICES

Cerial one step system gmm

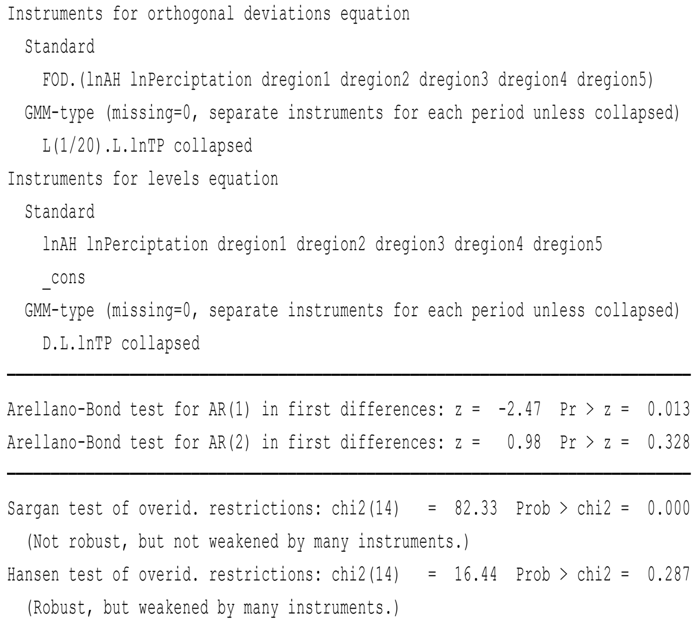
```
Dynamic panel-data estimation, one-step system GMM
──────────────────────────────────────────────────────────────────────────────
Group variable: zoneID                          Number of obs      =       380
Time variable : year                            Number of groups   =        19
Number of instruments = 229                     Obs per group: min =        20
Wald chi2(12) = 694309.39                                      avg =     20.00
Prob > chi2   =     0.000                                      max =        20
───────────────┬────────────────────────────────────────────────────────────────
          lnTP │      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
───────────────┼────────────────────────────────────────────────────────────────
          lnTP │
           L1. │   .0726649   .0254382     2.86   0.004     .0228069    .1225229
               │
          lnNH │   .1944644   .0575768     3.38   0.001      .081616    .3073129
          lnAH │    .343899   .0411198     8.36   0.000     .2633057    .4244923
  lnFertilizer │   .2151368   .0194362    11.07   0.000     .1770425    .2532312
lnPerciptation │  -.0590684   .0294028    -2.01   0.045    -.1166969   -.0014399
      lnTMPmin │  -.0100748   .0447552    -0.23   0.822    -.0977933    .0776437
      lnTMPmax │  -.0349026   .0541749    -0.64   0.519    -.1410835    .0712783
      lnRELHUM │   .1437124   .0416286     3.45   0.001     .0621219    .2253029
      dregion1 │   .7100522   .1212135     5.86   0.000     .4724782    .9476263
      dregion3 │    .740525   .1217533     6.08   0.000      .501893    .9791571
      dregion2 │   .8821704   .1746469     5.05   0.000     .5398688    1.224472
      dregion4 │   .5047427   .1109123     4.55   0.000     .2873585    .7221268
         _cons │   4.117846   .8447157     4.87   0.000     2.462234    5.773458
───────────────┴────────────────────────────────────────────────────────────────

Instruments for orthogonal deviations equation
  Standard
    FOD.(lnAH lnPerciptation dregion1 dregion2 dregion3 dregion4 dregion5)
  GMM-type (missing=0, separate instruments for each period unless collapsed)
    L(1/20).L.lnTP collapsed
Instruments for levels equation
  Standard
    lnAH lnPerciptation dregion1 dregion2 dregion3 dregion4 dregion5
    _cons
  GMM-type (missing=0, separate instruments for each period unless collapsed)
    D.L.lnTP collapsed
──────────────────────────────────────────────────────────────────────────────
Arellano-Bond test for AR(1) in first differences: z =  -2.59  Pr > z =  0.010
Arellano-Bond test for AR(2) in first differences: z =   0.51  Pr > z =  0.611
──────────────────────────────────────────────────────────────────────────────
Sargan test of overid. restrictions: chi2(14)   =  82.33  Prob > chi2 =  0.000
  (Not robust, but not weakened by many instruments.)
Hansen test of overid. restrictions: chi2(14)   =  16.44  Prob > chi2 =  0.287
  (Robust, but weakened by many instruments.)
```

Two step system GMM cereals



```
Dynamic panel-data estimation, two-step system GMM
------------------------------------------------------------------------------
Group variable: zoneID                          Number of obs      =       380
Time variable : year                            Number of groups   =        19
Number of instruments = 229                     Obs per group: min =        20
Wald chi2(12) =  4.46e+07                                      avg =     20.00
Prob > chi2   =     0.000                                      max =        20
------------------------------------------------------------------------------
        lnTP |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
        lnTP |
         L1. |   .0706485   .0106452     6.64   0.000     .0497843    .0915127
             |
        lnNH |   .1423517   .0717674     1.98   0.047     .0016903    .2830132
        lnAH |   .4324249   .1022248     4.23   0.000      .232068    .6327818
 lnFertilizer|   .2022189   .0141032    14.34   0.000     .1745771    .2298607
lnPerciptation|  -.0559539   .0201684    -2.77   0.006    -.0954833   -.0164245
    lnTMPmin |  -.0442276   .0718396    -0.62   0.538    -.1850306    .0965754
    lnTMPmax |   .0530454   .1717569     0.31   0.757     -.283592    .3896828
    lnRELHUM |   .1017922   .0547143     1.86   0.063    -.0054459    .2090303
    dregion1 |   .5665873   .1681968     3.37   0.001     .2369276     .896247
    dregion3 |   .6114507   .1487417     4.11   0.000     .3199223    .9029791
    dregion2 |   .7650268   .1351575     5.66   0.000      .500123    1.029931
    dregion4 |    .442653   .0724738     6.11   0.000      .300607    .5846991
       _cons |   3.897414   .6174987     6.31   0.000     2.687139    5.107689
------------------------------------------------------------------------------
```



```
Instruments for orthogonal deviations equation
  Standard
    FOD.(lnAH lnPerciptation dregion1 dregion2 dregion3 dregion4 dregion5)
  GMM-type (missing=0, separate instruments for each period unless collapsed)
    L(1/20).L.lnTP collapsed
Instruments for levels equation
  Standard
    lnAH lnPerciptation dregion1 dregion2 dregion3 dregion4 dregion5
    _cons
  GMM-type (missing=0, separate instruments for each period unless collapsed)
    D.L.lnTP collapsed
------------------------------------------------------------------------------
Arellano-Bond test for AR(1) in first differences: z =  -2.47  Pr > z =  0.013
Arellano-Bond test for AR(2) in first differences: z =   0.98  Pr > z =  0.328
------------------------------------------------------------------------------
Sargan test of overid. restrictions: chi2(14)   =  82.33  Prob > chi2 =  0.000
  (Not robust, but not weakened by many instruments.)
Hansen test of overid. restrictions: chi2(14)   =  16.44  Prob > chi2 =  0.287
  (Robust, but weakened by many instruments.)
```

