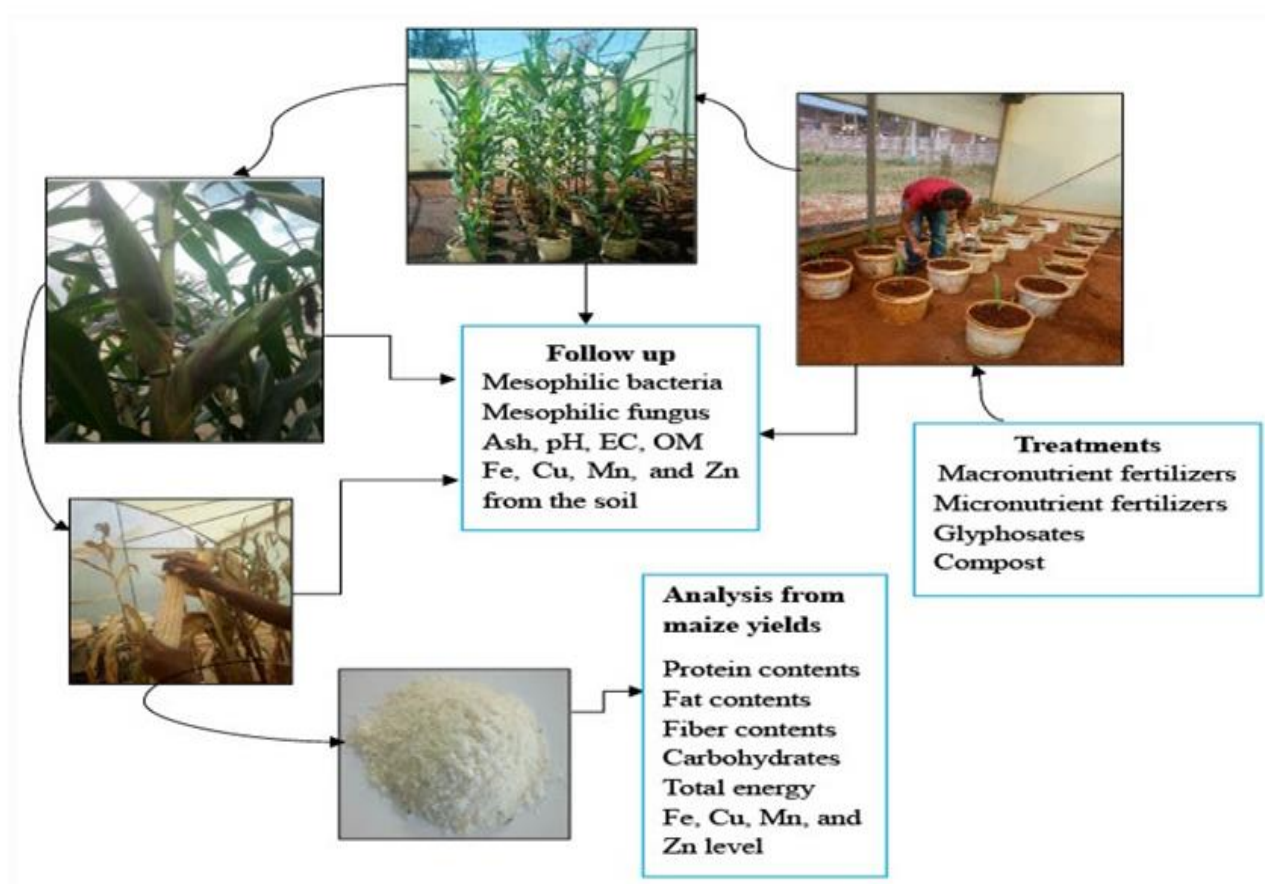




# INFLUENCE OF AGROCHEMICALS ON MICRONUTRIENT AVAILABILITY AND HEALTH IMPLICATIONS AMONG SMALL-SCALE FARMERS IN KELLEM WELLEGA ZONE

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**JIMMA UNIVERSITY,  
INSTITUTE OF HEALTH  
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DEPARTMENT OF ENVIRONMENTAL HEALTH SCIENCE AND  
TECHNOLOGY**

**INFLUENCE OF AGROCHEMICALS ON MICRONUTRIENT  
AVAILABILITY AND HEALTH IMPLICATIONS AMONG  
SMALL-SCALE FARMERS IN KELLEW WELLEGA ZONE**

A PHD DISSERTATION SUBMITTED TO THE SCHOOL OF GRADUATE  
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ENVIRONMENTAL HEALTH SCIENCES

BY: TARIKU NEME

August, 2024

JIMMA UNIVERSITY

## **Declaration Form**

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

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## **Declaration of Interest Statement**

The authors declare that there are no conflicts of interest regarding the publication of this manuscript. We affirm that we have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

All authors have participated in (a) the conception and design, or analysis and interpretation of the data; (b) drafting the article or revising it critically for important intellectual content; and (c) approval of the final version.

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If any conflicts of interest arise in the future, we will promptly disclose them to the appropriate parties.

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## Summary

**Background:** Micronutrients are crucial for the growth and development of plants, animals, and humans. In Western Ethiopia, small-scale farmers rely on local soil and food sources for their livelihood. Agricultural practices significantly influence soil microbial populations and physicochemical properties, which are essential for crop growth and quality. Additionally, the presence of agricultural pesticide residues can cause adverse health effects.

**Objectives:** This study aims to assess soil properties and nutrient dynamics of cereals, legumes, and tubers in small-scale farms in Western Ethiopia. It investigates the impact of different agrochemical applications on soil microbial dynamics, physicochemical properties, and the yield and proximate properties of maize. Additionally, the study assesses the prevalence of pesticide use and its occupational exposure among small-scale farmers in the Kellem Wellega Zone. Finally, it evaluates the level of pesticides in the blood of small-scale farmers and associated risk factors.

**Methods:** Samples of various agricultural products, including cereals, legumes, and tubers were collected from small-scale farmers. Soil samples were randomly collected from selected sub-sites and analyzed using standardized procedures, measuring soil pH, electrical conductivity, moisture, organic matter, and ash content. Microbial analysis involved serial dilution and plating techniques, while mineral content (Mn, Zn, Fe, and Cu) was determined through acid digestion and atomic absorption spectrophotometry. Statistical analyses included chi-square, ANOVA, and graphical representation.

Additionally, a cross-sectional study design using a structured questionnaire collected data from small-scale farmers' households via face-to-face interviews to assess pesticide use prevalence. Statistical analysis included descriptive statistics, chi-square test, and binary logistic regression ( $p < 0.05$  at 95%CI). Furthermore, blood samples from exposed and non-exposed small-scale farmers using gas-liquid chromatography with an electron capture detector (GC-ECD). Logistic regression models defined relationships between outcomes and explanatory variables.

**Results:** Soil samples had low levels of Mn, Zn, Fe, and Cu, with percentages of 41.7, 61.7, 66.7, and 63.3 mg/kg, respectively. A decrease in pH value was observed in 76.7% of the soil samples. Total mesophilic bacteria levels were below  $10^5$  cfu/g in 23.3% of samples, and fungus levels were

below  $10^4$  cfu/g in 53.3%. Only 3.3% of organic matter was beneficial, while 86.7% of ash content was unwanted. One-way ANOVA showed significant differences in moisture, ash contents, organic matter, Zn, Fe, and Mn ( $p < 0.05$ ). Food samples also showed significant differences in crude protein, fats, and fibers ( $p < 0.05$ ).

The highest total mesophilic bacterial count was in compost-treated pots (G), while the lowest was in pots with macronutrient fertilizers and glyphosates (B). Similar trends were observed for total mesophilic fungal counts. Pots with macronutrient fertilizers and glyphosate had the lowest Fe, Zn, Mn, and Cu levels. Compost-treated maize had the highest levels of Fe, Cu, and Zn, while macronutrient fertilizer combined with glyphosate resulted in the lowest micronutrient content.

The prevalence of pesticide use was 87.15%. Poor knowledge, practice, and negative attitudes towards pesticide use were observed in 44.2%, 40.2%, and 43.8% of participants, respectively. Farmers directly involved in farming were 2.2 times more likely to be exposed to pesticides (AOR=2.2; 95%CI: 1.12-4.3). Good knowledge reduced exposure likelihood by 58% (AOR = 0.42; 95%CI: 0.24-0.76). Poor practice increased exposure likelihood by 1.84 times (AOR=1.84; 95%CI: 1.05-3.24). Non-symptomatic farmers were 56% less likely to be exposed compared to those showing symptoms of coughing (AOR=0.44; 95%CI: 0.25-0.79).

p,p'-DDT, heptachlor, and deltamethrin were frequently detected in blood samples. Exposed farmers had higher mean concentrations of permethrin and p,p'-DDT. Farmers under 40 were 21% less likely to be exposed to permethrin (AOR, 0.21; 95% CI: 0.1-0.44). Male farmers were 17 times more likely to be exposed to heptachlor (AOR, 17.36; 95%CI: 7.34-41.09). Inappropriate PPE use increased exposure to cypermethrin and p,p'-DDE.

**Conclusions:** The study highlights significant deficiencies in micronutrient levels in soil and crops, the impact of agrochemicals on soil and crop quality, and the prevalence of pesticide use and its health risks among small-scale farmers. These findings underscore the need for improved agricultural practices, better education on pesticide use, and appropriate safety measures to protect farmers' health and ensure adequate micronutrient availability in the local agricultural ecosystem.

**Key phrases:** Agricultural practices, Blood, Crop quality, Food samples, Micronutrient, Micronutrient concentrations, Occupational exposure, Pesticide prevalence, Pesticide residues, Physicochemical properties, Risk factors, Small-scale farmers, Soil, Soil ecosystem, Soil microbial populations, Western Ethiopia

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## **Abbreviation and acronyms**

AAS - Atomic absorption spectroscopy

AC - Ash contents

ANOVA- Analysis of variance

DDD- Dichloro-Diphenyl –Dichloro -Ethane

DDE -Dichloro-Diphenyldichloro-Ethylene

DDT- Dichloro-Diphenyl- Trichloroethane

ECD -Electron Capture Detector

EDHS- Ethiopian Demographic Health Survey

FAO- Food and Agricultural Organization

GC -Gas Chromatography

IPM - Integrated Pest Management

LOD - Limit of Detection

LOQ - Limit of Quantification

MC - Moisture contents

MS - Mass Spectrometer

ND- Non-Detected

NESSFs- Non Exposed Small Scale Farmers

NGOs - Non Government Organizations

OCPs - Organochlorine Pesticides

OM- Organic Matter

PDA - Potato dextrose agar

PPEs- Personal Protective Equipment

SPSS- Statistical Package for the Social Sciences

SSFs - Small-Scale Farmers

SPs - Synthetic Pyrateriods

TMBC - Total Mesophilic Bacteria Count

TMFC - Total Mesophilic Fungus Count

WHO - World Health Organization

## **Chapter one: Introduction and general background**

## **1.1. Introduction**

Agrochemicals such as fertilizers and pesticides raise concerns about their long-term impact on soil health and sustainability (Mandal et al., 2020). Their extensive application can lead to soil degradation, reduced soil fertility, and environmental pollution, thus posing a threat to agricultural sustainability (Tefera et al., 2024). One primary concern is the effect of agrochemicals on soil microbiological activity. Soil microorganisms are essential for maintaining soil health as they contribute to nutrient cycling, organic matter decomposition, and suppression of soil-borne diseases (Idowu et al., 2019). Agrochemicals can disrupt these microbial communities, leading to reduced soil fertility and negatively impacting plant growth (Meena et al., 2020).

## **1.2. Micronutrient Deficiency in Small-Scale Farmers**

Micronutrient deficiency among small-scale farmers is a significant issue with extensive implications for public health, agricultural productivity, and socio-economic development (Mhoro et al., 2023). Farmers in low- and middle-income countries face unique challenges that increase the prevalence of these deficiencies (Fraval et al., 2019). One major challenge is limited access to diverse and nutrient-rich foods, largely due to socioeconomic constraints such as poverty and lack of education (Grace, 2015). These constraints restrict their ability to afford and obtain a variety of foods necessary for a balanced diet. As a result, their diets often rely heavily on staple crops that do not provide all essential micronutrients (Herforth et al., 2020).

. Soil degradation, driven by factors such as erosion, over-cultivation, and inadequate use of fertilizers, leads to the depletion of essential micronutrients like zinc, iron, and vitamin A in the soil (Kibret et al., 2023). This degradation, in turn, results in crops that are less nutritious, further exacerbating the deficiency among those who consume them (Lal, 2015).

Small-scale farmers frequently lack the knowledge and resources needed to implement effective soil management practices (Mizik, 2021). Without proper training and access to agricultural extension services, they may continue using methods that harm soil health, such as monocropping and improper use of chemical inputs (Warra and Prasad, 2020). These practices degrade soil fertility and decrease the bioavailability of essential micronutrients to plants (Haq et al., 2014).

### **1.3. Micronutrient Levels in Local Soil and Foods**

Micronutrients are essential nutrients required in small amounts for life. However, their deficiency in soil, plants, and animals is a global issue of varying severity across different countries (Arigony et al., 2013). This problem arises from improper soil management practices, such as intensive cultivation without adequate nutrient replenishment, limited crop rotations, and insufficient addition of organic matter. As a result, micronutrient deficiencies in soils and crops worldwide lead to reduced crop yield and quality (Shukla et al., 2018).

In Ethiopia, soil fertility is generally poor, and micronutrient deficiencies are worsening due to intensified agricultural practices. Recent estimates indicate that approximately 1.8 million tons of micronutrients are depleted each year (Abate and Hadis, 2011, Alemayehu et al., 2020, Gurmessa, 2021). Especially, the declining levels of zinc, iron, copper, and manganese in agricultural soil globally have shed significant light on the complex factors contributing to soil micronutrient deficiencies and their impacts on crop productivity, soil health, and human nutrition (Ahmed et al., 2024). Factors such as soil erosion, intensive agricultural practices, inadequate fertilization, and environmental pollution have depleted soil reserves of these micronutrients (Alemineu and Alemayehu, 2020).

Furthermore, climate change exacerbates soil micronutrient deficiencies by altering soil moisture, temperature, and nutrient cycling processes, aggravating deficiencies in various regions globally (Bhengu and Onyeka, 2024). Additionally, nutrient leaching, soil acidification, and loss of soil organic matter further diminish the bioavailability of these micronutrients to plants, exacerbating deficiencies and negatively affecting crop growth, yield, and nutritional quality (Lal, 2015, Wani et al., 2017, Samota et al., 2024).

These interactions between soil micronutrient levels and human nutrition translate to reduced levels of essential micronutrients in crops, impacting food quality and contributing to malnutrition and associated health issues worldwide (Kumssa et al., 2015, White and Brown, 2010). Similarly, the ongoing decrease in soil micronutrient levels in Ethiopian agricultural areas is attributed to various factors, including soil erosion, intensive farming practices, limited use of micronutrient-containing fertilizers, and soil degradation. Consequently, soil reserves of these micronutrients are depleted,

leading to deficiencies that negatively impact crop growth, yield, and nutritional quality (Abate et al., 2017, Tadesse, 2018).

#### **1.4. Factors Contributing to Micronutrient Deficiency of Soil and Plants**

Micronutrient deficiencies in soil and plants are a significant concern that affects agricultural productivity, food security, and human nutrition (Shukla et al., 2018). Several interrelated factors contribute to the depletion of essential micronutrients like zinc, iron, copper, and manganese in soils, ultimately impacting plant health and crop yields (Shahid et al., 2016).

Firstly, intensive agricultural practices play a crucial role in depleting soil micronutrients. Continuous cropping, especially with high-yielding varieties, often leads to the removal of more nutrients than are replenished (Alemineu and Alemayehu, 2020). This imbalance is exacerbated by inadequate fertilization practices that do not compensate for the specific micronutrient needs of different crops. For example, conventional fertilizers primarily focus on macronutrients such as nitrogen, phosphorus, and potassium, often neglecting the necessary micronutrients (Shahena et al., 2021).

Soil erosion is a significant factor in the loss of micronutrients caused by wind and water strips away the topsoil, which is rich in organic matter and nutrients (Segovia et al., 2017). This process diminishes the soil's nutrient content, as well as its structure and water-holding capacity, which further impairs plant growth. According to (Lal, 2009), soil erosion leads to substantial nutrient losses, especially in areas with intensive agricultural practices.

Moreover, climate change exacerbates micronutrient deficiencies by altering soil moisture levels, temperature, and nutrient cycling processes (Agrimonti et al., 2021). Changes in precipitation patterns can lead to either excessive leaching of nutrients in wetter conditions or reduced nutrient availability in drier soils (Costa et al., 2022). These climate-induced changes disrupt the balance of soil nutrients and negatively impact plant health (Food and Agriculture Organization, 2019).

Inadequate soil management practices, such as monocropping and lack of crop rotation, also contribute to the depletion of soil micronutrients (Belete and Yadete, 2023). Monocropping, which involves growing the same crop continuously on the same land, depletes specific nutrients required by that crop without allowing time for natural replenishment. Crop rotation, on the other hand, can

help maintain soil fertility by alternating crops with different nutrient requirements and root structures (Haq et al., 2014).