One step system GMM pulse

```
Dynamic panel-data estimation, one-step system GMM
------------------------------------------------------------------------------
Group variable: commodityid                     Number of obs      =       380
Time variable : year                            Number of groups   =        19
Number of instruments = 27                      Obs per group: min =        20
Wald chi2(12) = 682380.60                                      avg =     20.00
Prob > chi2   =     0.000                                      max =        20
--------------------------------------------------------------------------------
               |              Robust
          lnTP |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
---------------+----------------------------------------------------------------
          lnTP |
           L1. |  -.0075039   .0156641    -0.48   0.632     -.038205    .0231972
               |
          lnNH |  -.0444159   .0314879    -1.41   0.158    -.1061311    .0172993
          lnAH |   1.117066   .0527081    21.19   0.000      1.01376    1.220372
  lnFertilizer |   .0912015   .0208269     4.38   0.000     .0503815    .1320214
lnPerciptation |  -.0108007   .0308327    -0.35   0.726    -.0712318    .0496303
      lnTMPmin |   .2747132   .1153091     2.38   0.017     .0487114    .5007149
      lnTMPmax |  -.5358045   .1418902    -3.78   0.000    -.8139042   -.2577049
      lnRELHUM |   .1425091   .0536563     2.66   0.008     .0373447    .2476735
      dregion1 |  -.6575411   .1600487    -4.11   0.000    -.9712308   -.3438514
      dregion3 |   -.509901   .1798475    -2.84   0.005    -.8623956   -.1574064
      dregion2 |  -.3836873   .1531213    -2.51   0.012    -.6837996   -.0835751
      dregion4 |  -.3832632   .0778326    -4.92   0.000    -.5358123   -.2307142
         _cons |   2.631684   .3987995     6.60   0.000     1.850051    3.413316
--------------------------------------------------------------------------------
Instruments for orthogonal deviations equation
  Standard
    FOD.(lnAH lnPerciptation dregion1 dregion2 dregion3 dregion4 dregion5)
  GMM-type (missing=0, separate instruments for each period unless collapsed)
    L(1/20).L.lnTP collapsed
Instruments for levels equation
  Standard
    lnAH lnPerciptation dregion1 dregion2 dregion3 dregion4 dregion5
    _cons
  GMM-type (missing=0, separate instruments for each period unless collapsed)
    D.L.lnTP collapsed
------------------------------------------------------------------------------
Arellano-Bond test for AR(1) in first differences: z =  -2.92  Pr > z =  0.004
Arellano-Bond test for AR(2) in first differences: z =   0.46  Pr > z =  0.647
------------------------------------------------------------------------------
Sargan test of overid. restrictions: chi2(14)   =  37.98  Prob > chi2 =  0.001
  (Not robust, but not weakened by many instruments.)
Hansen test of overid. restrictions: chi2(14)   =  12.66  Prob > chi2 =  0.554
  (Robust, but weakened by many instruments.)
```

Two-step system GMM pulse result

```
Dynamic panel-data estimation, two-step system GMM
------------------------------------------------------------------------------
Group variable: commodityid                     Number of obs      =       380
Time variable : year                            Number of groups   =        19
Number of instruments = 42                      Obs per group: min =        20
Wald chi2(12) =  5.28e+06                                      avg =     20.00
Prob > chi2   =     0.000                                      max =        20
--------------------------------------------------------------------------------
          lnTP |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
---------------+----------------------------------------------------------------
          lnTP |
           L1. |  -.0272857   .0175075    -1.56   0.119    -.0615998    .0070283
               |
          lnNH |  -.0691527   .0291785    -2.37   0.018    -.1263416   -.0119639
          lnAH |   1.091151    .028377    38.45   0.000     1.035533    1.146768
  lnFertilizer |    .080108    .006722    11.92   0.000     .0669331     .093283
lnPerciptation |  -.0428842   .0188428    -2.28   0.023    -.0798154    -.005953
      lnTMPmin |   .3101064   .1203456     2.58   0.010     .0742334    .5459794
      lnTMPmax |  -.5073985   .1813218    -2.80   0.005    -.8627828   -.1520143
      lnRELHUM |   .1326463   .0422815     3.14   0.002      .049776    .2155166
      dregion1 |  -.6710076    .116859    -5.74   0.000    -.9000471   -.4419682
      dregion3 |  -.5240578   .1079041    -4.86   0.000    -.7355459   -.3125697
      dregion2 |  -.4961596   .2295274    -2.16   0.031     -.946025   -.0462942
      dregion4 |  -.4839075   .1327983    -3.64   0.000    -.7441873   -.2236276
         _cons |    3.54156   1.056511     3.35   0.001     1.470836    5.612283
--------------------------------------------------------------------------------
Warning: Uncorrected two-step standard errors are unreliable.

Instruments for orthogonal deviations equation
  Standard
    FOD.(lnAH lnPerciptation dregion1 dregion2 dregion3 dregion4 dregion5)
  GMM-type (missing=0, separate instruments for each period unless collapsed)
    L(1/20).(L.lnTP dregion1 dregion2 dregion3 dregion4 dregion5) collapsed
Instruments for levels equation
  Standard
    lnAH lnPerciptation dregion1 dregion2 dregion3 dregion4 dregion5
    _cons
  GMM-type (missing=0, separate instruments for each period unless collapsed)
    D.(L.lnTP dregion1 dregion2 dregion3 dregion4 dregion5) collapsed
------------------------------------------------------------------------------
Arellano-Bond test for AR(1) in first differences: z =  -2.13  Pr > z =  0.033
Arellano-Bond test for AR(2) in first differences: z =   0.52  Pr > z =  0.601
------------------------------------------------------------------------------
Sargan test of overid. restrictions: chi2(29)   = 101.34  Prob > chi2 =  0.000
  (Not robust, but not weakened by many instruments.)
Hansen test of overid. restrictions: chi2(29)   =  14.30  Prob > chi2 =  0.990
  (Robust, but weakened by many instruments.)
```

One step-system GMM oilseed result

```
Dynamic panel-data estimation, one-step system GMM
------------------------------------------------------------------------------
Group variable: zoneidd                         Number of obs      =       380
Time variable : Year                            Number of groups   =        19
Number of instruments = 27                      Obs per group: min =        20
Wald chi2(12) = 252120.96                                      avg =     20.00
Prob > chi2   =     0.000                                      max =        20
--------------------------------------------------------------------------------
               |              Robust
          lnTP |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
---------------+----------------------------------------------------------------
          lnTP |
           L1. |   .0041523   .0271138     0.15   0.878    -.0489897    .0572942
               |
          lnNH |   .5507295   .1892761     2.91   0.004     .1797552    .9217038
          lnAH |   .6296002   .0872961     7.21   0.000     .4585029    .8006974
  lnFertilizer |   .0616193    .041415     1.49   0.137    -.0195527    .1427913
lnPerciptation |  -.4703872   .0711003    -6.62   0.000    -.6097413   -.3310332
      lnTMPmin |  -.0028052    .235231    -0.01   0.990    -.4638495    .4582391
      lnTMPmax |   .9672511   .2646676     3.65   0.000     .4485123     1.48599
      lnRELHUM |   .6018032   .1834356     3.28   0.001      .242276    .9613303
      dregion1 |  -.0545215   .3655129    -0.15   0.881    -.7709137    .6618706
      dregion3 |   .4509051     .21683     2.08   0.038     .0259261    .8758841
      dregion2 |   1.571018   .2947079     5.33   0.000     .9934015    2.148635
      dregion4 |  -1.380066   .2138896    -6.45   0.000    -1.799281   -.9608498
         _cons |  -7.370909   1.722109    -4.28   0.000    -10.74618   -3.995636
--------------------------------------------------------------------------------
Instruments for orthogonal deviations equation
  Standard
    FOD.(lnAH lnPerciptation dregion1 dregion2 dregion3 dregion4 dregion5)
  GMM-type (missing=0, separate instruments for each period unless collapsed)
    L(1/20).L.lnTP collapsed
Instruments for levels equation
  Standard
    lnAH lnPerciptation dregion1 dregion2 dregion3 dregion4 dregion5
    _cons
  GMM-type (missing=0, separate instruments for each period unless collapsed)
    D.L.lnTP collapsed
------------------------------------------------------------------------------
Arellano-Bond test for AR(1) in first differences: z =  -3.06  Pr > z =  0.002
Arellano-Bond test for AR(2) in first differences: z =  -0.14  Pr > z =  0.892
------------------------------------------------------------------------------
Sargan test of overid. restrictions: chi2(14)   =  88.96  Prob > chi2 =  0.000
  (Not robust, but not weakened by many instruments.)
Hansen test of overid. restrictions: chi2(14)   =  15.89  Prob > chi2 =  0.320
  (Robust, but weakened by many instruments.)
```

Two step-system GMM oilseed result

```
Dynamic panel-data estimation, two-step system GMM
------------------------------------------------------------------------------
Group variable: zoneidd                         Number of obs      =       380
Time variable : Year                            Number of groups   =        19
Number of instruments = 42                      Obs per group: min =        20
Wald chi2(12) =  6.23e+06                                      avg =     20.00
Prob > chi2   =     0.000                                      max =        20
--------------------------------------------------------------------------------
          lnTP |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
---------------+----------------------------------------------------------------
          lnTP |
           L1. |   .0033806   .0125691     0.27   0.788    -.0212544    .0280155
               |
          lnNH |   .4657323   .1489216     3.13   0.002     .1738513    .7576133
          lnAH |   .6711279     .09001     7.46   0.000     .4947116    .8475443
  lnFertilizer |    .073028   .0485522     1.50   0.133    -.0221326    .1681885
lnPerciptation |  -.4354267   .1084315    -4.02   0.000    -.6479486   -.2229049
      lnTMPmin |   .3179484   .1830815     1.74   0.082    -.0408847    .6767815
      lnTMPmax |   .1849605   .3428205     0.54   0.590    -.4869554    .8568764
      lnRELHUM |   .5873008   .1427063     4.12   0.000     .3076016        .867
      dregion1 |  -.0226656   .2153933    -0.11   0.916    -.4448288    .3994976
      dregion3 |   .4189357   .1756267     2.39   0.017     .0747136    .7631578
      dregion2 |   1.208429   .2577269     4.69   0.000     .7032939    1.713565
      dregion4 |  -1.207146   .1553715    -7.77   0.000    -1.511668   -.9026233
         _cons |  -4.261968   1.574771    -2.71   0.007    -7.348462   -1.175475
--------------------------------------------------------------------------------
Warning: Uncorrected two-step standard errors are unreliable.

Instruments for orthogonal deviations equation
  Standard
    FOD.(lnAH lnPerciptation dregion1 dregion2 dregion3 dregion4 dregion5)
  GMM-type (missing=0, separate instruments for each period unless collapsed)
    L(1/20).(L.lnTP dregion1 dregion2 dregion3 dregion4 dregion5) collapsed
Instruments for levels equation
  Standard
    lnAH lnPerciptation dregion1 dregion2 dregion3 dregion4 dregion5
    _cons
  GMM-type (missing=0, separate instruments for each period unless collapsed)
    D.(L.lnTP dregion1 dregion2 dregion3 dregion4 dregion5) collapsed
------------------------------------------------------------------------------
Arellano-Bond test for AR(1) in first differences: z =  -3.25  Pr > z =  0.001
Arellano-Bond test for AR(2) in first differences: z =   0.32  Pr > z =  0.749
------------------------------------------------------------------------------
Sargan test of overid. restrictions: chi2(29)   = 140.43  Prob > chi2 =  0.000
  (Not robust, but not weakened by many instruments.)
Hansen test of overid. restrictions: chi2(29)   =  15.82  Prob > chi2 =  0.978
  (Robust, but weakened by many instruments.)
```