Furthermore, the overuse of chemical pesticides and herbicides has a detrimental effect on soil health. These chemicals can alter soil pH, reduce microbial activity, and disrupt the natural processes of nutrient cycling (Mandal et al., 2020). For instance, glyphosate, a widely used herbicide, has been shown to bind with soil particles, potentially reducing the availability of essential micronutrients to plants (Mohy-Ud-Din et al., 2024). The impact of such practices on soil micronutrient levels is profound, affecting both crop productivity and nutritional quality.

Additionally, the lack of organic matter in soil is a significant contributor to micronutrient deficiencies (Kiani et al., 2022). Organic matter not only provides nutrients but also enhances soil structure, water retention, and microbial activity. Practices such as composting and the use of green manure can help increase organic matter content, thereby improving the overall nutrient status of the soil (Wani et al., 2017).

Moreover, soil bacteria and fungi play crucial roles in nutrient cycling, soil aggregation, and plant-microbe interactions (Mohapatra et al., 2024). Decreases in microbial diversity compromise the essential ecosystem services, leading to decreased soil fertility, increased susceptibility to soil-borne diseases, and reduced agricultural productivity (Abebe et al., 2020, Haq et al., 2014). This decline may be attributed to intensive tillage, pesticide use, and monoculture practices, which disrupt soil microbial communities, leading to decreased biomass and diversity (Delelegn et al., 2018).

Additionally, reductions in soil organic matter content due to land degradation, deforestation, and unsustainable agricultural practices deprive soil microorganisms of essential nutrients, further decreasing microbial activity and diversity (Zhao et al., 2014, Condrón et al., 2010, Shahane and Shivay, 2022). Furthermore, changes in temperature and precipitation patterns also influence microbial activity and distribution by altering soil moisture and temperature regimes (Cates et al., 2022). These changes can favor the proliferation of certain microbial taxa while suppressing others, resulting in shifts in soil microbial communities (Mekala and Polepongu, 2019, Abatenh et al., 2018).

Recent research in Ethiopia revealed the decline in agricultural soil's pH, electrical conductivity, moisture, and ash content. This decline may be attributed to factors such as acid rain deposition, soil

erosion, and unsustainable agricultural practices, which negatively impact soil nutrient availability and crop productivity (Gurmessa, 2021, Tesfahunegn, 2014).

Furthermore, the reduction in soil moisture levels, caused by climate variability, deforestation, and unsustainable land use practices, worsens the region's agricultural challenges, adversely affecting crop growth, water availability, and soil structure (Tadese et al., 2020). Additionally, traditional farming methods in Ethiopia often worsen nutrient deficiencies, thereby influencing the nutritional content of crops grown in the country (Abate and Anteneh, 2024, Gurmessa, 2020).

Additionally, dietary habits that heavily depend on staple grains such as sorghum, maize, and potatoes, which are low in nutrients, result in overall poor nutritional quality. Consequently, Ethiopian diets often lack essential nutrients like protein, carbohydrates, fiber, and fats (Sibhatu and Qaim, 2018).

### **1.5. Prevalence of Pesticide Use and Its Exposure in Small-Scale Farmers**

The prevalence of pesticide uses and its exposure among small-scale farmers is a pressing issue that poses significant health risks and environmental concerns (Afata et al., 2022). While pesticides are essential for controlling pests and increasing agricultural productivity, their widespread use among small-scale farmers, particularly in developing countries, has led to numerous adverse effects (Tolera, 2020).

Small-scale farmers frequently lack proper training and knowledge regarding the safe use of pesticides. This inadequacy can lead to improper application, which may result in both immediate and chronic health issues (Mergia et al., 2021). Evidence suggests that exposure to pesticides can cause a range of acute symptoms such as headaches, nausea, breathing difficulties, and skin irritations (Tudi et al., 2022). Additionally, chronic exposure can lead to more severe health issues such as cognitive, motor, sensory, and neurological deficiencies (Lucero and Muñoz-Quezada, 2021).

Additionally, not using proper protective equipment's when applying pesticides significantly increases the risk of exposure (Sapbamrer and Thammachai, 2020). Many small-scale farmers forgo personal protective equipment (PPE) due to its cost or limited availability, making them more susceptible to pesticide-related health problems. The World Health Organization estimates that over

200,000 individuals in rural areas of developing countries die annually from pesticide poisoning, underscoring the gravity of this issue (Yadav et al., 2015).

Furthermore, pesticide residues in food and the environment pose additional health risks to farmers and their families (Mehmood et al., 2021). The consumption of contaminated food, proximity to treated fields, and occupational exposure during spraying and handling are common pathways of pesticide exposure (Tudi et al., 2022). Research indicates that pesticide residues in food can lead to long-term health problems, including cancer, endocrine disruption, and reproductive issues (Mekonen et al., 2014, Tudi et al., 2022).

The environmental consequences of pesticide use are significant and must not be ignored. Pesticides can pollute soil and water sources, posing risks to human health, biodiversity, and ecosystem services (Zhou et al., 2024). Small-scale farmers, who often depend on local water sources for irrigation and household needs, face increased exposure and health hazards due to pesticide runoff contaminating these water supplies.

### **1.6. Association of Micronutrient Deficiency and Pesticide Use**

The association between micronutrient deficiency and pesticide use is a complex and multifaceted issue that has significant implications for agricultural productivity, environmental health, and human well-being (Yetgin, 2023). Pesticides, while crucial for controlling pests and increasing crop yields, can inadvertently contribute to soil degradation and nutrient imbalance (Zhou et al., 2024). This paradox highlights the delicate balance between agricultural practices and sustainable soil health.

Firstly, the use of pesticides, particularly herbicides like glyphosate, can influence the availability of essential soil micronutrients such as copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn). Glyphosate binds strongly to soil particles, potentially reducing the bioavailability of these nutrients to plants (Haq et al., 2014). Consequently, this can lead to deficiencies in crops, which, in turn, impact the nutritional quality of food produced.

Furthermore, the use of pesticides can negatively impact soil microbial populations, which are crucial for nutrient cycling. These soil microbes are essential for decomposing organic matter and making nutrients available for plant absorption (Raza et al., 2023). When pesticides alter the microbial community, the efficiency of these processes can decrease, resulting in diminished soil

fertility and reduced availability of micronutrients (Haq et al., 2014). For instance, intensive pesticide use can decrease microbial biomass and diversity, which are essential for maintaining soil health and plant productivity (Hartmann and Six, 2023)

Additionally, overreliance on chemical fertilizers and pesticides can lead to long-term soil health issues. While these inputs may boost short-term yields, they can degrade soil structure and reduce organic matter content over time (Hossain et al., 2022). This degradation further exacerbates micronutrient deficiencies because organic matter is a key reservoir of nutrients and supports microbial activity that aids nutrient uptake (Lal, 2009).

Furthermore, the impact of pesticides on soil health extends to human health. The deficiency of essential micronutrients in soil translates into lower concentrations in food crops, which can contribute to malnutrition in populations reliant on these crops for their dietary needs (Dwivedi et al., 2023). For example, deficiencies in iron and zinc are particularly concerning as they are critical for immune function, cognitive development, and overall health. Studies have shown that in regions where pesticide use is prevalent, such as in parts of Ethiopia, there are significant micronutrient deficiencies in both soil and human populations (Kumssa et al., 2015).

Despite the known risks of pesticide exposure, significant data gaps remain regarding the prevalence of pesticide use, the level of knowledge and practices among small-scale farmers, and the associated risks in regions like the Kellem Wellega zone of Ethiopia. These gaps are critical because small-scale farmers often engage in unsafe pesticide handling practices due to a lack of education and training, increasing their vulnerability to acute and chronic health issues.

Additionally, there is a notable lack of understanding of the concentrations of essential minerals like zinc, iron, manganese, and copper in the soils and crops of this region, as well as the effects of agrochemical treatments on soil micronutrient availability and microbial dynamics. Addressing these gaps is crucial for developing effective strategies to enhance soil health, crop productivity, and food security. Therefore, this study aims to provide detailed insights into pesticide use, occupational exposure, and soil and crop nutrient dynamics in the Kellem Wellega zone.

## **1.7. The framework of the research**

Agriculture, a cornerstone of human civilization, has evolved significantly over the centuries. However, the advent of modern agricultural practices, including the widespread use of agrochemicals, has introduced complex challenges and opportunities. Small-scale farmers, who play a crucial role in global food security and rural economies, are particularly affected by these changes. This study examines the interplay between soil micronutrient content, agrochemical use, and the health of small-scale farmers, with a specific focus on pesticide exposure.

The conceptual framework of this study is based on the interaction between soil micronutrient levels, agrochemical use, and health outcomes among small-scale farmers. It suggests that optimal soil micronutrient content enhances crop productivity and nutritional quality, while improper agrochemical use may disrupt soil health and exacerbate health risks for farmers.

The significance of this study lies in its potential to fill knowledge gaps about how soil and agrochemical management affect farmer health, offering actionable insights for improving agricultural practices and safeguarding health. The hypothesis is that elevated pesticide residues in the blood of small-scale farmers are linked to adverse health outcomes, and that soil micronutrient levels and agrochemical practices significantly influence these outcomes.

The chapter on "soil micronutrient content and crop composition of small-scale farming communities" explores the impact of soil micronutrient levels such as manganese, zinc, iron, and copper on soil properties and crop composition. The findings reveal that soil with optimal levels of these micronutrients shows significant differences in soil pH, organic matter, and microbial biomass compared to soils with deficient levels.

For example, higher pH and organic matter were observed in soils with adequate levels of manganese, zinc, and iron, while deficient soils had lower pH and reduced microbial activity. Crops grown in soils with low micronutrient concentrations often have lower nutrient content and poorer composition, highlighting the need to improve soil micronutrient levels to enhance crop nutritional quality and overall soil health.

The chapter on "the effect of agrochemicals on soil microbiological activity, micronutrient availability, and nutrient uptake by plants" investigates how various agrochemicals including macronutrient and micronutrient fertilizers, glyphosates, and compost affect soil microbiological activity, micronutrient availability, and nutrient uptake by plants. It reveals that compost consistently results in higher moisture content, pH, and electrical conductivity, whereas glyphosates and macronutrient fertilizers often lead to lower soil quality parameters and micronutrient availability. Compost treatment enhances soil microbial biomass and micronutrient concentrations, while glyphosate treatments tend to deplete essential soil nutrients. This chapter emphasizes that agrochemical use significantly influences soil health and nutrient dynamics, with compost showing beneficial effects compared to other treatments.

The chapter on "the prevalence of pesticide use and occupational exposure among small-scale farmers" examines the prevalence of pesticide use among small-scale farmers and the associated occupational exposure risks. It finds that a high percentage of farmers use pesticides but many lack proper knowledge and training regarding safe usage. Issues such as improper handling, inadequate protective measures, and unsafe disposal practices contribute to significant health risks. The chapter underscores the need for improved education and training on pesticide safety and better safety practices to reduce exposure and protect farmer health.

Finally, the chapter on "evaluating the level of pesticides in the blood of small-scale farmers and its associated risk factors" focuses on quantifying pesticide levels in the blood of small-scale farmers and exploring associated risk factors. It presents data on the prevalence of pesticide residues in blood samples, analyzing correlations with exposure practices such as the frequency of pesticide application, use of protective equipment, and adherence to safety guidelines. The chapter investigates health outcomes related to elevated pesticide levels, including potential chronic effects and acute symptoms. Findings reveal significant associations between high pesticide concentrations in blood and adverse health effects, emphasizing the need for regular monitoring and improved safety measures. The chapter advocates for better regulatory practices and health interventions to mitigate risks and protect the well-being of farmers.

### 1.8. Conceptual Framework

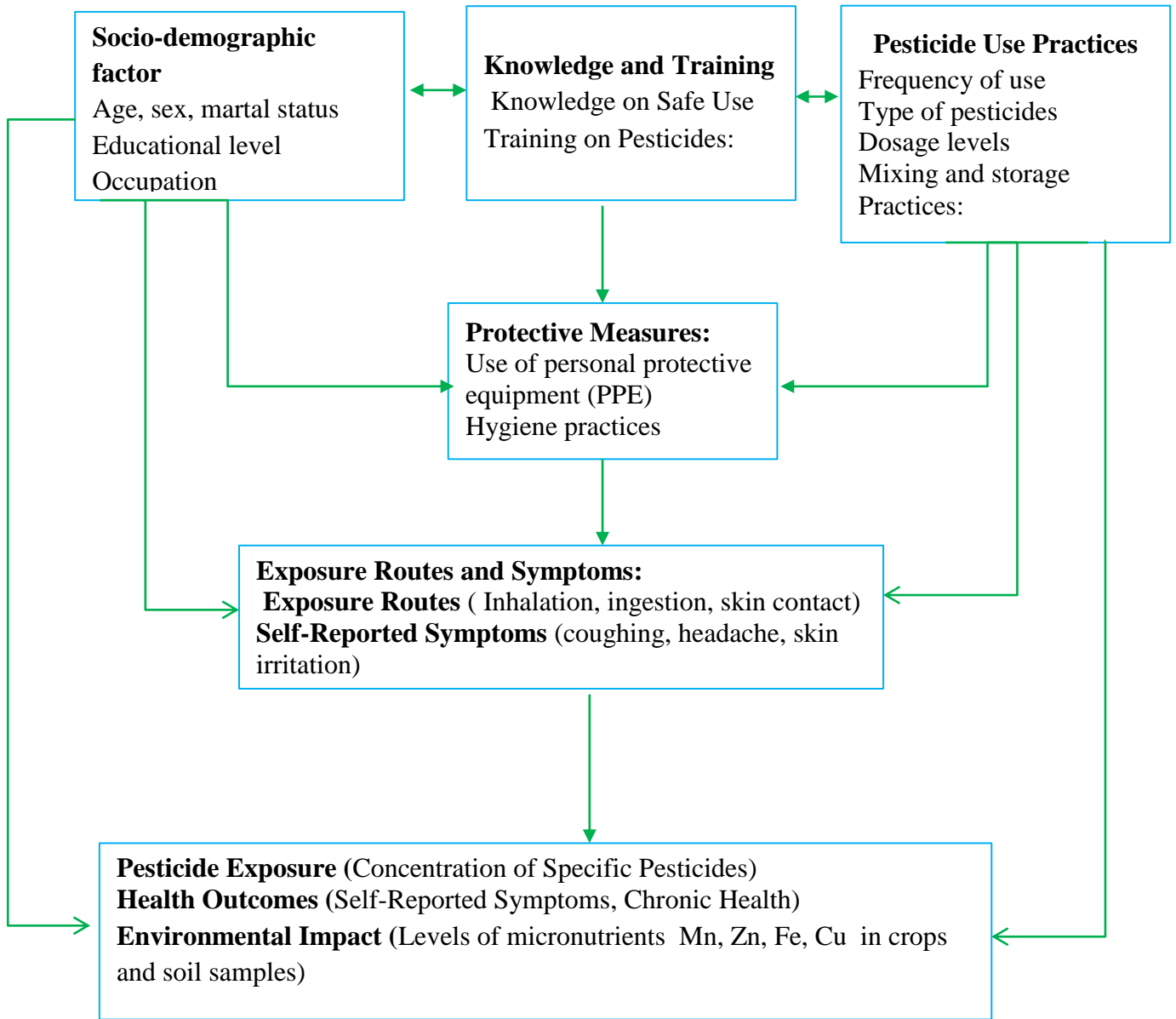


Figure1: Conceptual frame work

## **1.9. General objectives**

Investigating the influence of agrochemicals on micronutrient availability and health of small-scale farmers in Kellem Wellega Zone, Western Ethiopia

Specific objectives

- To assess the soil micronutrient content and crop composition of small-scale farming communities in Western Ethiopia.
- To investigate the impact of agrochemicals on soil microbiological activity, micronutrient availability, and nutrient uptake by maize (*Zea mays* L) crops.
- To evaluate the prevalence of pesticide use and the level of occupational exposure among small-scale farmers in Western Ethiopia, identifying the associated risk factors and potential health impacts
- To determine the levels of pesticides concentration in the blood of small-scale farmers in Western Ethiopia and to identify the associated risk factors contributing to pesticide exposure.

### **1.10. Significance of the study**

The research titled "Agrochemicals Impact on Micronutrient Availability and Health Effects among Small-Scale Farmers in Western Ethiopia" holds considerable significance for several reasons. It investigates the prevalence of pesticide use and the exposure risks faced by small-scale farmers in the Kellem Wellega Zone. The study measures pesticide levels in farmers' blood, evaluates local soil and crop nutrient content, and assesses the impact of agrochemicals on soil microbiological activity and micronutrient availability.

This research is of great societal importance as it addresses the severe health impacts of pesticide exposure and micronutrient deficiencies on farmers, affecting their overall well-being and productivity. By exploring these issues, the study aims to improve health outcomes and enhance the quality of life for these individuals. From a scientific perspective, the research provides crucial data on how agrochemicals affect soil health and micronutrient availability, which is essential for understanding the broader impacts of agricultural practices on human health and environmental sustainability. The findings can guide policymakers in crafting regulations and interventions to mitigate the negative effects of agrochemicals and promote sustainable farming.

Various stakeholders stand to benefit from this research. Healthcare providers and nutritionists can use the results to create targeted health and nutrition programs. Agricultural extension workers and development organizations can leverage the findings to implement sustainable farming practices that reduce agrochemical reliance. Policymakers and public health officials can use the data to develop policies regulating agrochemical use and advancing public health initiatives.