One step -system GMM for vegetable production

```
Dynamic panel-data estimation, one-step system GMM
------------------------------------------------------------------------------
Group variable: zoneID                          Number of obs      =       374
Time variable : year                            Number of groups   =        19
Number of instruments = 23                      Obs per group: min =        18
Wald chi2(12) = 245687.94                                      avg =     19.68
Prob > chi2   =     0.000                                      max =        20
--------------------------------------------------------------------------------
               |              Robust
          lnTP |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
---------------+----------------------------------------------------------------
          lnTP |
           L1. |   .0140605    .037416     0.38   0.707    -.0592735    .0873945
               |
          lnNH |   .5928957   .1207989     4.91   0.000     .3561343    .8296572
          lnAH |   .5630202   .0618463     9.10   0.000     .4418036    .6842368
  lnFertilizer |  -.1193562   .0401336    -2.97   0.003    -.1980166   -.0406959
lnPerciptation |   .0757507   .0414706     1.83   0.068    -.0055303    .1570316
      lnTMPmin |  -.5170332   .1902912    -2.72   0.007    -.8899971   -.1440693
      lnTMPmax |   .7307545   .2400556     3.04   0.002     .2602542    1.201255
      lnRELHUM |  -.5209186   .0859395    -6.06   0.000     -.689357   -.3524802
      dregion1 |  -.7248152   .0708909   -10.22   0.000    -.8637587   -.5858716
      dregion3 |   -.472416   .0679026    -6.96   0.000    -.6055026   -.3393294
      dregion2 |  -.5734114   .2245705    -2.55   0.011    -1.013562   -.1332613
      dregion4 |  -.0590429   .1132866    -0.52   0.602    -.2810806    .1629947
         _cons |   2.250847   1.454983     1.55   0.122    -.6008661     5.10256
--------------------------------------------------------------------------------
Instruments for orthogonal deviations equation
  Standard
    FOD.(lnAH lnPerciptation)
  GMM-type (missing=0, separate instruments for each period unless collapsed)
    L(1/20).L.lnTP collapsed
Instruments for levels equation
  Standard
    lnAH lnPerciptation
    _cons
  GMM-type (missing=0, separate instruments for each period unless collapsed)
    D.L.lnTP collapsed
------------------------------------------------------------------------------
Arellano-Bond test for AR(1) in first differences: z =  -3.27  Pr > z =  0.001
Arellano-Bond test for AR(2) in first differences: z =  -1.24  Pr > z =  0.216
------------------------------------------------------------------------------
Sargan test of overid. restrictions: chi2(10)   =  42.94  Prob > chi2 =  0.000
  (Not robust, but not weakened by many instruments.)
Hansen test of overid. restrictions: chi2(10)   =  14.64  Prob > chi2 =  0.146
  (Robust, but weakened by many instruments.)
```

Two step-System GMM result for Vegetable production

```
Dynamic panel-data estimation, two-step system GMM
------------------------------------------------------------------------------
Group variable: zoneID                          Number of obs      =       374
Time variable : year                            Number of groups   =        19
Number of instruments = 23                      Obs per group: min =        18
Wald chi2(12) = 109628.41                                      avg =     19.68
Prob > chi2   =     0.000                                      max =        20
---------------+----------------------------------------------------------------
               |              Corrected
          lnTP |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
---------------+----------------------------------------------------------------
          lnTP |
           L1. |   .0711499   .0956531     0.74   0.457    -.1163268    .2586266
               |
          lnNH |   .6350151   .1873209     3.39   0.001      .267873    1.002157
          lnAH |   .5530088   .1041065     5.31   0.000     .3489638    .7570538
  lnFertilizer |  -.1696662   .0941455    -1.80   0.072    -.3541881    .0148556
lnPerciptation |   .0464506   .1088334     0.43   0.670    -.1668588    .2597601
      lnTMPmin |  -.2800036   .5101429    -0.55   0.583    -1.279865    .7198582
      lnTMPmax |   .5919644   .5665837     1.04   0.296    -.5185192    1.702448
      lnRELHUM |  -.4711113   .1092013    -4.31   0.000     -.685142   -.2570807
      dregion1 |   -.647701   .1706905    -3.79   0.000    -.9822482   -.3131539
      dregion3 |   -.410202   .1143763    -3.59   0.000    -.6343754   -.1860287
      dregion2 |   -.565834   .2849468    -1.99   0.047    -1.124319   -.0073487
      dregion4 |   .1853306   .3753068     0.49   0.621    -.5502572    .9209183
         _cons |   .9452823   2.612482     0.36   0.717    -4.175088    6.065652
---------------+----------------------------------------------------------------
Instruments for orthogonal deviations equation
  Standard
    FOD.(lnAH lnPerciptation)
  GMM-type (missing=0, separate instruments for each period unless collapsed)
    L(1/20).L.lnTP collapsed
Instruments for levels equation
  Standard
    lnAH lnPerciptation
    _cons
  GMM-type (missing=0, separate instruments for each period unless collapsed)
    D.L.lnTP collapsed
------------------------------------------------------------------------------
Arellano-Bond test for AR(1) in first differences: z =  -3.16  Pr > z =  0.002
Arellano-Bond test for AR(2) in first differences: z =  -0.20  Pr > z =  0.840
------------------------------------------------------------------------------
Sargan test of overid. restrictions: chi2(10)   =  42.94  Prob > chi2 =  0.000
  (Not robust, but not weakened by many instruments.)
Hansen test of overid. restrictions: chi2(10)   =  14.64  Prob > chi2 =  0.146
  (Robust, but weakened by many instruments.)
```

Panel unit root for cereals production

Levin-Lin-Chu unit-root test

```
. xtunitroot llc lnTP

Levin-Lin-Chu unit-root test for lnTP
-------------------------------------
Ho: Panels contain unit roots              Number of panels  =     19
Ha: Panels are stationary                  Number of periods =     21

AR parameter: Common                       Asymptotics: N/T -> 0
Panel means:  Included
Time trend:   Not included

ADF regressions: 1 lag
LR variance:     Bartlett kernel, 8.00 lags average (chosen by LLC)
------------------------------------------------------------------------------
                    Statistic      p-value
------------------------------------------------------------------------------
 Unadjusted t       -15.9587
 Adjusted t*         -6.1063        0.0000
------------------------------------------------------------------------------
```

```
. xtunitroot llc lnNH

Levin-Lin-Chu unit-root test for lnNH
-------------------------------------
Ho: Panels contain unit roots              Number of panels  =     19
Ha: Panels are stationary                  Number of periods =     21

AR parameter: Common                       Asymptotics: N/T -> 0
Panel means:  Included
Time trend:   Not included

ADF regressions: 1 lag
LR variance:     Bartlett kernel, 8.00 lags average (chosen by LLC)
------------------------------------------------------------------------------
                    Statistic      p-value
------------------------------------------------------------------------------
 Unadjusted t       -18.4913
 Adjusted t*        -10.9645        0.0000
------------------------------------------------------------------------------
```

```
. xtunitroot llc lnAH

Levin-Lin-Chu unit-root test for lnAH
-------------------------------------
Ho: Panels contain unit roots              Number of panels  =     19
Ha: Panels are stationary                  Number of periods =     21

AR parameter: Common                       Asymptotics: N/T -> 0
Panel means:  Included
Time trend:   Not included

ADF regressions: 1 lag
LR variance:     Bartlett kernel, 8.00 lags average (chosen by LLC)
------------------------------------------------------------------------------
                    Statistic      p-value
------------------------------------------------------------------------------
 Unadjusted t       -16.8474
 Adjusted t*         -8.2186        0.0000
------------------------------------------------------------------------------
```

```
. xtunitroot llc lnFertilizer

Levin-Lin-Chu unit-root test for lnFertilizer
---------------------------------------------
Ho: Panels contain unit roots               Number of panels  =     19
Ha: Panels are stationary                   Number of periods =     21

AR parameter: Common                        Asymptotics: N/T -> 0
Panel means:  Included
Time trend:   Not included

ADF regressions: 1 lag
LR variance:     Bartlett kernel, 8.00 lags average (chosen by LLC)
------------------------------------------------------------------------------
                    Statistic      p-value
------------------------------------------------------------------------------
 Unadjusted t       -15.2965
 Adjusted t*         -7.4566        0.0000
------------------------------------------------------------------------------
```

```
. xtunitroot llc lnTMPmax

Levin-Lin-Chu unit-root test for lnTMPmax
-----------------------------------------
Ho: Panels contain unit roots               Number of panels  =     19
Ha: Panels are stationary                   Number of periods =     21

AR parameter: Common                        Asymptotics: N/T -> 0
Panel means:  Included
Time trend:   Not included

ADF regressions: 1 lag
LR variance:     Bartlett kernel, 8.00 lags average (chosen by LLC)
------------------------------------------------------------------------------
                    Statistic      p-value
------------------------------------------------------------------------------
 Unadjusted t       -14.4454
 Adjusted t*         -4.7513        0.0000
------------------------------------------------------------------------------
```

```
. xtunitroot llc lnTMPmin

Levin-Lin-Chu unit-root test for lnTMPmin
-----------------------------------------
Ho: Panels contain unit roots               Number of panels  =     19
Ha: Panels are stationary                   Number of periods =     21

AR parameter: Common                        Asymptotics: N/T -> 0
Panel means:  Included
Time trend:   Not included

ADF regressions: 1 lag
LR variance:     Bartlett kernel, 8.00 lags average (chosen by LLC)
------------------------------------------------------------------------------
                    Statistic      p-value
------------------------------------------------------------------------------
 Unadjusted t       -15.2434
 Adjusted t*         -6.9675        0.0000
------------------------------------------------------------------------------
```

```
. xtunitroot llc lnRELHUM

Levin-Lin-Chu unit-root test for lnRELHUM
-----------------------------------------
Ho: Panels contain unit roots               Number of panels  =     19
Ha: Panels are stationary                   Number of periods =     21

AR parameter: Common                        Asymptotics: N/T -> 0
Panel means:  Included
Time trend:   Not included

ADF regressions: 1 lag
LR variance:     Bartlett kernel, 8.00 lags average (chosen by LLC)
------------------------------------------------------------------------------
                    Statistic      p-value
------------------------------------------------------------------------------
 Unadjusted t       -17.3899
 Adjusted t*         -8.3890        0.0000
------------------------------------------------------------------------------
```