The study addresses key information gaps by providing empirical evidence on the prevalence of pesticide use and occupational exposure among small-scale farmers, demonstrating that many are at risk due to insufficient knowledge and inadequate practices. It highlights direct health risks associated with pesticide exposure and identifies factors such as age, gender, and lack of protective equipment as significant risks.

Additionally, the research reveals deficiencies in essential micronutrients like zinc, iron, manganese, and copper in local soil and crops, emphasizing the potential nutritional challenges faced by farming communities. It also shows that certain agrochemical treatments can significantly impact soil

microbial health and reduce the availability of crucial nutrients. This underscores the need for sustainable farming methods to maintain soil health and ensure nutrient availability for crops.

Overall, this study makes significant contributions by linking agrochemical exposure, soil micronutrient levels, and health outcomes among small-scale farmers. It provides a comprehensive analysis of how agricultural practices affect soil health, crop quality, and human health, highlighting the need for more sustainable farming approaches.

## **1.11. Outline of the dissertation**

The research aims to address several critical objectives concerning the agricultural and nutritional landscape of small-scale farming communities in the Kellem Wellega Zone, Western Ethiopia. Firstly, the study focuses on identifying and analyzing the research endeavors to analyze local soil nutrient dynamics and crop composition within small-scale farming communities. This includes assessing soil nutrient levels and understanding their impact on crop composition and nutritional quality. The goal is to elucidate potential pathways for enhancing agricultural productivity and food security in the region. Furthermore, the study examines the effects of agrochemicals on soil microbiological activity, micronutrient availability, and nutrient uptake by maize plants.

In addition, the study also aims to evaluate the prevalence of pesticide use and occupational exposure among small-scale farmers, identifying risk factors and potential health impacts. This involves measuring pesticide use, assessing levels of occupational exposure, and analyzing health implications for farmers and their communities.

Lastly, the research assesses pesticide residues in the blood of small-scale farmers in the Kellem Wellega Zone. By measuring pesticide levels in blood samples and identifying associated risk factors, the study aims to provide insights into the extent of pesticide exposure and its potential health risks. This involves investigating the impact of agrochemical use on soil health, crop nutrition, and overall agricultural sustainability, focusing on implications for small-scale farming communities in Western Ethiopia.

### **11.1.1. Soil and Crop Nutrient Analysis**

To address these objectives, To assess the soil micronutrient content and crop composition of small-scale farming communities in Western Ethiopia. we implemented a detailed and methodologically rigorous approach. We began by collecting representative soil and crop samples from various sub-sites within small-scale farming communities in Western Ethiopia. Soil properties, including pH, electrical conductivity, moisture, organic matter, and ash content, were measured using standardized procedures. We conducted microbial analysis through serial dilution and plating to assess bacterial and fungal populations. For nutritional assessment, we employed acid digestion and atomic absorption spectrophotometry to measure essential micronutrients such as manganese, zinc, iron, and

copper. The collected data were analyzed using chi-square tests and ANOVA to identify significant differences and ensure the reliability of the results.

### **11.1.2. Agrochemical Impact Study**

To investigate the impact of agrochemicals on soil microbiological activity, micronutrient availability, and nutrient uptake by maize (*Zea mays* L) crops. In a controlled experimental setup, we evaluated the effects of different agrochemical treatments on soil health and maize quality. Soil samples were used to cultivate maize under various treatment conditions, including compost, macronutrient fertilizers, micronutrient fertilizers, and glyphosates. Over a 120-day period, we collected soil and maize samples at regular intervals to monitor changes in microbial populations, soil pH, and nutrient content. One-way ANOVA was applied to analyze the impact of each agrochemical treatment on these parameters, revealing how different practices affect soil and crop health.

### **11.1.3. Pesticide Exposure Assessment**

To evaluate the prevalence of pesticide use and the level of occupational exposure among small-scale farmers, the study focused on their knowledge, practices, and symptoms related to pesticide use. Descriptive statistics, chi-square tests, and binary logistic regression analyses were performed to identify significant risk factors and associations between pesticide exposure and health outcomes. The results highlighted that inadequate knowledge and poor practices contributed significantly to higher exposure levels, underscoring the need for better education and safety measures.

### **11.1.4. Pesticide Residue Analysis**

To determine the levels of pesticides concentration in the blood of small-scale farmers in and to identify the associated risk factors contributing to pesticide exposure. The final phase of the research involved assessing pesticide residues in the blood of 240 small-scale farmers. We analyzed blood samples from both exposed and non-exposed groups using gas-liquid chromatography with an electron capture detector. The samples were prepared following standard extraction and cleanup procedures. Logistic regression models were used to explore the relationship between pesticide residues and demographic factors such as age, sex, education, and use of personal protective

equipment. The findings emphasized significant pesticide residues and identified key risk factors associated with higher exposure levels.

Together, these chapters offer a comprehensive analysis of soil and crop health, agrochemical impacts, pesticide exposure, and residue levels, providing valuable insights to improve agricultural practices and health outcomes for small-scale farming communities.

## **Chapter two: Soil Micronutrient Content and Crop Composition of Small-Scale Farming Communities in Western Ethiopia**

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## Abstract

**Introduction:** Micronutrients are essential for the growth and development of plants, animals, and humans. This study explores the micronutrient content in soils and crop yields of Eastern Ethiopia. It aims to understand soil micronutrient status and crop composition in small-scale farming communities of Western Ethiopia

**Methods:** Soil samples were collected randomly from selected sub-sites and pooled for analysis. Standardized procedures were employed to measure soil pH, electrical conductivity, moisture, organic matter, and ash content. Soil microbial analysis utilized serial dilution and plating techniques, while soil micro nutrient content (Mn, Zn, Fe, and Cu) was determined through acid digestion and atomic absorption spectrophotometry. The analysis was employed by using one-way ANOVA while maintaining a significance threshold of  $p < 0.05$ .

**Results:** This study investigated the physicochemical and proximate properties of various crops and soil samples from small-scale farms, revealing significant differences across several parameters. Potatoes exhibited the highest moisture ( $54.67 \pm 6.67$  g/kg) and organic matter content ( $94 \pm 0.09$ g/kg), while bean seeds had the lowest moisture content ( $20.33 \pm 2.91\%$ ), but the highest ash content ( $23.67 \pm 1.2$ g/kg). Bean seeds had the highest manganese ( $14.29 \pm 4.22$  mg/kg) and crude protein content ( $15.08 \pm 1.83$  g/100g), whereas potatoes had the lowest levels of both manganese ( $1.95 \pm 1.23$  mg/kg) and crude protein ( $0.88 \pm 0.52$  g/100g). Maize was the richest source of zinc ( $20.37 \pm 7.45$  mg/kg), and sorghum had the highest iron ( $30.24 \pm 11.57$  mg/kg) and crude fat content ( $3.23 \pm 0.69$  g/100g). Millet had the lowest zinc ( $0.96 \pm 0.33$  mg/kg) and iron content ( $4.97 \pm 1.67$  mg/kg). The crude fiber content was highest in maize ( $6.67 \pm 0.45$  g/100g) and lowest in potatoes ( $0.87 \pm 0.19$ g/100g). Millet provided the highest total energy content ( $264.86 \pm 13.33$  kcal/100g), while potatoes provided the least ( $130.98 \pm 25.55$  kcal/100g).

The soil analysis generally revealed significant variations in micronutrient levels, as well as pH, microbial biomass, and organic matter. A considerable proportion of the soil samples had low levels of the essential micro nutrients manganese, zinc, iron, and copper. Specifically, 41.7% of the samples had low manganese levels ( $<60$ ), 61.7% had low zinc levels ( $<1.5$ ), and 66.7% had low iron levels ( $<25$ ) in ppm. Copper levels were also low ( $<1$  ppm) in 63.3% of the samples. Most soil samples exhibited low moisture content ( $<35\%$ ) and were classified as acidic (pH  $<6$ ). Optimal

levels of organic matter (3-10%) were found in 65% of the samples, while 86.7% of the samples had unwanted high ash content (>15%). The variation in pH and organic matter often explained the low plant availability of selected micro nutrients.

**Conclusions:** The findings highlight the need for targeted soil and crop management strategies to enhance micronutrient availability and improve agricultural productivity and quality. Regular soil testing of micro nutrient content, implementing soil amendment strategies, and using organic fertilizers are recommended to optimize soil health, crop yield, and crop nutritional quality.

**Keywords:** Micronutrient, Soil, Food samples, Small-scale farmers, Western Ethiopia

## 2.1. Introduction

Micronutrients are essential nutrients that are needed in small amounts for life. Deficiency of micronutrients in soil, plants, animals, and humans is a global problem of many countries with different magnitudes of severity (Arigony et al., 2013). The deficiency is often due to improper soil management, including intensive cultivation without proper replenishment of soil nutrients, limited crop rotations, and less recycling of organic matter (Geremew, 2021). The micronutrient deficiency in soils and crops causes, worldwide, a reduced yield and quality of crops

The problem of micronutrient deficiencies in food and feed plants is widespread in Africa (Berkhout et al., 2017, Berkhout et al., 2019). The fertility of soils in Ethiopia is poorly exacerbated by progressively emerging micronutrient deficiencies due to agricultural intensification, and catalysing removal. According to the latest estimates, about 1.8 million tons of micronutrients are removed each year by yield (Aleminew and Alemayehu, 2020, Gurmessa, 2021, Abate and Anteneh, 2024).

Especially, the declining levels of zinc, iron, copper, and manganese in agricultural soil have shed significant light on the complex factors contributing to soil micronutrient deficiencies and their impacts on crop productivity, soil health, as well as animal and human nutrition. Factors such as erosion, intensive agricultural practices, inadequate fertilization, and pollution have depleted soil reserves of these micronutrients (Aleminew and Alemayehu, 2020).

Additionally, climate change may exacerbate soil micronutrient deficiencies by altering the nutrient cycling through changes in soil moisture and temperature (Jansson and Hofmockel, 2020). Furthermore, nutrient leaching, soil acidification, and loss of soil organic matter may diminish soil microbial activity, and the bioavailability of micronutrients, exacerbating symptoms of deficiencies in plants, and negatively affecting crop growth, yield, as well as nutritional quality (Lal, 2009, Wani et al., 2017, Samota et al., 2024). Interactions between soil micronutrient levels and human malnutrition are coupled to reduced levels of essential micronutrients in crops, impacting malnutrition and associated health issues (White and Brown, 2010, Kumssa et al., 2015).

Soil bacteria and fungi play a crucial role in nutrient cycling and general soil health. A decrease in microbial diversity and functionality compromises essential soil ecosystem services, leading to decreased soil fertility, increased susceptibility to soil-borne diseases, and reduced agricultural

productivity (Haq et al., 2014, Abebe et al., 2020). A decline in soil bacteria and fungi may be attributed to the intensive agronomic cultivation, i.e. by intensive tillage, pesticide use, and monoculture practices (Johnson, et2020, Delelegn et al., 2018). Additionally, reductions in soil organic matter content due to e.g. land degradation, deforestation, and unsustainable agricultural practices deprive soil microorganisms of essential nutrients (Zhao et al., 2014, Condrón et al., 2010, Shahane and Shivay, 2022). Changes in temperature and precipitation patterns also influence microbial activity and distribution. These changes can favour the proliferation of certain microbial taxa while suppressing others, resulting in shifts in soil microbial communities (Mekala and Polepongu, 2019, Abatenh et al., 2018).

Recent research in Ethiopia revealed a decline in pH, electrical conductivity, moisture, and ash content of agricultural soil (Abate et al., 2017). These declines may be attributed to increased soil erosion, and unsustainable agricultural practices, which all negatively impact soil nutrient availability and crop productivity (Gurmessa, 2021, Tesfahunegn, 2014). Particularly the reduction in soil moisture levels, caused by climate variability, deforestation, and unsustainable land use practices, worsens the agricultural challenges in the Ethiopian region (Tadese et al., 2020).

However, the more traditional farming methods usually used by smallholder farmers in Ethiopia also led to low content of organic matter in soils and nutrient deficiencies by human (Abate and Anteneh, 2024, Gurmessa, 2020). Local human dietary habits that rely heavily on staple grains like teff, wheat, barley, sorghum, maize, and potato, which are low in nutrients, contribute to an overall poor nutritional value of diets. The quite monotonous diet entails low levels of essential micronutrients as well as protein, carbohydrates, fiber, and fats in Ethiopian human beings (Sibhatu and Qaim, 2018).

Thus, understanding the relationship between local soil and crop nutritional quality is crucial in order to improve human nutrition in the western part of Ethiopia. There is a lack of data regarding the concentrations of vital micro minerals, such as zinc, iron, manganese, and copper, in cereals, legumes, and tubers commonly cultivated and consumed in the Kellem Wellega zone. The physicochemical properties and proximate composition of yield samples from this area have not been thoroughly evaluated. Limited information is available on certain physicochemical attributes of the local soil, including microbial activity, electrical conductivity, organic content, ash, and moisture levels, and essential trace elements. To address these gaps, this study aimed to provide insights into

the status of local soil and crop micro nutrients in the western part of Ethiopia. Here, the micronutrient content in soils from small-scale farms in the Western part of Ethiopia, with various crop productions were investigated.

### **2.1.1. Materials and methods**

#### **2.1.2. Study area settings**

The sampling was conducted in June 2023 across the Sayo, Hawa Gelan, and Dale Wabara districts within the Kellem Wellega zone of Western Ethiopia. Kellem Wellega Zone in Oromia, western Ethiopia, has a tropical highland climate with bimodal rainfall ranging from 1,200 to 2,000 mm annually. The topography is diverse, with elevations between 1,200 and 2,600 meters, featuring plains, hills, and mountains (Ademe et al., 2020). Agriculture, mainly subsistence-based, is the key economic activity, with crops like maize, teff, sorghum, and coffee, the latter being a major cash crop. To enhance agricultural output, farmers commonly employ pesticides including insecticides, herbicides, and fungicides to combat pests, weeds, and fungal infections, respectively. The zone's vegetation includes tropical highland forests, though deforestation for farming is widespread. Despite fertile Nitisol soils in the highlands, socioeconomic challenges such as limited infrastructure and market access hinder development (Asefa et al., 2020). The study area map is referenced in Figure 2.1

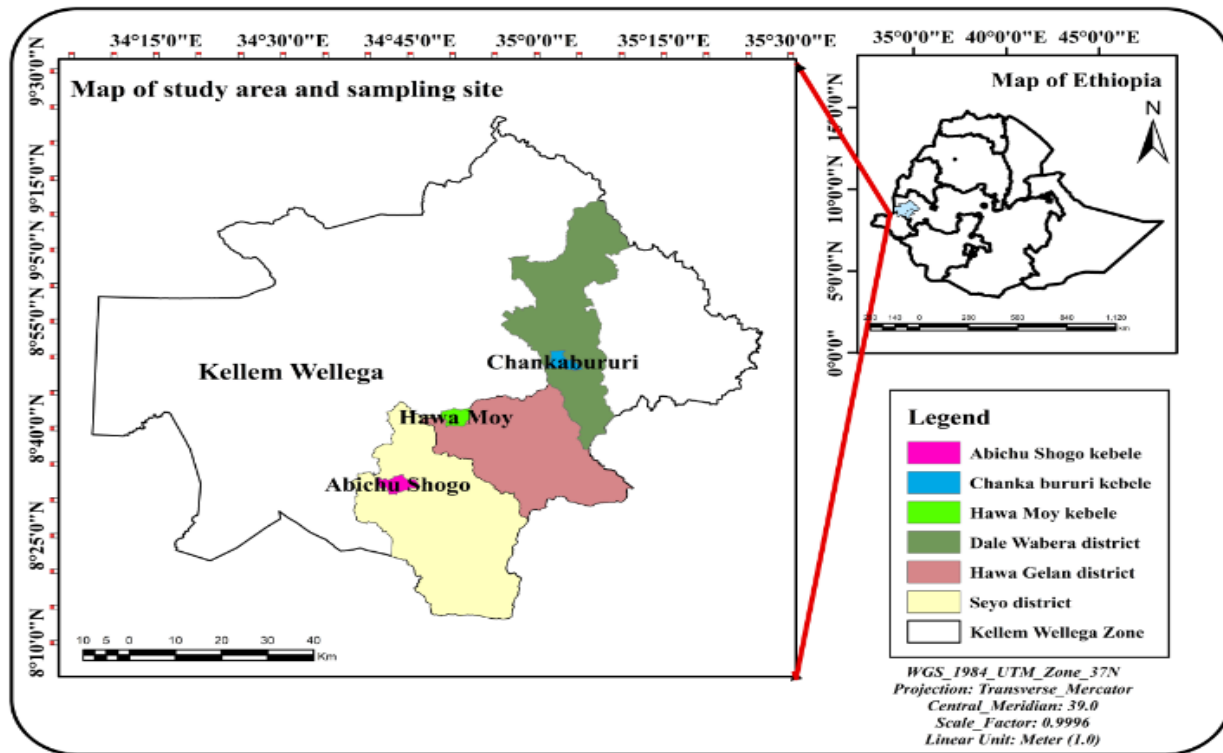


Figure 2.1.: Study Area Map for Sayo, Hawa Gelan, and Dale Wabara districts in Kellem Wellega zone, Western Ethiopia in 2021

### 2.1.3. Collection and preparation of crop yield and soil samples

Approximately one kg samples of cereals (sorghum, maize), legumes (red kidney beans), and tubers (onion, potato) were collected from each of the ten different sites within the study area. Similarly, about one kg of soil samples were taken from a 15 cm depth for the same study area. Finally, all samples were stored in polythene bags and transported to the laboratory for analysis.

### 2.1.4. Moisture, ash, and organic contents of crop yield and soil samples

The moisture content of crop yield was determined by cutting them into small pieces, placing them in acid-washed porcelain crucibles, and oven-drying at 105°C for 24 hours until constant weight (Schmugge et al., 1980). Similarly, the soil samples were dried by spreading them in a thin layer of clean trays, allowing them to air-dry at room temperature. Once dry, gently crush any clumps and sieve the soil through a 2 mm sieve to remove coarse debris, and through a 0.5 mm sieve (Carter and Gregorich, 2007). For all samples, the dried samples were stored in desiccators for subsequent

analysis. Five grams of ground samples were then ashed at 550°C in a muffle furnace for four hours, cooled in desiccators, and measured for ash and organic matter (William, 1980). Finally, moisture, ash, and organic contents of the soil samples analyzed were categorized into different levels based on established scientific procedures (Brady and Weil, 1996, Kallenbach et al., 2016).

#### **2.1.5. Soil pH and electrical conductivity**

The soil samples' pH and electrical conductivity were measured using methods from (Somenahally et al., 2011) and procedures from (Onet et al., 2019, Ashworth et al., 2017), respectively. Finally, soil pH and electrical conductivity analyzed were categorized into different levels based on established scientific procedures (Burt, 2014, da Rocha et al., 2023).

#### **2.1.6. Soil microbial biomass analysis**

Soil samples were taken from the arable layer (0-15 cm) using a 2 cm diameter steel auger during crop vegetation. Four subsamples per plot were homogenized, and mixed, and a 1 g (dry weight) suspension in 10 ml of sterile water was shaken at 170 rpm and then filtered (Pepper et al., 1995). One ml of the suspension was serially diluted (ten-fold) and used to estimate bacterial and fungal populations via the spread-plate method (Bryant et al., 1984). Finally, microbial analysis of soil samples was categorized into low and optimum levels based on established scientific procedures (Rousk et al., 2009).

#### **2.1.7. Crop yield micronutrient content**

Zn, Fe, Mn, and Cu contents were measured using acid digestion methods. Five grams of ground samples were weighed, transferred to crucibles, and dry-ashed at 550°C for 6 hours. The cooled ash was moistened with water and then digested with 2.5 ml concentrated HNO<sub>3</sub> on a hot plate at 90-95°C for 1 hour. After dissolving the ash in 5 ml of 9.25% HCl and further digestion, the cooled mixture was diluted to 50 ml and filtered. Samples were prepared in triplicate, and blanks were included to check for contamination, with analysis conducted using an atomic absorption spectrophotometer.

#### **2.1.8. Soil sample micronutrient analysis**

Soil samples were collected and dried at 105°C for 24 hours, ground to a fine powder, and then dry ashed at 550°C for 6 hours. After cooling, the ash was digested with HNO<sub>3</sub> and HCl, filtered, and analyzed for Zn, Fe, Mn, and Cu using an atomic absorption spectrophotometer (Gonfa et al., 2015). Finally, soil micronutrients analyzed were categorized into low and optimum levels based on established scientific procedures (Bulta et al., 2016).

#### **2.1.9. Preparation of standards and analysis of samples**

A stock solution containing Zn, Mn, Fe, and Cu was prepared by dissolving 10 mg/l of ZnSO<sub>4</sub>·7H<sub>2</sub>O, MnSO<sub>4</sub>·H<sub>2</sub>O, CuSO<sub>4</sub>·5H<sub>2</sub>O, and FeSO<sub>4</sub>·7H<sub>2</sub>O in distilled water. Subsequently, five different working standards (containing 10, 20, 30, 50, and 100 mg/L) were prepared by diluting the stock standards to 1,000 ml with deionized water. The AAS was configured to the operating wavelengths of iron (248.3), manganese (279.48), copper (324.7), and zinc (213.9) in nm. From the calibration graph constructed, the concentrations of the samples were determined. This calibration curve facilitated the determination of the concentrations of zinc, manganese, copper, and iron.

#### **2.1.10. Determination of crop yield nutritional quality parameters**

During sample preparation, the samples were homogenized for various nutritional analyses, with essential operations including drying and grinding tailored to the sample type and specific analyses required. These steps were conducted according to the methods outlined in (AOAC, 2005). For instance, total protein in maize samples was determined using the Kjeldahl method, where each sample was digested with CuSO<sub>4</sub>, K<sub>2</sub>SO<sub>4</sub>, and H<sub>2</sub>SO<sub>4</sub> at 420°C for 75 minutes.

After distillation with NaOH and hot boric acid, the resulting ammonia was titrated with standardized HCl, and protein content was quantified using an automatic Kjeldahl analyzer. Lipids were extracted from moisture-free samples using diethyl ether, followed by drying and cooling steps (AOAC, 2005). Crude fiber analysis involved igniting the residue from a fat-free sample boiled with H<sub>2</sub>SO<sub>4</sub> and NaOH, with calculations based on weight changes (AOAC, 2005). Additionally, total carbohydrates were calculated by subtracting percentages of crude protein, moisture, ash, crude fat, and fiber from 100. Furthermore, the gross energy value (in kilocalories) was computed using conversion factors specified in (FAO, 2003). 4 kcal/g for protein, 9 kcal/g for fat, 4 kcal/g for carbohydrates, and 2 kcal/g for fiber.

$$\text{Gross energy} \left( \frac{\text{kcal}}{100\text{g}} \right) \\ = 9(\text{crude fat}) + 4(\text{crude protein}) + 4(\text{Total carbohydrate}) + 2(\text{crude Fiber})$$

### 2.1.11. Statistical analysis

Initially, the data were entered into EPI-INFO version 7 and subsequently imported into the Statistical Package for the Social Sciences version 26 (SPSS). Then, descriptive statistics, encompassing mean, range, and standard deviations, were computed. Finally, a non-parametric test, specifically Kruskal-Wallis's test of one-way ANOVA, was used to determine significant associations between soil deficiencies and parameters such as pH, microbial counts, organic matter, and ash contents. Additionally, significant associations between physicochemical characteristics and the proximate composition of yield samples collected from small-scale farmers were analyzed using one-way ANOVA.

## 2.2. Results

### 2.2.1. Nutritional quality of yield

Yield moisture content varied significantly among the crops, with potatoes having the highest moisture content ( $54.67 \pm 6.67\%$ ) and bean seeds the lowest ( $20.33 \pm 2.91\%$ ) ( $p = 0.004$ ). Ash content also showed significant variation ( $p = 0$ ), with bean seeds containing the highest ash content ( $23.67 \pm 1.2\text{g/kg}$ ), suggesting a higher mineral content, while potatoes had the lowest ( $6 \pm 0.06\text{g/kg}$ ). Organic matter content was highest in potatoes ( $94 \pm 0.09\text{g/kg}$ ) and lowest in bean seeds ( $76.33 \pm 1.20\text{g/kg}$ ) ( $p = 0$ ).

There was high variability in zinc content for maize, which emerged as the nutrient-rich crop ( $20.37 \pm 7.45\text{mg/kg}$ ), while millet had the lowest ( $0.96 \pm 0.33\text{mg/kg}$ ) ( $p = 0.02$ ). Iron content in sorghum has the highest levels ( $30.24 \pm 11.57\text{g/kg}$ ) and millet the lowest ( $4.97 \pm 1.67\text{g/kg}$ ) showing significant differences ( $p = 0.03$ ). However, manganese content varied significantly ( $p = 0.013$ ), with bean seeds having the highest levels ( $14.29 \pm 4.22\text{mg/kg}$ ) and potatoes the lowest ( $1.95 \pm 1.23\text{mg/kg}$ ).

Crude protein content was significantly different ( $p = 0.002$ ), with bean seeds highest ( $15.08 \pm 1.83\text{g/100g}$ ) and potatoes lowest ( $0.88 \pm 0.52\text{g/100g}$ ). Crude fat content also differed significantly ( $p =$

0.014), with sorghum having the highest fat content ( $3.23 \pm 0.69$  g/100g) and potatoes the lowest ( $0.14 \pm 0.04$  g/100g). Crude fiber content was significantly higher in maize ( $6.67 \pm 0.45$  g/100g) and lower in potatoes ( $0.87 \pm 0.19$  g/100g) ( $p = 0.01$ ). Additionally, the total energy content was significantly different ( $p = 0.008$ ), with millet providing the most energy ( $264.86 \pm 13.33$  g/100g) and potatoes the least ( $130.98 \pm 25.55$  g/100 g) (Table 2.1).

Table 2.1: Physico-chemical characteristics and proximate composition of yield samples that were collected from small-scale farmers

Parameters	Maize	Sorghum	Millet	Potato	Onion	Bean seed	Sig.
Moisture contents (MC, g/kg)	30.67±2.85	41±10	22.33±3.33	54.67±6.67	46±0.58	20.33±2.91	0.004*
Ash contents (AC, g/kg)	7±0.58	13.33±0.33	12±0.04	6±0.06	8±0.02	23.67±1.20	0*
Organic matter (OM, g/kg)	93±0.58	86.67±0.33	88±0.05	94±0.09	92±0.7	76.33±1.20	0*
Zinc (Zn, mg/kg)	20.37±7.45	16.03±4.88	0.96±0.33	10.34±3.3	3.52±1.67	13.36±3.91	0.02*
Iron (Fe, mg/kg)	5.3±1.66	30.24±11.57	4.97±1.67	10.50±5.53	6.13±3.10	9.36±5.29	0.03*
Copper (Cu, mg/kg)	2.56±0.82	3.01±1.04	3.46±1.67	3.145±0.92	2.17±1	4.37±1.23	0.82
Manganese (Mn, mg/kg)	3.48±1.39	6.21±2.26	6.88±2.01	1.95±1.23	5.43±1.73	14.29±4.22	0.013*
Crude protein (PC, g/100g)	8.35±0.39	8.14±0.70	11.01±1.74	0.88±0.52	8.52±1.36	15.08±1.83	0.002*
Crude fats (CF, g/100g)	1.72±0.37	3.23±0.69	2.07±0.82	0.14±0.04	0.78±0.17	2.39±0.56	0.014*
Crude fibers (CF <sub>b</sub> , g/100g)	6.67±0.45	3.49±0.76	4.09±1.49	0.87±0.19	3.39±1.16	6.23±0.99	0.01*
Carbohydrates (CHO, g/100g)	45.60±3.85	30.81±9.28	48.49±3.51	31.10±5.85	33.31±1.79	32.3±1.04	0.091
Total Energy (kcal/100g)	244.58±11.8	191.82±	264.86±13.	130.98±25.5	181.12±0.79	223.49±13.7	0.008*
	6	37.81	33	5		4	

Keys: electrical conductivity (EC), moisture contents (MC), Organic matter (OM), total fats (TF), Crude Fibers (CF<sub>b</sub>), iron (Fe), Manganese (Mn), Copper (Cu), Zinc (Zn), level of significance at p-value < 0.05(\*)

### 2.2.2. Soil properties

Soil samples reveal significant micronutrient levels, pH, microbial biomass, and organic matter variations. Manganese concentrations in soil samples were categorized into two levels: less than 60 ppm (considered low) and between 100 and 300 ppm (considered optimum). Among the samples, 41.7% had low levels, while 58.3% were within the optimum range. Similarly, zinc levels of soil samples in ppm were classified as either low ( $< 1.5$ ) or optimum (1.5 - 10). A considerable proportion, 61.7%, of the samples fell into the low category, while 38.3% were within the optimum range.

The iron content was divided into low ( $< 25$ ppm) and optimum (25 - 300ppm) levels. The results showed that 66.7% of the samples had low iron levels, whereas 33.3% were within the optimum range. Copper levels in ppm were categorized as low ( $< 1$ ) and optimum (1- 20 ppm). The analysis revealed that 63.3% of the soil samples had low copper levels, while 36.7% were within the optimum range (Bulta et al., 2016).

Total microbial biomass carbon (TMBC) was classified as low ( $< 10^5$  cfu/g) or medium ( $> 10^5$ cfu/g). The findings indicated that 23.3% of the samples had low TMBC, while 76.7% had medium levels. Total microbial fungal content (TMFC) was divided into low ( $< 10^4$ cfu/g) and medium ( $> 10^4$  cfu/g) categories. The analysis showed that 53.3% of the samples had low TMFC, while 46.7% had medium levels.

The moisture content was assessed as either low ( $< 35\%$ ) or medium (36 - 42%). An overwhelming 95% of the samples had low moisture content, with only 5%, i.e. falling into the medium range. The soil pH was categorized into acidic ( $< 6$ ), slightly neutral (6 - 7.2), neutral (7.3 - 7.9), and basic ( $> 8.5$ ). The results showed that 76.7% of the samples were acidic, 10% were slightly neutral, 5% were neutral, and 8.3% were basic.

Soil organic matter content was categorized as beneficial (2 - 3%), optimal (3 - 10%), high or excessive (10 - 15%), and unwanted ( $> 15\%$ ). The results showed that 65% of the samples had optimal OM levels, 21.7% had high or excessive levels, 10% were unwanted high, and only 3.3% were at beneficial levels. Ash content was evaluated as good (1 - 5%) or unwanted ( $> 15\%$ ). The findings indicated that 86.7% of the samples had unwanted high ash content levels, while only 13.3% were regarded as good. Electrical conductivity (EC) was categorized into low ( $< 100$   $\mu\text{s}/\text{cm}$ )

and optimum (100 - 300  $\mu\text{s}/\text{cm}$ ). The results showed that 51.7% of the samples had low EC, while 48.3% were within the optimum range (Table 2.2).

Table 2.2: Physicochemical properties of soil samples of Kellem Wellega zone, western Ethiopia

Explanatory variables		F	%
Mn (ppm)	< 60 (Low)	25	41.7
	100 - 300 (Optimum)	35	58.3
Zn (ppm)	< 1.5 (Low)	37	61.7
	1.5 - 10 (Optimum)	23	38.3
Fe (ppm)	< 25 (Low)	40	66.7
	25 – three hundred (Optimum)	20	33.3
Cu (ppm)	<1 (Low)	38	63.3
	1 – 20 (Optimum)	22	36.7
MC (%)	< 35 (Low)	57	95
	36 - 42 (Medium)	3	5
pH	<6 (Acidic)	46	76.7
	6 - 7.2 (Slightly neutral)	6	10
	7.3 - 7.9 (Neutral)	3	5
	> 8.5 (Basic)	5	8.3
TMBC (cfu/g)	<10 <sup>5</sup> (Low)	14	23.3
	>10 <sup>5</sup> (Medium)	46	76.7
TMFC (cfu/g)	<10 <sup>4</sup> (Low)	32	53.3
	> 10 <sup>4</sup> (Medium)	28	46.7
OM (%)	2 – 3 (Beneficiary for soil)	2	3.3
	3 - 10 (Optimal)	39	65
	10 - 15 (High or excessive)	13	21.7
	> 15 (Unwanted)	6	10
AC (%)	1- 5 (Good for microbial)	8	13.3
	>15 (Unwanted)	52	86.7
EC ( $\mu\text{s}/\text{cm}$ )	<100 (Low)	31	51.7

	> 100- 300 (Optimum)	29	48.3
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**Keys:** Manganese (Mn), Zinc (Zn), iron (Fe), Copper (Cu), moisture contents (MC), total mesophilic bacteria count (TMBC), total mesophilic fungus count (TMFC), moisture contents (MC), and Organic matter (OM), Ash contents (AC), electrical conductivity (EC), F( frequency), %(Percentage)

### 2.2.3. Correlation between bio physicochemical characteristics

The Pearson correlation coefficients (r) showed that soil Manganese (Mn) exhibits a strong positive correlation with Zinc (Zn) (0.67\*\*) and Iron (Fe) (0.6\*\*). Mn is also significantly correlated with Copper (Cu) (0.50\*\*) and soil Organic Matter (OM) (0.31\*). Conversely, Mn shows a significant negative correlation with Electrical Conductivity (EC) (-0.47\*\*).

Zinc (Zn) demonstrates significant positive correlations with Fe (0.68\*\*), Cu (0.54\*\*), Total Mesophilic Bacterial Count (TMBC) (0.46\*\*), Total Microbial Biomass Fungal Count (TMFC) (0.43\*\*), and soil OM (0.54\*\*). Zn has a significant negative correlation with soil pH (-0.49\*\*), meaning that the higher Zn levels are found in more acidic soils.

Iron (Fe) is positively correlated with Cu (0.49\*\*), soil OM (0.32\*), and Ash Content (AC) (0.28\*). Fe shows significant negative correlations with pH (-0.56\*\*) and EC (-0.4\*\*), indicating that higher Fe concentrations are, as for Zn, also associated with lower pH (more acidic) and lower EC soils. Copper (Cu) correlates positively with soil OM (0.37\*\*) and Zn (0.54\*\*). As Cu does not show a significant correlation with pH, shows that its levels are relatively unaffected by soil acidity. Soil Moisture Content (MC) has weak correlations with most parameters (Table 2.3).