Harris-Tzavalis unit-root test FOR Cereals

```
. xtunitroot ht lnTP

Harris-Tzavalis unit-root test for lnTP
---------------------------------------
Ho: Panels contain unit roots               Number of panels  =     19
Ha: Panels are stationary                   Number of periods =     21

AR parameter: Common                        Asymptotics: N -> Infinity
Panel means:  Included                                   T Fixed
Time trend:   Not included
------------------------------------------------------------------------------
                    Statistic         z         p-value
------------------------------------------------------------------------------
 rho                  0.0954      -23.6864       0.0000
------------------------------------------------------------------------------
```

```
. xtunitroot ht lnNH

Harris-Tzavalis unit-root test for lnNH
---------------------------------------
Ho: Panels contain unit roots               Number of panels  =     19
Ha: Panels are stationary                   Number of periods =     21

AR parameter: Common                        Asymptotics: N -> Infinity
Panel means:  Included                                   T Fixed
Time trend:   Not included
------------------------------------------------------------------------------
                    Statistic         z         p-value
------------------------------------------------------------------------------
 rho                 -0.0986      -29.6688       0.0000
------------------------------------------------------------------------------
```

```
. xtunitroot ht lnAH

Harris-Tzavalis unit-root test for lnAH
---------------------------------------
Ho: Panels contain unit roots               Number of panels  =     19
Ha: Panels are stationary                   Number of periods =     21

AR parameter: Common                        Asymptotics: N -> Infinity
Panel means:  Included                                   T Fixed
Time trend:   Not included
------------------------------------------------------------------------------
                    Statistic         z         p-value
------------------------------------------------------------------------------
 rho                  0.0018      -26.5716       0.0000
------------------------------------------------------------------------------
```

```
. xtunitroot ht lnFertilizer

Harris-Tzavalis unit-root test for lnFertilizer
-----------------------------------------------
Ho: Panels contain unit roots               Number of panels  =     19
Ha: Panels are stationary                   Number of periods =     21

AR parameter: Common                        Asymptotics: N -> Infinity
Panel means:  Included                                   T Fixed
Time trend:   Not included
------------------------------------------------------------------------------
                    Statistic         z         p-value
------------------------------------------------------------------------------
 rho                  0.2116      -20.1037       0.0000
------------------------------------------------------------------------------
```

```
. xtunitroot ht lnTMPmax

Harris-Tzavalis unit-root test for lnTMPmax
───────────────────────────────────────────
Ho: Panels contain unit roots              Number of panels  =     19
Ha: Panels are stationary                  Number of periods =     21

AR parameter: Common                       Asymptotics: N -> Infinity
Panel means:  Included                                  T Fixed
Time trend:   Not included
──────────────────────────────────────────────────────────────────────────────
                    Statistic         z         p-value
──────────────────────────────────────────────────────────────────────────────
 rho                 -0.0927      -29.4860       0.0000
──────────────────────────────────────────────────────────────────────────────


. xtunitroot ht lnTMPmin

Harris-Tzavalis unit-root test for lnTMPmin
───────────────────────────────────────────
Ho: Panels contain unit roots              Number of panels  =     19
Ha: Panels are stationary                  Number of periods =     21

AR parameter: Common                       Asymptotics: N -> Infinity
Panel means:  Included                                  T Fixed
Time trend:   Not included
──────────────────────────────────────────────────────────────────────────────
                    Statistic         z         p-value
──────────────────────────────────────────────────────────────────────────────
 rho                 -0.0627      -28.5596       0.0000
──────────────────────────────────────────────────────────────────────────────


. xtunitroot ht lnRELHUM

Harris-Tzavalis unit-root test for lnRELHUM
───────────────────────────────────────────
Ho: Panels contain unit roots              Number of panels  =     19
Ha: Panels are stationary                  Number of periods =     21

AR parameter: Common                       Asymptotics: N -> Infinity
Panel means:  Included                                  T Fixed
Time trend:   Not included
──────────────────────────────────────────────────────────────────────────────
                    Statistic         z         p-value
──────────────────────────────────────────────────────────────────────────────
 rho                 -0.1733      -31.9708       0.0000
──────────────────────────────────────────────────────────────────────────────
```

Panel Unit root test for Pulse production : Levin-Lin-Chu unit-root test

```
Levin-Lin-Chu unit-root test for lnTP
-------------------------------------
Ho: Panels contain unit roots              Number of panels  =     19
Ha: Panels are stationary                  Number of periods =     21

AR parameter: Common                       Asymptotics: N/T -> 0
Panel means:  Included
Time trend:   Not included

ADF regressions: 1 lag
LR variance:     Bartlett kernel, 8.00 lags average (chosen by LLC)
------------------------------------------------------------------------------
                    Statistic      p-value
------------------------------------------------------------------------------
 Unadjusted t       -17.1887
 Adjusted t*        -10.0229        0.0000
------------------------------------------------------------------------------

.
. xtunitroot llc lnNH

Levin-Lin-Chu unit-root test for lnNH
-------------------------------------
Ho: Panels contain unit roots              Number of panels  =     19
Ha: Panels are stationary                  Number of periods =     21

AR parameter: Common                       Asymptotics: N/T -> 0
Panel means:  Included
Time trend:   Not included

ADF regressions: 1 lag
LR variance:     Bartlett kernel, 8.00 lags average (chosen by LLC)
------------------------------------------------------------------------------
                    Statistic      p-value
------------------------------------------------------------------------------
 Unadjusted t       -18.2806
 Adjusted t*        -11.6211        0.0000
------------------------------------------------------------------------------

.
. xtunitroot llc lnAH

Levin-Lin-Chu unit-root test for lnAH
-------------------------------------
Ho: Panels contain unit roots              Number of panels  =     19
Ha: Panels are stationary                  Number of periods =     21

AR parameter: Common                       Asymptotics: N/T -> 0
Panel means:  Included
Time trend:   Not included

ADF regressions: 1 lag
LR variance:     Bartlett kernel, 8.00 lags average (chosen by LLC)
------------------------------------------------------------------------------
                    Statistic      p-value
------------------------------------------------------------------------------
 Unadjusted t       -17.4249
 Adjusted t*        -10.7934        0.0000
------------------------------------------------------------------------------

.
. xtunitroot llc lnFertilizer

Levin-Lin-Chu unit-root test for lnFertilizer
---------------------------------------------
Ho: Panels contain unit roots              Number of panels  =     19
Ha: Panels are stationary                  Number of periods =     21

AR parameter: Common                       Asymptotics: N/T -> 0
Panel means:  Included
Time trend:   Not included

ADF regressions: 1 lag
LR variance:     Bartlett kernel, 8.00 lags average (chosen by LLC)
------------------------------------------------------------------------------
                    Statistic      p-value
------------------------------------------------------------------------------
 Unadjusted t       -14.2700
 Adjusted t*         -5.7843        0.0000
------------------------------------------------------------------------------
```