Table 2.3: Correlation between some selected physicochemical characteristics of the soil of Kellem Wellega western Ethiopia

Parameters	Mn	Zn	Fe	Cu	MC	pH	TMBC	TMFC	OM	ACC	EC
Mn	1										
Zn	0.67**	1									
Fe	0.6**	0.68**	1								
Cu	0.50**	0.54**	0.49**	1							
MC	0.19	-0.02	-0.16	0.14	1						
pH	-0.39**	-0.49**	-0.56**	0.1	-0.12	1					
TMBC	-0.23	0.46**	-0.28*	-0.15	0.13	-0.12	1				
TMFC	0.25	0.43**	0.12	0.19	0.25	0.15	-0.12	1			
OM	0.31*	0.54**	0.32*	0.37**	0.09	0.04	0.02	.39**	1		
AC	0.17	0.31*	0.28*	0.1	-0.36**	0.18	-0.22	0.07	.35**	1	
EC	-0.47**	-0.08	-0.4**	-0.11	-0.07	-0.24	-0.26*	0.03	-0.01	0.09	1

Keys: \* Correlation is significant at the 0.05 level, \*\* Correlation is significant at the 0.01 level, Manganese (Mn), Zinc (Zn), iron (Fe), Copper (Cu), moisture contents (MC), Organic matter (OM), Ash contents (AC), electrical conductivity (EC)

#### **2.2.4. Impact of selected physicochemical properties on soil micronutrient availability**

Table 2.4 shows results from the one-way ANOVA and significant differences in various soil parameters between the lowest (L) and optimum (Opt) groups for micronutrient concentrations of manganese (Mn), zinc (Zn), iron (Fe), and copper (Cu) are revealed. Soil pH exhibited highly significant differences between the lowest and optimum groups for Mn, Zn, and Fe, with p-values all below 0.05.

The total microbial biomass carbon (TMBC) showed significant differences for Zn and Fe. TMBC was higher in the lowest group for Zn compared to the optimum group, while for Fe, the TMBC was higher in the optimum group compared to the lowest group.

The total microbial fungal content (TMFC) showed significant differences for Zn ( $p = 0.001$ ), with the optimum group having higher fungal content than the lowest group. Soil OM significantly differed between the lowest and optimum groups for all the micronutrients analysed. The optimum groups consistently show higher OM levels for Mn, Zn, Fe, and Cu. Ash content (AC) demonstrated significant differences for Zn and Fe, with higher values in the optimum groups compared to the lowest groups. Finally, electrical conductivity (EC) showed significant differences for Mn and Fe, with lower EC values in the optimum groups compared to the lowest groups.

Table 2.4: one-way ANOVA analysis of micronutrients of soil between the lowest (L) and optimum (Opt) Groups

Parameters	Mn			Zn			Fe			Cu		
	<60 (L)	100-300 (Opt)	p-value	<1.5(L)	1.5- 10 (Opt)	p-value	<25 (L)	25 - 300 (Opt)	P value	<1 (L)	1 -20 (Opt)	P value
MC (%)	29	31.57	0.14	30.62	30.3	0.86	31.25	29.00	0.21	29.79	31.73	0.27
pH	23.5	35.50	0*	25.61	38.37	0*	25.45	40.60	0*	29.08	32.95	0.26
TMBC (cfu/g)	33.9	28.07	0.08	35.07	23.15	0*	33	25.50	0.032*	31.97	27.95	0.24
TMFC (cfu/g)	26.1	33.64	0.06	25.42	38.67	0.001*	29.25	33.00	0.36	28.34	34.23	0.15
OM (% , g/kg)	25.56	34.03	0.03*	24.41	40.3	0*	26.89	37.73	0.007*	26.64	37.16	0.01*
AC (% , mg/kg)	28.5	31.93	0.20	28.01	34.5	0.018*	28.5	34.50	0.033*	29.76	31.77	0.47
EC (µs/cm)	38.8	24.57	0*	31.41	29.04	0.56	34.75	22.00	0.002*	31.79	28.27	0.39

Key: Moisture Contents (MC), Total Mesophilic Bacteria Count (TMBC), Total Mesophilic Fungus Count (TMFC), Organic Matter (OM), Ash Content (AC), Electrical Conductivity (EC), and Low (L), Optimum (Opt), level of significance at p-value < 0.05 (\*)

### 2.3. Discussion

This study highlights the significant differences in the quality characteristics and proximate composition of crop yield samples collected from the small-scale farmers. According to (Marschner and Rengel, 2023), soil water content influences plant nutrient availability and uptake, which might explain the higher moisture content in crops like potatoes that require more water.

High ash content indicates a high mineral content, which can be linked to the soil's fertility and the plant's ability to accumulate minerals. (Brady et al., 2008), noted that crops grown in mineral-rich soils tend to have higher ash content. This signifies the mineral content of yields, and the variation observed can be linked to differences in soil composition, cultivation practices, and plant genetics (Khoshgoftarmanesh et al., 2010). Legumes like bean seeds tend to accumulate more minerals from the soil, resulting in higher ash content (Hall et al., 2017), whereas potatoes may have lower ash content due to their lower mineral uptake, but can also be a result of processing methods that may remove mineral-rich outer layers.

Crop zinc (Zn) levels varied significantly. The plant availability of Zn is strongly influenced by soil pH. According to (Noulas et al., 2018), higher pH levels can reduce Zn availability, which might explain the lower Zn levels in some crops. (Colombo et al., 2014) highlighted how Fe availability is also affected by soil pH, which can vary widely between different crops and regions. (Sparrow and Uren, 2014), explained that Mn availability decreases in soils with high pH levels, which might account for the lower Mn levels in certain crops.

The significant variations among the crops in proximate composition ( crude protein (PC), crude fats (CF), and crude fibers (CFb) might be due to nutrient composition in crops being influenced by genetic factors and soil nutrient availability (Rengel and Marschner, 2005). The crop total energy content varies significantly among crop yields and is usually determined by their carbohydrate, protein, and fat content, which again are influenced by the soil nutrient condition and agronomic practices (Kaur, 2016).

In Figure 2 the measured micronutrient concentrations in various crops were compared with FAO 2001 guidelines, revealing significant disparities. Firstly, manganese (Mn) levels in crops like sorghum, millet, and onion are notably lower than the FAO guidelines. This can here be attributed to

soil pH and organic matter content. According to (Sparrow and Uren, 2014), Mn availability decreases in soils with high pH levels.

The highly variable yield of copper (Cu) content is influenced by soil texture and organic matter content. Studies by (Bravin et al., 2012), indicate that Cu tends to bind strongly with organic matter, which tends to reduce its bioavailability. The yield of iron (Fe) concentrations was significantly lower in crops like maize, millet, and onion compared to the FAO guidelines. The bioavailability of Fe in soil is highly dependent on soil pH and redox conditions. As noted by (Colombo et al., 2014), Fe solubility decreases in well-drained, aerated soils, which are common in many agricultural areas. This could lead to Fe deficiencies in the crops grown in these conditions.

The zinc (Zn) levels in maize and sorghum are below the FAO guidelines. Zinc availability is influenced by soil pH and phosphate levels. According to (Alloway, 2008b), high soil pH and phosphate fertilization can reduce Zn availability. This suggests that regions with high pH soils or intensive phosphate fertilization practices might face Zn deficiencies reflected in the lower Zn levels in these crops.

Finally, bean seeds show higher levels of Mn, Cu, Fe, and Zn compared to other crops, but are still far below of FAO guidelines. This could be due to the legumes' ability to fix nitrogen and improve soil organic matter, enhancing micronutrient availability (Virk et al., 2021). The differences in micronutrient levels can be explained by soil properties, such as pH and organic matter content, crop-specific nutrient uptake, and local agronomic practices. This disparity highlights the importance of incorporating a variety of yields into the human diet to meet e.g. the copper requirements for optimal health and well-being (Adamu et al., 2021, Afata et al., 2023, Bedassa et al., 2017).

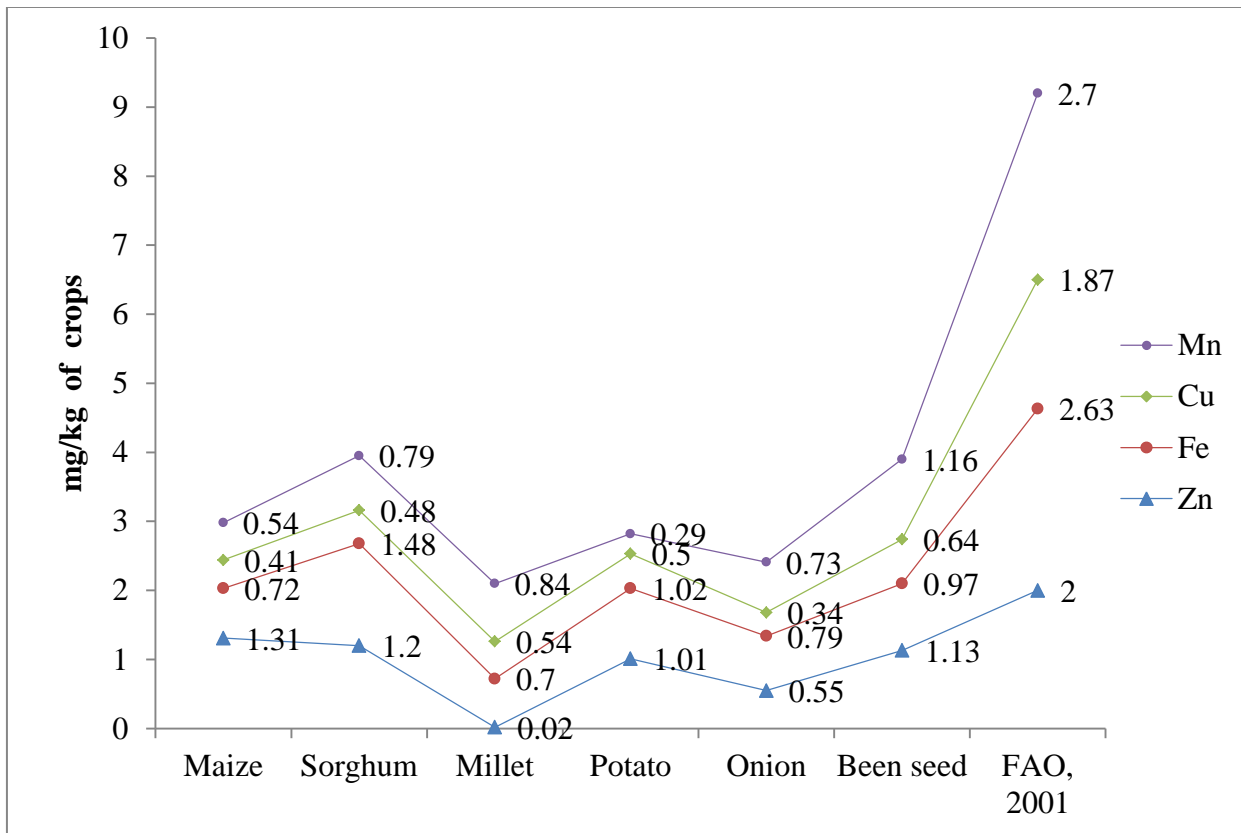


Figure 2.2: A figure that compares the micronutrients of some selected yield samples with FAO, 2001 guide lines (Note: To easily compare the results, the graph was computed using logarithms)

Regarding the soil biophysicochemical properties, the pH was significantly associated with the levels of Mn, Zn, and Fe. The pH levels tend to reduce the solubility and availability of Zn, Mn, and Fe (Colombo et al., 2014). In this study, 76.7% of the soil samples had acidic conditions, known to facilitate the solubility and uptake of micronutrients (Hartemink and Barrow, 2023).

The increase in soil acidity could exacerbate micronutrient deficiencies, posing significant challenges to agricultural productivity (Abate et al., 2017). Agricultural practices such as frequent tillage, removal of crop residues, and continuous cropping can degrade soil quality, e.g. reducing its capacity to buffer hydrogen ions ( $H^+$ ) (Bhattacharyya et al., 2022, McCauley et al., 2009). Moreover, increasing fertilizer application rates, particularly ammonia-N-containing fertilizers like urea and DAP, further contribute to soil acidity by release of hydrogen ions ( $H^+$ ) during plant uptake or nitrification (for the urea) (Yadav et al., 2020, Fageria and Baligar, 2008).

In Ethiopia, urea is commonly used as a nitrogen source, releasing significant amounts of hydrogen ions ( $H^+$ ) into the soil solution, thereby decreasing soil pH. Additionally, the widespread use of sulphate-containing fertilizers, in response to government initiatives aimed at improving sulfur levels in agricultural soils, can exacerbate soil nutrient leaching in the long term (Gurmessa, 2021). Furthermore, atmospheric deposition of sulfur dioxide ( $SO_2$ ) further contributes to nutrient leaching and soil acidity, compounding the issue (Goulding, 2016).

The total mesophilic bacterial count (TMBC) was higher in the group of lowest soil Zn but higher in the optimum group of Fe. This revealed microbial activity in soil can influence nutrient cycling and availability (Smith, 2018). The higher TMBC in the lowest group for Zn might indicate more active microbial processes that affect Zn dynamics differently compared to Fe.

23.3% of all the soil samples had total mesophilic bacteria levels below  $10^5$  cfu/g. Insufficient levels of bacteria can disrupt essential soil processes for plant growth and ecosystem functioning. Factors such as pesticide use, soil compaction, or poor organic matter can contribute to low bacterial populations (Hartmann and Six, 2023). Consequently, decreasing soil fertility, and nutrient availability, and compromising plant health (Reeve et al., 2016).

Also, the total microbial fungal content (TMFC) demonstrated significant differences for Zn with the optimum group having higher fungal content than the lowest group. This is consistent with findings by (Dotaniya and Meena, 2015), who highlighted the role of soil fungi in enhancing nutrient availability, particularly Zn, through various biochemical processes. The higher fungal content in the optimum group contributes to improved Zn availability.

The presence of fungi in the soil is vital for organic matter decomposition, nutrient mineralization, and disease suppression (Rousk et al., 2010). Low fungal levels, which observed in 53.3% of soil samples here, can hinder these important functions, impacting soil structure, nutrient cycling, and plant resilience to pathogens (Wardle et al., 2004). Soil disturbance, different kinds of chemical and environmental stressors can contribute to reduced fungal populations in soils (Zak et al., 2003).

As indicated by (Dotaniya and Meena, 2015), higher organic matter improves soil structure and often micronutrient retention, thereby enhancing the soil concentration of micronutrients. Here only 3.3% of the organic matter in soil samples was deemed beneficial, while an alarming 86.7% of the

ash content was considered unwanted. This indicates that there is low return and decomposition of organic matter on the farming land of the small-scale farmers (Ai et al., 2018, Tefera et al., 2018). Poor organic matter enhances also the process of soil erosion (Berhe et al., 2012). Furthermore, organic matter acts as a reservoir for a range of essential nutrients, contributing to soil fertility, structure, and plant production (Lehmann et al., 2011, Mohiuddin et al., 2022) noted that lower EC indicates lower salinity levels, which can enhance the availability of certain micronutrients like Mn and Fe.

Here, 51.7% of the soil samples exhibited the lowest electrical conductivity levels, indicating poor soil fertility and reduced nutrient availability (Abate and Anteneh, 2024). Electrical conductivity serves as an indicator of soil salinity and ion concentration, with low values often associated with nutrient deficiencies and limited microbial activity (Qadir and Schubert, 2002). Limitations of the study include the focus on a specific geographic area or farming practices, which may limit generalizability. Additionally, the study did not investigate the impact of external factors such as climate variability or pest management on crop nutrient composition, which could be areas for future exploration.

#### **2.4. Conclusion**

The study concerns the yield of sorghum, maize, red kidney beans, onion, and potato collected from small-scale farmers. They showed low levels of crude protein, fats, carbohydrates, gross energy, and fibers, as well as low content of the essential micro nutrients Mn, Cu, Fe, and Zn compared to the nutritional recommendations in the FAO guidelines (Ababa, 2011).

The soil analysis revealed significant variations in micro nutrient levels and other soil characteristics: 66.7, 61.7, 41.7, and 63.3% of the soil samples showed low levels of iron, zinc, manganese, and copper, respectively. Soil pH analysis indicated that 76.7% of the samples were acidic. Furthermore, 23.3% and 53.3% of the soil samples had low total mesophilic bacterial count (TMBC) and total mesophilic fungal count (TMFC), respectively. Additionally, 51.7% of the soil samples had low electrical conductivity.

The findings should influence policymakers to prioritize enhancing agricultural practices and soil management which improve crop nutrition as well as soil sustainability and health. Supporting

research on innovative farming techniques that boost soil fertility and crop resilience will further strengthen human and animal nutrition and health. The relationships between soil physicochemical properties and crop yield should be further explored, as well as the impacts of different soil management practices on micronutrient availability and crop quality. Region-specific guidelines for optimizing soil and crop management should be developed to enhance yield, nutritional value, and then human and animal health.