Harris-Tzavalis unit-root test for pulse production

```
. xtunitroot ht lnTP

Harris-Tzavalis unit-root test for lnTP
───────────────────────────────────────
Ho: Panels contain unit roots               Number of panels  =     19
Ha: Panels are stationary                   Number of periods =     21

AR parameter: Common                        Asymptotics: N -> Infinity
Panel means:  Included                                   T Fixed
Time trend:   Not included
──────────────────────────────────────────────────────────────────────────────
                    Statistic         z         p-value
──────────────────────────────────────────────────────────────────────────────
 rho                  0.0096      -26.3316       0.0000
──────────────────────────────────────────────────────────────────────────────

.
. xtunitroot ht lnNH

Harris-Tzavalis unit-root test for lnNH
───────────────────────────────────────
Ho: Panels contain unit roots               Number of panels  =     19
Ha: Panels are stationary                   Number of periods =     21

AR parameter: Common                        Asymptotics: N -> Infinity
Panel means:  Included                                   T Fixed
Time trend:   Not included
──────────────────────────────────────────────────────────────────────────────
                    Statistic         z         p-value
──────────────────────────────────────────────────────────────────────────────
 rho                 -0.1068      -29.9207       0.0000
──────────────────────────────────────────────────────────────────────────────

.
. xtunitroot ht lnAH

Harris-Tzavalis unit-root test for lnAH
───────────────────────────────────────
Ho: Panels contain unit roots               Number of panels  =     19
Ha: Panels are stationary                   Number of periods =     21

AR parameter: Common                        Asymptotics: N -> Infinity
Panel means:  Included                                   T Fixed
Time trend:   Not included
──────────────────────────────────────────────────────────────────────────────
                    Statistic         z         p-value
──────────────────────────────────────────────────────────────────────────────
 rho                 -0.0318      -27.6093       0.0000
──────────────────────────────────────────────────────────────────────────────

.
. xtunitroot ht lnFertilizer

Harris-Tzavalis unit-root test for lnFertilizer
───────────────────────────────────────────────
Ho: Panels contain unit roots               Number of panels  =     19
Ha: Panels are stationary                   Number of periods =     21

AR parameter: Common                        Asymptotics: N -> Infinity
Panel means:  Included                                   T Fixed
Time trend:   Not included
──────────────────────────────────────────────────────────────────────────────
                    Statistic         z         p-value
──────────────────────────────────────────────────────────────────────────────
 rho                  0.1155      -23.0655       0.0000
──────────────────────────────────────────────────────────────────────────────
```

Panel unit root test for oilseed

```
. xtunitroot llc lnTP

Levin-Lin-Chu unit-root test for lnTP
-------------------------------------
Ho: Panels contain unit roots               Number of panels  =     19
Ha: Panels are stationary                   Number of periods =     21

AR parameter: Common                        Asymptotics: N/T -> 0
Panel means:  Included
Time trend:   Not included

ADF regressions: 1 lag
LR variance:     Bartlett kernel, 8.00 lags average (chosen by LLC)
------------------------------------------------------------------------------
                    Statistic      p-value
------------------------------------------------------------------------------
 Unadjusted t       -14.4675
 Adjusted t*         -4.8550        0.0000
------------------------------------------------------------------------------

.
. xtunitroot llc lnNH

Levin-Lin-Chu unit-root test for lnNH
-------------------------------------
Ho: Panels contain unit roots               Number of panels  =     19
Ha: Panels are stationary                   Number of periods =     21

AR parameter: Common                        Asymptotics: N/T -> 0
Panel means:  Included
Time trend:   Not included

ADF regressions: 1 lag
LR variance:     Bartlett kernel, 8.00 lags average (chosen by LLC)
------------------------------------------------------------------------------
                    Statistic      p-value
------------------------------------------------------------------------------
 Unadjusted t       -19.0757
 Adjusted t*        -10.2061        0.0000
------------------------------------------------------------------------------

.
. xtunitroot llc lnAH

Levin-Lin-Chu unit-root test for lnAH
-------------------------------------
Ho: Panels contain unit roots               Number of panels  =     19
Ha: Panels are stationary                   Number of periods =     21

AR parameter: Common                        Asymptotics: N/T -> 0
Panel means:  Included
Time trend:   Not included

ADF regressions: 1 lag
LR variance:     Bartlett kernel, 8.00 lags average (chosen by LLC)
------------------------------------------------------------------------------
                    Statistic      p-value
------------------------------------------------------------------------------
 Unadjusted t       -16.2192
 Adjusted t*         -7.7344        0.0000
------------------------------------------------------------------------------

.
. xtunitroot llc lnFertilizer

Levin-Lin-Chu unit-root test for lnFertilizer
---------------------------------------------
Ho: Panels contain unit roots               Number of panels  =     19
Ha: Panels are stationary                   Number of periods =     21

AR parameter: Common                        Asymptotics: N/T -> 0
Panel means:  Included
Time trend:   Not included

ADF regressions: 1 lag
LR variance:     Bartlett kernel, 8.00 lags average (chosen by LLC)
------------------------------------------------------------------------------
                    Statistic      p-value
------------------------------------------------------------------------------
 Unadjusted t       -14.0675
 Adjusted t*         -8.0540        0.0000
------------------------------------------------------------------------------

.
```