**Chapter three: Examining the effect of agrochemicals on soil microbiological activity, micronutrient availability, and uptake by Maize (*Zea mays L*) plants**

Afata, T.N.; Mekonen, S.; Sogn, T.A.; K. Pandey, M.; Janka, E.; Tucho, G.T. Examining the Effect of Agrochemicals on Soil Microbiological Activity, Micronutrient Availability, and Uptake by Maize (*Zea mays L.*) Plants. *Agronomy* 2024, 14, 1321. <https://doi.org/10.3390/agronomy14061321>

## **Abstract**

Agricultural practices profoundly influence soil microbial populations and physicochemical properties, vital for crop growth and quality. This study aims to explore the impact of diverse agrochemical applications on soil microbial dynamics, physicochemical properties, and maize yield and proximate properties. Topsoil samples, collected at depths of 1 to 15 cm, were transported to Jimma University for maize cultivation. Over 120 days, soil and maize samples were collected at specified intervals for analysis, including soil pH, microbial populations, and nutrient content. Statistical analysis using one-way ANOVA ( $p < 0.05$ ) was conducted. Soil bacterial and fungal populations were measured on days 5, 10, 20, 40, 80, and 120. The highest total mesophilic bacterial count (TMBC) was in compost-treated pots (G) and the lowest in those receiving macronutrient fertilizers and glyphosates (B). The highest total mesophilic fungal count (TMFC) was in pots with glyphosates and compost (F) and the lowest was in pots treated with macronutrient fertilizers and glyphosates (B). Pots treated with macronutrient fertilizers and glyphosates (B), macronutrient fertilizers (A), and micronutrient fertilizers (C) showed the lowest Fe and Zn levels. Maize in pots treated with macronutrient fertilizer combined with glyphosate (B) exhibited the lowest protein, fats, and carbohydrates. Notably, compost-treated soils showed the highest bacterial and fungal counts, Fe, and Zn concentrations, while micro-mineral fertilizer combined with glyphosate (B) depleted the soil. Agrochemical treatments negatively affected maize yield quality, indicating complex treatment-related changes in soil parameters.

**Keywords:** Agricultural practices; Compost-treated; crop quality; Glyphosates; Micronutrient concentrations; physicochemical properties; soil ecosystem; Soil microbial populations

### 3.1. Introduction

Agriculture stands at the intersection of human survival and economic prosperity, with maize (*Zea mays* L.) being one of the most vital crops globally (Edmeades et al., 2017). As a staple food, a key livestock feed, and a raw material for industrial products, maize significantly influences local economies and global markets. Enhancements in agricultural practices, particularly through agrochemicals, have led to remarkable increases in crop productivity and have helped meet the growing food demand (Nadarajah and Abdul Rahman, 2023).

However, agrochemicals such as fertilizers and pesticides raise concerns about their long-term impact on soil health and sustainability. Their extensive application can lead to soil degradation, reduced soil fertility, and environmental pollution, thus posing a threat to agricultural sustainability (Tefera et al., 2024).

One primary concern is the effect of agrochemicals on soil microbiological activity. Soil microorganisms are essential for maintaining soil health as they contribute to nutrient cycling, organic matter decomposition, and suppression of soil-borne diseases (Idowu et al., 2019). Agrochemicals can disrupt these microbial communities, leading to reduced soil fertility and negatively impacting plant growth (Meena et al., 2020).

Currently, micronutrient deficiencies have emerged as a significant challenge to crop productivity in Ethiopia, with widespread deficiencies of Zinc (Zn), Iron (Fe), Manganese (Mn), and Copper (Cu) noted across various regions (Abera and Kassa, 2017, Afata et al., 2022). Practices such as increased cropping intensity, use of high-yielding varieties, and extensive fertilizer and pesticide application are expected to exacerbate these problems (Pogrzeba et al., 2017, Abera and Kassa, 2017).

Inadequate food crop concentration and thus human intake of these elements can result in nutritional deficiency, anemia, compromised immune function, skin diseases, delayed child development, and intelligence-related issues (Parida et al., 2023, Afata et al., 2023, Islam et al., 2023). This issue poses a growing threat to food and nutrition security in developing countries (Jatav et al., 2020, Kumar et al., 2020).

Moreover, soil salinity, exacerbated by improper irrigation practices and excessive agrochemical use, poses a significant threat to agricultural productivity. High salinity levels can inhibit plant growth,

reduce crop yields, and lead to long-term soil degradation (Safdar et al., 2019). Furthermore, decreased pH (Losak et al., 2011) and use of pesticides can influence the availability of soil micronutrients (Cu, Fe, Mn, and Zn) and microbial populations (Devi et al., 2008, Paul et al., 2013).

In particular glyphosate, a commonly used herbicide, strongly binds to soil components, potentially affecting soil microbial communities and thus the general agro-ecosystem sustainability (Kepler et al., 2020). Despite certain prokaryotic and fungal species metabolizing glyphosate to protect susceptible species, the effectiveness of this mechanism in mitigating the herbicide's impact is still under scrutiny (Dill et al., 2010).

Several studies reveal that glyphosate concentrations exceed approved rates, possibly concealing the buffering effects of resistant members (Kepler et al., 2020). An overuse of glyphosate can affect soil microbial respiration and biomass (Imfeld and Vuilleumier, 2012). Furthermore, long-term glyphosate use can lead to substantial changes in vegetation composition and growth by interfering with soil ecosystems and micronutrient availability (Davet, 2004).

The use of mineral fertilizers and pesticides, aiming to increase soil fertility and crop productivity, may also negatively impact the soil health and environment (Tripathi et al., 2020) by altering soil physicochemical properties, disrupting soil ecological balances, and disturbing the soil nutrient balance, decomposition rates, and nutrient bioavailability (Prashar and Shah, 2016).

Furthermore, overuse of these chemicals can reduce the populations of beneficial soil microorganisms and enzyme activities that are essential for soil health and plant productivity (Prashar and Shah, 2016). Although mineral fertilizers alone may increase crop production, concerns exist regarding their environmental and long-term soil sustainability implications. Mineral fertilizers can increase crop disease incidence and reduce soil micronutrient availability (Luo et al., 2015).

In addition, prolonged and uninterrupted cropping practices over several decades often result in modifications to soil properties, e.g. leading to a reduction in the levels of organic matter and essential micronutrients such as iron (Fe), manganese (Mn), zinc (Zn), and copper (Cu) both as plant available species and bound to soil organic matter and other surfaces of the soil particles (Wang et al., 2023).

Ethiopia currently confronts numerous soil fertility challenges, including organic matter and micronutrient depletion due to factors such as topsoil erosion, acidity, and salinity (Girma, 2016). Additionally, prolonged use of inorganic fertilizers and excessive pesticide application exacerbate these challenges (Laekemariam et al., 2016). The micronutrient deficiency in the soil system directly impacts plant uptake and, indirectly, human health (Afata et al., 2023, Abera and Kassa, 2017).

Prolonged continuous cropping modifies soil physicochemical and biological characteristics and diminishes micronutrient availability, exacerbating soil fertility challenges in Ethiopia (Girma, 2016). While widespread micronutrient deficiencies are evident in the western part of Ethiopia, data regarding the effects of agrochemicals on soil micronutrient availability and plant uptake are lacking (Laekemariam and Kibret, 2020). This study aims to fill this gap by investigating the impacts of different agrochemical treatments on soil micronutrient availability, microbial dynamics, and maize proximate properties in western Ethiopia.

### **3.1.1. Materials and Methods**

#### **3.1.2. The Intervention Approach of the Study**

Initially, soil samples were gathered from three districts within the Kellem Wellega Zone: Sayo, Hawa Gelan, and Dale Wabara, all three from small-scale farmers' cultivated fields. Due to the environmental homogeneity at these three sites, the soil samples were combined. The pot experiment was conducted, implementing the intervention approaches of the study in the following manner.

This study involves a split-plot experimental design to assess the impact of different soil treatments on various soil properties and microbial activities. Initially, soil samples were collected and subjected to different treatment allocations. These treatments included macronutrient fertilizers (A), macronutrient fertilizers and glyphosates (B), micronutrient fertilizers (C), glyphosates (D), a control group with no additives (E), compost combined with glyphosates (F), and compost (G).

Following the application of these treatments, the soil samples were monitored for changes in mesophilic bacteria and fungus populations, along with measurements of ash, pH, electrical conductivity (EC), moisture content (MC), and organic matter (OM). Additionally, the levels of copper (Cu), zinc (Zn), and iron (Fe) were evaluated.

After this follow-up period, a comprehensive analysis was conducted to further assess ash content, pH, EC, moisture, and organic matter. The analysis also included an evaluation of total protein, fat, fibers, carbohydrates, and gross energy content, along with the levels of zinc (Zn), iron (Fe), manganese (Mn), and copper (Cu). This thorough approach ensures a detailed understanding of how different soil treatments influence both the chemical and biological properties of the soil.

### **3.1.3. Study Setting**

The pot experiment was carried out at Jimma University. However, the soil was collected from the Kellem Wellega zone, in the western part of Ethiopia's Oromia region, during June 2023. This zone lies approximately 672 km from Addis Ababa. Comprising 10 districts with a total population of 965,000 individuals, nearly half of whom are female (PSA, 2008). Within this zone, there are approximately 175,000 households, each with an average size of 4.5 members (EDHS, 2016).

For our study, we deliberately selected three specific districts: Sayo, Hawa Gelan, and Dale Wabara. These districts were chosen due to their adoption of high-yielding crop varieties, intensive cultivation methods, prolonged fertilizer use, soil acidification, and the absence of organic manure, management practices contributing to the observed micronutrient deficiencies.

The selected areas were positioned at an elevation ranging from 1701 to 1830 meters above sea level. The climate pattern is characterized by abundant summer rains, a brief wet season, and a dry winter. Annual precipitation varies from 800 to 1200 mm, while daily temperatures range between 15 and 25 degrees Celsius (Gonfa et al., 2015). Renowned for its prolific agricultural output, the region produces a variety of crops, including coffee, maize, teff, wheat, barley, bean seed, and sorghum. The study area map is depicted in Figure 3.1.

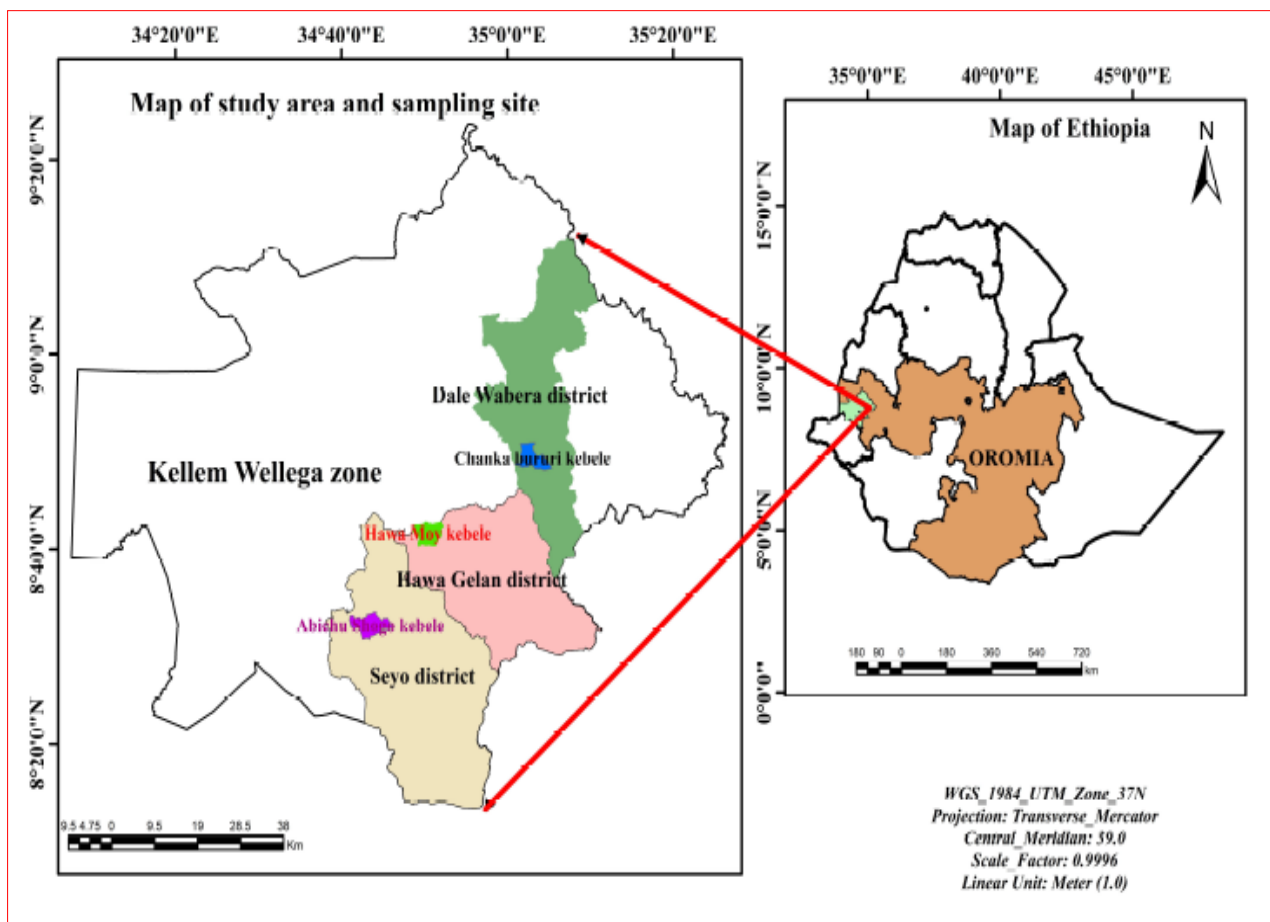


Figure 3.1. Geographical location of the study area for Sayo, Hawa Gelan, and Dale Wabara districts in Kellem Wellega zone, Western Ethiopia

### 7.2.3. Sample Collection from Farming Sites

Using a soil auger, topsoil samples were collected from the three selected districts of Kellem Wellega, i.e. Sayo, Hawa Gelan, and Dale Wabara, extracting topsoil from depths of 1 to 15cm. Before the collection process, surface debris and plant materials were carefully cleared by hand and stored in polyethylene bags for later disposal. The gathered samples were subsequently transported to Jimma University of Agricultural College, where they were mixed and utilized to cultivate maize within an open greenhouse environment.

### 3.1.4. Experimental Design and Treatment

The experiment employed a completely split-plot experimental design, each treatment consisting of three replications ( $n = 3$ ) and labeled treatments A to G. Pots were arranged in an open greenhouse to

ensure exposure to sunlight. The soils were collected from the farmers' fields during the period from September to November 2022. A survey has identified glyphosate as a prevalent herbicide in the local community (Afata et al., 2022).

Commonly used concentrations of active ingredients were combined in the plastic pots containing soil (10 cm deep) and homogenized. Plastic pots in seven treatment combinations including a control group, all in three replications were arranged in a split-plot experimental design. Maize, identified as a commonly consumed plant, was planted and allowed to germinate and grow until maturity, in which the temperature requirements can vary depending on the type of environment, and watered twice daily, in the morning and the evening.

The soil was sampled during the experiment. Parameters including Total Aerobic Mesophilic Bacteria Count (TMBC), total Mesophilic fungi count (TMFC), organic matter, moisture content, pH, electrical conductivity (EC), ash content, as well as iron, zinc, manganese, and copper levels were measured at intervals of 5, 10, 20, 40, 80, and 120 days.

Glyphosate quantities added were calculated based on soil density and volume. For glyphosate, 0.75 pounds or 0.34 kg of glyphosate is used per hectare, which translates to  $2.67 \times 10^{-6}$  kg or 2.61 mg of glyphosate per 16 kg of soil for each pot. The treatments included a control group that contains only the local soil or free of any treatments, as well as application of an herbicide, i.e. glyphosate, at a rate of 0.75 pounds per acre of soil, which is equivalent to 2.67 mg of glyphosate per 16 kg of soil. As per our experimental design, the soil was divided into seven equal-weight portions of 16 kg each, which were transferred into plastic pots given in Table 3.1.

**Table 3.1.** Designation of treatments and types of fertilizers utilized in the soil pot experiment.

Treatments	Added fertilizers
A	Macronutrient fertilizers
B	Macronutrient fertilizers and glyphosates
C	Micronutrient's fertilizers
D	Glyphosates
E	Control (free of any treatments)
F	Compost and glyphosates

This study investigates the effects of macro and micronutrient fertilizers on maize growth and soil health, applying precise rates per 16 kg soil pots. Key nutrients include nitrogen, phosphorus, and potassium, alongside zinc, iron, copper, and manganese. Furthermore, the added amounts for all kinds of fertilizers are shown in Table 3.2.

**Table 3.2.** Types, sources, and rate of fertilizers required for the soil pot experiment.

Macro and micro fertilizers	Source	rate kg/ha	required for 16kg soil (each pot)
N	NH <sub>4</sub> NO <sub>3</sub>	120	0.96
P	P <sub>2</sub> O <sub>5</sub>	60	0.48
K	K <sub>2</sub> O	50	0.4
Zn	ZnSO <sub>4</sub> .5H <sub>2</sub> O	60	0.48
Fe	FeSO <sub>4</sub> .7H <sub>2</sub> O	15	0.12
Cu	CuSO <sub>4</sub> .5H <sub>2</sub> O	2	0.02
Mn	MnSO <sub>4</sub> .H <sub>2</sub> O	360	2.88

### 3.1.5. Preparation of Compost Samples

Compost was prepared according to the methods outlined in (M.P.C.A., 2013), and it was mixed in a ratio of one part compost to four parts soil for maize cultivation, as described in (Smith, 2011).

### 3.1.6. Moisture contents (MC), Organic Matter( OM) , and Ash contents(AC)

The moisture content (MC), organic matter (OM), and ash contents (AC) of soil and crop yield samples were determined by methods(AOAC, 2005).

### 3.1.7. Determination of pH and Electrical Conductivity from Soil Samples

Soil pH was measured using a pH meter(Carter, 1998) , and electrical conductivity was determined with a digital multi-parameter device (Bante 900-UK)

### 3.1.8. . Determination of Micronutrients from Soil Samples

Soil samples were collected on days 5, 10, 20, 40, 80, and 120 after pesticide application. Samples were dried at 105°C for 24 hours, ground to a fine powder, and then dry-ashed at 550°C for 6 hours.

After cooling, the ash was digested with HNO<sub>3</sub> and HCl, filtered, and analyzed for Zn, Fe, Mn, and Cu using an atomic absorption spectrophotometer (Akinyele and Shokunbi, 2015).

### **3.1.9. Determination of Total Mesophilic Bacteria and Fungi Counts in Soil Samples**

Polyethylene bags were sterilized for 12 hours, glassware at 160°C for 2 hours, and growth media autoclaved at 121°C for 15 minutes. A gram of fresh-weight soil samples was collected on days 5, 10, 20, 40, 80, and 120, and analyzed using serial dilution and pour plate techniques (Pramer, 1965), asparagus mannitol agar (Thornton, 1922), and Potato dextrose agar (Martin, 1950). Bacterial colonies were incubated at 28 ± 2°C for 18-24 hours, and fungi on PDA with chloramphenicol at room temperature for 48-72 hours.

### **3.1.10. Quantification and Quality Analysis of Harvested Maize**

#### **3.1.11. Sample Preparation for Proximate Composition**

Sample preparation converted the samples into homogeneous material for various quantity and quality analyses. Maize plant samples were dried and ground. Specific sample preparation was then conducted according to the sample type and analyses requested. Protein, fat, crude fiber, moisture, and ash were determined by the methods of (AOAC, 2005).

### **7.10.2. Total Carbohydrates and Energy Gross**

Total carbohydrates were determined using proteins, fats; ash, fibers, and moisture proportions were added and subtracted from 100. (Totalcarbohydrae = 100 – % of (Crude protein + Moisture + Ash + Crude fat + Crude Fiber ). The gross energy value (expressed in kilocalories) was calculated using Atwater's conversion factors of 4 kcal/g for protein, 9 kcal/g for fat, 4 kcal/g for carbohydrates, and 2 kcal/g for Fiber (FAO, 2003).

$$\begin{aligned} \text{Gross energy} \left( \frac{\text{kcal}}{100\text{g}} \right) \\ = 9(\text{Crude fat}) + 4(\text{Crude protein}) + 4(\text{Total carbohydrate}) + 2(\text{Crude Fiber}) \end{aligned}$$

### **3.1.12. Statistical Analysis**

Initially, the data were entered into EPI-INFO version 7 and subsequently imported into the Statistical Package for the Social Sciences version 26 (SPSS). Following this, descriptive statistics, encompassing mean, range, and standard deviations, were computed. Furthermore, the nutritional composition of agrochemical-treated maize was analyzed. Finally, a non-parametric test, specifically the Kruskal-Wallis's test of one-way ANOVA, was used to compare the primary effects of the treatments.

### 3.2. Results

#### 3.2.1. Soil Physicochemical Properties

#### 3.2.2. Soil Moisture (MC), ash (AC), and Organic Matter (OM) Content

When comparing the results across treatments labeled A to G (Table 1), notable variations emerge in the parameters measured. For soil moisture content, treatment of macronutrient fertilizers (A) consistently exhibits lower levels compared to other treatments, while treatments of micronutrient fertilizers(C), glyphosates (D), and control (E) generally display intermediate moisture levels. Conversely, the treatment of compost and glyphosates (F) consistently resulted in the highest moisture content, particularly at longer time intervals (Table 3.3).

Regarding ash contents, the treatment of compost (G) consistently presents lower levels compared to other treatments. Treatment F tends to show relatively higher ash content, especially in extended durations (Table 3). In terms of organic matter, the treatment of compost (G) consistently displays higher levels compared to other treatments, especially over longer periods, while the treatment of compost and glyphosates (F) shows relatively lower organic matter content, particularly in extended durations (Table 8.2). The non-parametric, one-way ANOVA analysis revealed notable variations in ash ( $p = 0.01$ ) and organic matter ( $p = 0.01$ ) contents.

**Table 3.3.** Moisture, ash, and organic matter of soil samples from pot experiments were recorded at 5, 10, 20, 80, and 120<sup>th</sup> days of intervals.

Sampling days	Parameters	Treatments(g/kg)						
		A	B	C	D	E	F	G
5	Moisture contents	25.6	27.6	24.4	26.2	25.8	35.4	28.6
	Ash contents	93.2	93.2	93	93.2	93	91.4	89.4

	Organic matter	6.8	6.8	7	6.8	7	8.6	10.6
10	Moisture contents	18.8	26	25.4	22	21.8	23.8	23.6
	Ash contents	89.2	87.6	91.2	91	91.2	91.2	85
	Organic matter	10.8	12.4	8.8	9	8.8	8.8	15
20	Moisture contents	23	24.6	24	24.4	24.4	28.2	27.6
	Ash contents	91.4	91.6	91.6	92	91.8	88.6	88.4
	Organic matter	8.6	8.4	8.4	8	8.2	11.4	11.6
40	Moisture contents	24.51	21.34	22.57	25.1	23.55	27.06	23.21
	Ash contents	91.74	91.7	91.88	92.16	92.02	89.02	89.48
	Organic matter	8.26	8.3	8.12	7.84	7.98	10.98	10.52
80	Moisture contents	24.8	22.9	22.38	23.06	22.42	23.38	21.43
	Ash contents	92.26	92.59	91.88	92.25	91.67	88.98	90.08
	Organic matter	7.74	7.41	8.12	7.75	8.33	11.02	9.92
120	Moisture contents	17.69	23.1	20.2	24.97	15.22	18.81	16.75
	Ash contents	91.05	91.61	92.4	90.95	90.91	87.72	89.51
	Organic matter	8.95	8.39	7.6	9.05	9.09	12.28	10.49

Keys: Fertilizers (A), Fertilizers and Glyphosates (B), micronutrient fertilizers (C), Glyphosates (D), Control (E), Compost and Glyphosates (F), Compost (G).

### 3.2.3. Electrical Conductivity (EC) and pH

Comparing the results across different sampling days for treatments labeled A to G reveals significant variations. For pH levels, compost (G) treatment consistently gave higher pH values than other treatments across various sampling days (Table 3.4). In contrast, treatments of macronutrient fertilizers (A), micronutrient fertilizers, and glyphosates (B), tend to exhibit lower pH levels, particularly at longer trial durations. Notably, treatments of micronutrient fertilizers (C) and glyphosates (D) display fluctuating pH levels, showing both higher and lower values throughout the trial period ( $p = 0.00$ ).

Regarding electrical conductivity (EC), the treatment of compost (G) consistently displays the highest values across most trial days, indicating greater conductivity compared to other treatments (Table 4). Treatments of micronutrient fertilizers (C) and glyphosates (D) also show relatively high

EC values, especially at certain time points, while treatments of macronutrient fertilizers (A), micronutrient fertilizers, and glyphosates (B) generally exhibit lower conductivity levels. The treatment of compost and glyphosates (F) stands out with significantly elevated EC values, particularly at later trial days, suggesting unique effects compared to other treatments ( $p = 0.03$ ) (Table 3.4)

**Table 3.4.** Electrical conductivity (EC,  $\mu\text{s}/\text{cm}$ ) and pH physicochemical properties of soil samples from pot experiments that were recorded at 5, 10, 20, 80, and 120<sup>th</sup> days of intervals

Sampling days	Parameters	Treatments						
		A	B	C	D	E	F	G
5	pH	5.32	5.45	5.72	6.21	6.28	5.95	6.55
	EC	80.1	68.64	90.62	78.35	78.28	68.64	328.6
10	pH	5.58	5.63	5.4	6.2	6.04	6.5	6.51
	EC	68.08	80.37	117.6	70.55	95.8	139.8	164.1
20	pH	5.31	5.13	6.17	5.42	6.43	6.4	6.35
	EC	125.5	115	194.3	138.9	140.2	242.1	260.1
40	pH	5.47	5.04	6.42	6.23	5.84	6.39	6.42
	EC	83.52	78.44	89.95	86.3	93.15	152.2	152.2
80	pH	5.72	5.93	5.9	5.9	6.3	6.35	6.34
	EC	37	39.1	41.9	48.1	50.1	123.1	120.4
120	pH	5.82	5.5	5.89	6.26	5.96	6.36	6.45
	EC	91	69.7	55.9	47.9	36.2	120.4	79.7

Keys: Fertilizers (A), Fertilizers and Glyphosates (B), Micronutrient fertilizers (C), Glyphosates (D), Control (E), Compost and Glyphosates (F), Compost (G), Electrical conductivity (EC).

### 3.2.4. Total Mesophilic Bacterial Count (TMBC) and Fungus (TMFC)

Comparing the results across sampling days and treatments labeled A to G reveals intricate patterns in TMBC (Table 3.5). At day 5, treatment compost and glyphosates (F) demonstrate the highest counts for both TMBC and TMFC, with counts of  $2.4 \times 10^6$  and  $7 \times 10^3$  colony forming units (cfu), respectively. Treatment of compost (G) also shows notably high TMBC counts ( $8 \times 10^5$  cfu). However,

control treatment E displays the lowest TMBC count ( $2 \times 10^5$ ) while treatment macronutrient fertilizers (A) record the lowest TMFC ( $9.8 \times 10^4$  cfu).

**Table 3.5.** Microbial count of soil samples from pot experiments that were recorded at 5, 10, 20, 80, and 120<sup>th</sup> days of intervals

Sampling days	Microbial Count	Treatment (cfu/g)						
		A	B	C	D	E	F	G
5	TMBC	$8 \times 10^5$	$2.3 \times 10^5$	$1 \times 10^5$	$1 \times 10^6$	$2 \times 10^5$	$2.4 \times 10^6$	$8 \times 10^5$
	TMFC	$9.8 \times 10^4$	$3.8 \times 10^4$	$3.5 \times 10^4$	$1.07 \times 10^5$	$1 \times 10^3$	$7 \times 10^3$	$5 \times 10^3$
10	TMBC	$1 \times 10^6$	$3 \times 10^5$	$1.3 \times 10^6$	$1.4 \times 10^6$	$2.5 \times 10^6$	$4 \times 10^5$	$5 \times 10^5$
	TMFC	$1.02 \times 10^5$	$5.2 \times 10^4$	$9 \times 10^3$	$1.32 \times 10^5$	$3 \times 10^3$	$2.9 \times 10^4$	$2.1 \times 10^4$
20	TMBC	$1.4 \times 10^6$	$6.1 \times 10^5$	$3.6 \times 10^6$	$1.5 \times 10^6$	$6.2 \times 10^5$	$3.7 \times 10^6$	$4 \times 10^6$
	TMFC	$1.11 \times 10^5$	$4.2 \times 10^4$	$4.7 \times 10^5$	$6.5 \times 10^5$	$6.2 \times 10^5$	$5.1 \times 10^5$	$5.7 \times 10^5$
40	TMBC	$5 \times 10^6$	$6 \times 10^6$	$6 \times 10^6$	$5 \times 10^6$	$7 \times 10^6$	$7.5 \times 10^6$	$9 \times 10^6$
	TMFC	$5 \times 10^4$	$4 \times 10^4$	$5 \times 10^4$	$7 \times 10^4$	$2 \times 10^4$	$8 \times 10^4$	$7 \times 10^4$
80	TMBC	$1.9 \times 10^6$	$7 \times 10^5$	$9 \times 10^5$	$6 \times 10^5$	$4 \times 10^5$	$1.1 \times 10^6$	$1.5 \times 10^6$
	TMFC	$4 \times 10^4$	$2 \times 10^4$	$3 \times 10^3$	$2 \times 10^3$	$1 \times 10^3$	$6 \times 10^3$	$4 \times 10^3$
120	TMBC	$7 \times 10^4$	$4 \times 10^4$	$1 \times 10^4$	$4 \times 10^4$	$2 \times 10^4$	$5 \times 10^4$	$9 \times 10^4$
	TMFC	$2 \times 10^3$	$2 \times 10^3$	$1 \times 10^3$	$2 \times 10^3$	$2 \times 10^3$	$3 \times 10^3$	$5 \times 10^3$

Keys: Fertilizers (A), Fertilizers and Glyphosates (B), micronutrient fertilizers (C), Pesticides (D), Control (E), Compost and pesticides (F), Compost (G), Total Mesophilic Bacteria Count (TMBC), Total Mesophilic Fungus Count (TMFC).

By day 10, TMBC counts peak in the treatment of compost and glyphosates (F) at  $2.5 \times 10^6$ , whereas the treatment of macronutrient fertilizers and glyphosates (B) exhibits the lowest count at  $3 \times 10^5$ . For TMFC, treatment compost and glyphosates (F) again lead with a count of  $2.9 \times 10^4$ , while treatment of micronutrient fertilizers (C) shows the lowest count at  $9 \times 10^3$  cfu.

By day 20, treatment of compost G emerges with the highest TMBC count at  $4 \times 10^6$ , contrasting with treatment macronutrient fertilizers A's count of  $1.4 \times 10^6$  cfu. Similarly, treatment of compost G

leads in TMFC counts at  $5.7 \times 10^5$ , while treatment of macronutrient fertilizers and glyphosates B presents the lowest count at  $4.2 \times 10^4$  cfu.

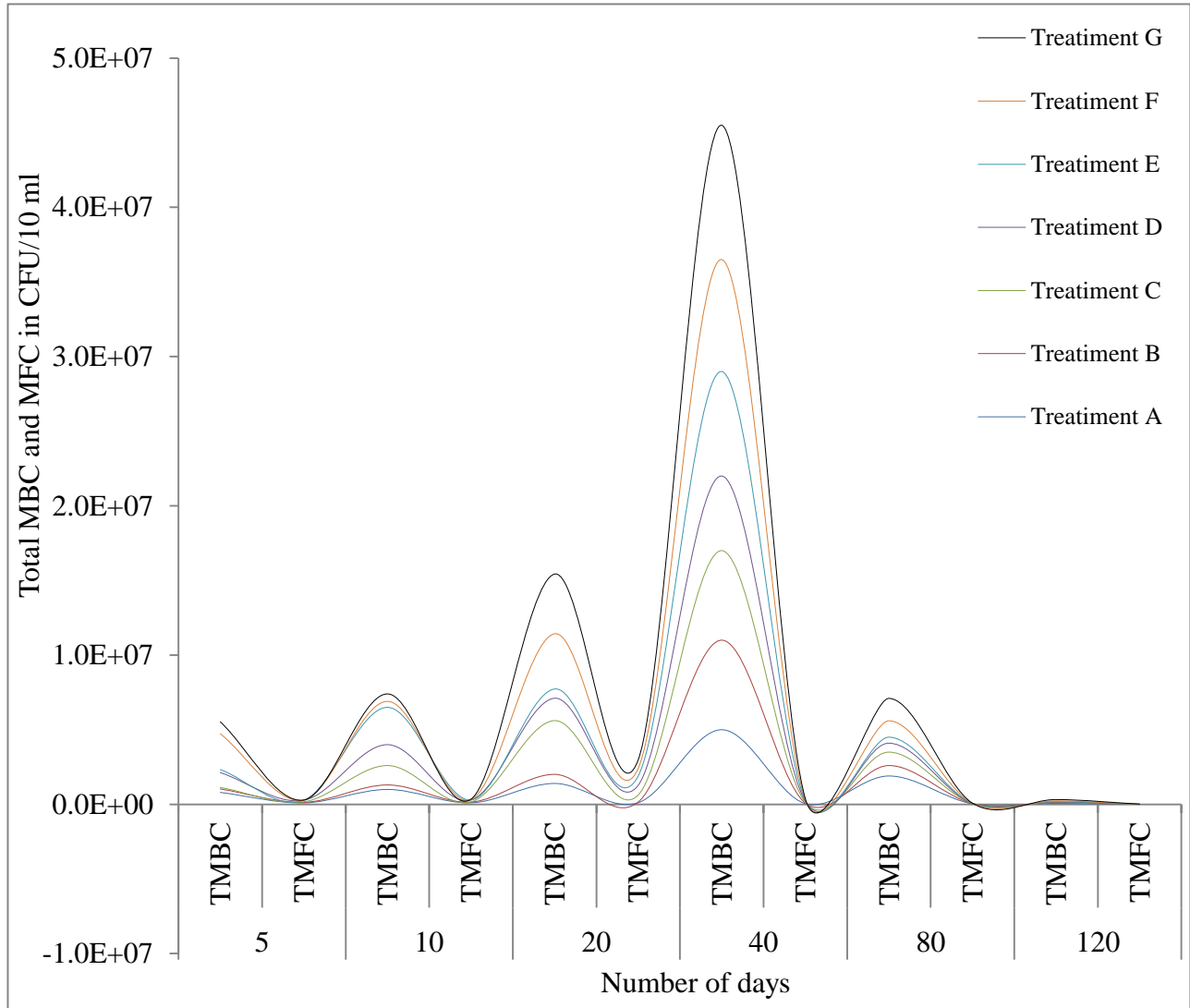
By day 40, treatment of compost G maintains dominance with the highest TMBC count at  $9 \times 10^6$ , contrasting sharply with treatment A's count of  $5 \times 10^6$  colony-forming units (cfu). For TMFC, all treatments exhibit relatively low counts compared to previous days.