Unit root test Harris-Tzavalis unit-root test for oilseed

```
Harris-Tzavalis unit-root test for lnTP
---------------------------------------

Ho: Panels contain unit roots               Number of panels  =     19
Ha: Panels are stationary                   Number of periods =     21

AR parameter: Common                        Asymptotics: N -> Infinity
Panel means:  Included                                   T Fixed
Time trend:   Not included
------------------------------------------------------------------------------
                   Statistic         z         p-value
------------------------------------------------------------------------------
 rho                 0.0314      -25.6600       0.0000
------------------------------------------------------------------------------

.
. xtunitroot ht lnNH

Harris-Tzavalis unit-root test for lnNH
---------------------------------------

Ho: Panels contain unit roots               Number of panels  =     19
Ha: Panels are stationary                   Number of periods =     21

AR parameter: Common                        Asymptotics: N -> Infinity
Panel means:  Included                                   T Fixed
Time trend:   Not included
------------------------------------------------------------------------------
                   Statistic         z         p-value
------------------------------------------------------------------------------
 rho                -0.0453      -28.0243       0.0000
------------------------------------------------------------------------------

.
. xtunitroot ht lnAH

Harris-Tzavalis unit-root test for lnAH
---------------------------------------

Ho: Panels contain unit roots               Number of panels  =     19
Ha: Panels are stationary                   Number of periods =     21

AR parameter: Common                        Asymptotics: N -> Infinity
Panel means:  Included                                   T Fixed
Time trend:   Not included
------------------------------------------------------------------------------
                   Statistic         z         p-value
------------------------------------------------------------------------------
 rho                 0.0069      -26.4152       0.0000
------------------------------------------------------------------------------

.
. xtunitroot ht lnFertilizer

Harris-Tzavalis unit-root test for lnFertilizer
-----------------------------------------------

Ho: Panels contain unit roots               Number of panels  =     19
Ha: Panels are stationary                   Number of periods =     21

AR parameter: Common                        Asymptotics: N -> Infinity
Panel means:  Included                                   T Fixed
Time trend:   Not included
------------------------------------------------------------------------------
                   Statistic         z         p-value
------------------------------------------------------------------------------
 rho                 0.2605      -18.5972       0.0000
------------------------------------------------------------------------------

.
```

Panel unit root for vegetable

```
. xtunitroot llc lnTMPmax

Levin-Lin-Chu unit-root test for lnTMPmax
─────────────────────────────────────────
Ho: Panels contain unit roots               Number of panels  =     19
Ha: Panels are stationary                   Number of periods =     21

AR parameter: Common                        Asymptotics: N/T -> 0
Panel means:  Included
Time trend:   Not included

ADF regressions: 1 lag
LR variance:     Bartlett kernel, 8.00 lags average (chosen by LLC)
──────────────────────────────────────────────────────────────────────────────
                    Statistic      p-value
──────────────────────────────────────────────────────────────────────────────
 Unadjusted t       -14.4499
 Adjusted t*         -4.7996        0.0000
──────────────────────────────────────────────────────────────────────────────

.
. xtunitroot llc lnTMPmin

Levin-Lin-Chu unit-root test for lnTMPmin
─────────────────────────────────────────
Ho: Panels contain unit roots               Number of panels  =     19
Ha: Panels are stationary                   Number of periods =     21

AR parameter: Common                        Asymptotics: N/T -> 0
Panel means:  Included
Time trend:   Not included

ADF regressions: 1 lag
LR variance:     Bartlett kernel, 8.00 lags average (chosen by LLC)
──────────────────────────────────────────────────────────────────────────────
                    Statistic      p-value
──────────────────────────────────────────────────────────────────────────────
 Unadjusted t       -15.3956
 Adjusted t*         -6.6346        0.0000
──────────────────────────────────────────────────────────────────────────────

.
. xtunitroot llc lnRELHUM

Levin-Lin-Chu unit-root test for lnRELHUM
─────────────────────────────────────────
Ho: Panels contain unit roots               Number of panels  =     19
Ha: Panels are stationary                   Number of periods =     21

AR parameter: Common                        Asymptotics: N/T -> 0
Panel means:  Included
Time trend:   Not included

ADF regressions: 1 lag
LR variance:     Bartlett kernel, 8.00 lags average (chosen by LLC)
──────────────────────────────────────────────────────────────────────────────
                    Statistic      p-value
──────────────────────────────────────────────────────────────────────────────
 Unadjusted t       -17.3899
 Adjusted t*         -8.3890        0.0000
──────────────────────────────────────────────────────────────────────────────

. xtunitroot llc lnPerciptation

Levin-Lin-Chu unit-root test for lnPerciptation
───────────────────────────────────────────────
Ho: Panels contain unit roots               Number of panels  =     19
Ha: Panels are stationary                   Number of periods =     21

AR parameter: Common                        Asymptotics: N/T -> 0
Panel means:  Included
Time trend:   Not included

ADF regressions: 1 lag
LR variance:     Bartlett kernel, 8.00 lags average (chosen by LLC)
──────────────────────────────────────────────────────────────────────────────
                    Statistic      p-value
──────────────────────────────────────────────────────────────────────────────
 Unadjusted t       -18.4304
 Adjusted t*        -12.4275        0.0000
──────────────────────────────────────────────────────────────────────────────
```