By day 80, TMBC counts decreased across all treatments, with treatment of compost G retaining the highest count at  $1.5 \times 10^6$ , and treatment macronutrient fertilizers and glyphosates B showing the lowest count at  $7 \times 10^5$  cfu. TMFC counts also decline, with treatment of compost G leading at  $6 \times 10^3$  and treatment of micronutrient fertilizers C recording the lowest count at  $3 \times 10^3$  cfu.

At day 120, TMBC counts decrease further, with Treatment of compost G maintaining the highest count at  $5 \times 10^4$  and treatment macronutrient fertilizers A recording the lowest count at  $7 \times 10^4$  cfu ( $p = 0.00$ ).

Similarly, TMFC counts diminish, with treatment of compost G leading at  $5 \times 10^3$  and treatments of macronutrient fertilizers A, macronutrient fertilizers and glyphosates B, and control E displaying the lowest count at  $2 \times 10^3$  cfu ( $p = 0.03$ ) (Table 5).

In general, the graphical representation of total mesophilic bacteria count (TMBC), and total mesophilic fungus count (TMFC) (Figure 3.2.) show that mesophilic bacterial found in pots initially increase up to 40 days after the startup of a growing season, followed by a significant decline until the harvesting period while mesophilic fungal population count tended to increase up to day 20 and then gradually decline (Figure 3.2).



**Keys:** Exponent(E), Fertilizers (A), Fertilizers and Glyphosates (B), micronutrient fertilizers (C), Pesticides (D), Control (E), Compost and pesticides (F), Compost (G), Total Mesophilic Bacteria Count (TMBC), Total Mesophilic Fungus Count (TMFC)

**Figure 3.2.** A graphical representation illustrating the colony formation of total mesophilic bacteria count (TMBC) and mesophilic fungi (TMFC) in soil samples from pot experiments, recorded at intervals of 5, 10, 20, 80, and 120 days.

### 3.2.5. . Soil Micronutrient Level Analyzed from Pot Experiment

Comparing the results across trial days and treatments labeled A to G revealed variations in soil micronutrient concentration (Table 3.6). At day 5, the treatment of compost and glyphosates (F) stands out with notably higher values in Fe, Mn, and Zn, suggesting its efficacy in promoting the accumulation of these elements. Conversely, treatment of macronutrient fertilizers and glyphosates (B) show to exhibit lower values, particularly noticeable in the Fe and Mn content.

By day 10, treatment of compost (G) displays elevated levels of Fe and Mn, while treatment of glyphosates (D) shows a significant increase in Zn content. In contrast, treatment of micronutrient fertilizers (C) demonstrates relatively lower values across most parameters.

**Table 3.6.** Fe, Mn, Cu, and Zn micronutrients of soil samples analyzed from pot experiments that were recorded at 5, 10, 20, 80, and 120<sup>th</sup> days of intervals

Sampling days	Parameters	Treatments (ppm)						
		A	B	C	D	E	F	G
5	Fe	20.38	22.99	222.49	23.57	226.56	223.94	218.85
	Mn	60.95	65.69	210.67	64.22	244.62	208.76	238.18
	Cu	4.35	4.22	6.93	4.99	6.96	5.39	5.94
	Zn	2.18	2.81	23.41	2.4	25.58	30.81	29.8
10	Fe	29.72	30.71	258.37	27.66	289.37	253.53	305.84
	Mn	71.59	74.48	111.9	82.8	162.63	109.03	238.71
	Cu	4.12	3.36	2.89	1.1	1.75	3.26	4.02
	Zn	1.45	2.1	19.21	6.5	1.33	7.96	8.65
20	Fe	23.1	21.54	300.79	20.52	257.68	273.21	270.37
	Mn	121.48	204.4	127.91	88.38	114.01	222.73	170.17
	Cu	1.75	3.09	4.74	2.44	1.99	7.49	2.41
	Zn	4.84	16.75	1.12	1.06	5.79	20.86	22.75
40	Fe	27.22	28.13	308.89	30.51	305.89	349.26	292.95
	Mn	80.67	96.53	393.38	128.49	272.51	285.57	283.72
	Cu	3.06	5.18	7.25	7.04	5.81	7.9	2.3

	Zn	1.49	2.77	40.59	3.87	29.93	37.9	54.94
80	Fe	22.18	20.18	234.93	23.86	227.94	232.11	247.46
	Mn	103.34	82.67	288.48	121.83	220.87	223.59	260.21
	Cu	6.01	4.92	7.5	4.06	4.92	5.69	5.5
	Zn	1.53	1.74	24.67	1.11	24.36	24.12	23.63
120	Fe	23.74	21.96	235.36	22.98	226.27	232.87	233.06
	Mn	122.18	20.35	305.37	118.05	203.89	237.84	234.14
	Cu	4.79	3.71	7.06	5.05	3.61	6.04	4.79
	Zn	1.93	1.31	19.94	1.83	12.36	35.19	27.02
Overall mean	Fe	24.39	24.25	260.14	24.85	255.62	255.49	261.42
	Mn	93.37	90.69	239.62	100.63	203.09	214.59	237.52
	Cu	4.01	4.08	6.06	4.11	4.17	5.97	4.16
	Zn	2.24	4.58	21.49	2.8	16.56	26.14	27.8

**Key:** Fertilizers (A), Fertilizers and Glyphosates (B), micronutrient fertilizers (C), Glyphosates (D), Control (E), Compost and Glyphosates (F), Compost (G), iron (Fe), Zinc (Zn), Copper (Cu), Manganese (Mn).

Moving to day 20, the treatment of compost (G) maintains its dominance with consistently high micronutrient values, especially evident for Fe and Mn. The control (E), however, presents lower values for Fe and Mn compared to the other treatments.

By day 40, treatment compost and glyphosates (F) continue to exhibit the highest values for Fe and Mn, while treatment of compost G surpasses others in Zn content. Notably, treatment of micronutrient fertilizers C consistently displays relatively lower values across all parameters.

As the trial progresses to day 80, the treatment of compost (G) maintains its lead with consistently high values for Fe, Mn, and Zn. Treatments of macronutrient fertilizers and glyphosates (B) and glyphosates (D) show varying patterns with fluctuations with time.

Finally, by day 120, the treatment of compost (G) remains prominent with notably high values of Fe, Mn, and Zn. Treatment micronutrient fertilizers (C) on the other hand, consistently demonstrate lower values.

Overall, compost treatment (G) consistently demonstrates higher values of Fe ( $p = 0.00^*$ ), and Zn ( $p = 0.01$ ), indicating its potential efficacy in promoting the accumulation of these essential elements in the soil. Conversely, Treatment A, B, and D consistently display lower values across all parameters. The highest concentrations of Mn were found in the treatments of micronutrient fertilizers (C), while the lowest was observed in the treatments of macronutrient fertilizers (A), macronutrient fertilizers, and glyphosates (B), and glyphosates (D) ( $p = 0.00$ ) (Table 6).

### **3.2.6. Maize Yield Quality**

Analyzing the results across different sampling days for treatments A to G reveals significant variations (Table 3.6). The lowest plant moisture contents (MC) and ash content (AC) were found in maize grown in the compost (G) treatment, with values of  $12.63 \pm 0.13$  and  $1.69 \pm 0.1$  in g/100g of samples, respectively. The highest significance of plant moisture contents ( $p = 0.00$ ) was found in the macronutrient fertilizer treatment (A), and the highest plant ash content was observed for micronutrient fertilizer treatment (C) ( $p = 0.00$ ) in g/100g of maize.

**Table 3.6.** Physicochemical characteristics and proximate composition of maize plants grown under fertilizer and chemical soil treatments in pot experiments

Parameters	A	B	C	D	E	F	G
MC(g/100g)	14.41±0.15**	12.76±0.05	13.23±0.25	12.63±0.1	14.2±0.25	13.25±0.1	12.265±0.13*
AC(g/100g)	8.855±0.03	7.53±0.1	11.2±0.25**	8.62±0.1	8.14±0.25	8.51±0.05	1.685±0.1*
PC(g/100g)	9.48±0.25	11.29±0.8	8.569±0.25*	9.688±0.3	10.57±0.3	10.825±0.7	11.42±0.8**
TFC(g/100g)	2.675±0.1*	2.21±0.2*	3.21±0.1	3.977±0.01*	3.22±0.1	3.48±0.2	3.535±0.13
CF(g/100g)	6.265±0.1*	8.195±0.03*	8.21±0.2	7.835±0.03	6.585±0.13	6.64±0.1	6.855±0.03
CHO(g/100g)	58.915±0.03	59.315±0.2	66.23±0.1**	57.34±0.1*	58.41±0.2	58.53±0.15	65.49±0.2
Gross energy(kcal/100g)	308.375±0.13	313.265±0.13	343.845±0.03	320.16±0.1	315.37±0.05	317.23±0.10	348.465±0.08**
Fe(ppm)	48.165±0.1	79.495±0.03	78.545±0.03	19.9875±0.04*	54.905±0.03	45.84±0.05	81.4650.13**
Mn(ppm)	6.1±0.05	5.9575±0.05	9.845±0.03**	3.13±0.1*	4.375±0.13	6.0125±0.06	4.585±0.13
Cu(ppm)	1.17±0.2	0.775±0.01*	1.425±0.2	1.24±0.25	0.9675±0.08	1.27±0.15	1.995±0.14**
Zn(ppm)	38.5±0.05	37.095±0.08	48.375±0.1	36.615±0.08*	38.435±0.1	37.8±0.05	50.855±0.03**

**Keys:** Fertilizers(A), Fertilizers and Glyphosates (B), micronutrient fertilizers (C), Glyphosates (D), Control (E), Compost and Glyphosates (F), Compost(G), moisture contents (MC), total fats (TFA), Crude fibers (CF), iron (Fe), Manganese (Mn), Copper (Cu), Zinc (Zn), Lowest (\*) and Highest (\*\*) treatment effect.

Regarding crude protein content ( $p = 0.01$ ), in g/100g, the highest significant concentration was found in maize from the treatment of compost (G) ( $11.42 \pm 0.8$ ). For total crude fats (TCF), the highest level was seen in the glyphosate treatment (D) ( $3.98 \pm 0.01$ ). For total carbohydrates ( $p = 0.00$ ) and crude fibers ( $p = 0.00$ ) the highest contents were found in the micronutrient fertilizer treatment (C), with values of  $66.23 \pm 0.1$  and  $8.21 \pm 0.02$  in g/100g of maize samples, respectively. Lastly, the highest total gross energy (kcal/100g) level was found in compost treatment (G) ( $348.465 \pm 0.08$ ) ( $p = 0.00$ ).

The lowest concentration of crude protein (PC) was observed in treatment C ( $8.57 \pm 0.25$ ). For total crude fats (TCF), the lowest level was found in macronutrient fertilizer and glyphosate treatment B ( $2.21 \pm 0.2$ ), while the total carbohydrates (CHO) exhibited the lowest concentration in glyphosate treatment D ( $57.34 \pm 0.1$ ) in g/100g of maize samples. The lowest total gross energy (kcal/100g) and crude fibers (CF) in g/100g were recorded for maize from macronutrient treatment A, with values of ( $308.375 \pm 0.1$ ) and ( $6.265 \pm 0.1$ ), respectively.

In terms of plant micronutrient concentrations, Fe ( $p = 0.00$ ), Cu ( $p = 0.03$ ), and Zn ( $p = 0.00$ ) concentrations were the highest for compost treatment (G) and the lowest in the glyphosate treatment (D) and the treatments with macronutrient fertilizers and glyphosates (B). Finally, plant Mn ( $p = 0.00$ ) concentration in ppm was the highest in micronutrient treatment (C) and lowest for glyphosate treatment (D) (Table 3.7).

### **3.3. Discussion**

This study highlights the significant impact of commonly used effort factors used in intensive agricultural management. The use of chemical fertilizer and glyphosate showed clear effects on soil biological and physicochemical properties, soil micronutrient concentration, as well as maize yield and quality. This experiment illustrates how excessive use of inorganic fertilizers diminishes the population of beneficial soil microorganisms by altering the functional diversity of the soil microbial community.

The total mesophilic bacterial count (TMBC) and total mesophilic fungal count (TMFC) exhibited significant differences among treatment groups. The compost-treated soil exhibited the highest TMBC and TMFC, suggesting a positive influence on soil bacterial populations (Table 3.5). Compost is known to enrich soil microbial diversity and activity, providing organic substrates and favorable conditions for bacterial growth (Aulakh et al., 2022).

Additionally, the presence of glyphosates in compost-treated soil did not seem to hinder bacterial populations, actually indicating potential synergistic effects or tolerance to glyphosates (Somenahally et al., 2011). Likewise, the introduction of inorganic fertilizers alters the structure of the soil microbial community, thereby impacting the composition and diversity of mesophilic bacteria, leading to periodic decreases in their population (Onet et al., 2019, Ashworth et al., 2017).

Furthermore, we observed a significant drop in mesophilic bacterial and fungal count in the pots treated with both macro and micronutrient fertilizers, as well as glyphosate, compared to untreated pots. This decrease may be attributed to the addition of glyphosate, a non-selective organophosphate herbicide that has been found to reduce phosphate enzyme activity (Sannino and Gianfreda, 2001).

The reduction of phosphate enzyme activity causes the death of sensitive microorganisms (Govedarica et al., 2002). Glyphosate, a common herbicide in agrochemicals disrupts soil microbial communities by inhibiting specific microbial pathways and reducing microbial biomass (Wolmarans, 2013). Conversely, compost amendments positively influenced bacterial populations, while chemical inputs had detrimental effects.

Furthermore, our study shows that glyphosate and inorganic fertilizer treatment initially may increase mesophilic bacterial up to 40 days after the startup of a growing season, followed by a significant decline until the harvesting period while mesophilic fungal population count tended to increase up to day 20 and then gradually decline (Figure 3).

The microbial counts may temporarily rise due to their ability to mineralize glyphosate and fertilizers for energy, but later on, these chemicals can selectively promote the growth of certain microbes while inhibiting others, leading to shifts in microbial diversity and overall abundance (Srinivasulu and Ortiz, 2017).

Additionally, inorganic fertilizers and glyphosate can be toxic to certain microorganisms and contribute to the decrease in microbial count in farming soil (Baboo et al., 2013). Moreover, the synergistic interactions between glyphosates, macro, and micronutrient fertilizers can further inhibit microbial soil community functions, ultimately leading to a decrease in microbial populations (Chen and Dixon, 2007, Mishra and Ekielski, 2019, Hussain et al., 2009).

Compost-treated soil (G) exhibited the highest pH values, indicating alkaline conditions favorable for nutrient availability and microbial activity. The alkalinity of compost-amended soil may be attributed to the buffering capacity of organic matter, which helps maintain pH stability (Lehmann and Kleber, 2015).

Additionally, the decomposition of organic materials releases alkaline substances, further contributing to elevated pH levels (Nardi et al., 2000). In contrast, treatments of macronutrient fertilizers (A), micronutrient fertilizers, and glyphosates (B), tend to exhibit lower pH levels, particularly at longer trial durations (Table 8.3). The acidifying effect of chemical fertilizers may stem from the presence of ammonium-based nitrogen sources, which undergo nitrification and release protons, lowering soil pH (Hassink, 1997).

Moreover, acidic conditions can inhibit the growth and activity of beneficial soil microbes, disrupting soil biological processes (Rousk et al., 2010). Compost application promotes alkaline conditions conducive to nutrient availability and microbial activity, while chemical fertilizers may contribute to soil acidification and nutrient imbalances.

Electrical conductivity (EC) values exhibited significant variation among treatments, which reflects differences in soil salinity and nutrient concentrations. Compost-treated soil recorded the highest conductivity levels, indicating higher nutrient concentrations and organic matter content. The elevated EC in compost-amended soil may result from the decomposition of organic materials, which releases soluble ions and increases the electrical conductivity of soil solutions (El-Ramady et al., 2024). Additionally, the presence of organic matter enhances cation exchange capacity, facilitating the retention and release of nutrients, further contributing to elevated EC levels (Nelson and Sommers, 1996).

Conversely, treatments involving macronutrient fertilizers (A) and macronutrient fertilizers combined with glyphosate application (B) generally exhibited lower EC levels (Table 3.4). This observation is consistent with the notion that chemical fertilizers may not contribute significantly to soil ion concentration compared to organic inputs like compost (El Bey et al., 2024). Additionally, glyphosate, a common herbicide used in conjunction with fertilizers, might further influence soil conductivity due to its impact on microbial activity and nutrient cycling (Lane et al., 2012). This finding aligns with previous research suggesting that organic matter decomposition, as facilitated by

compost application, can increase soil ion concentration and, consequently, electrical conductivity (El Bey et al., 2024).

Similarly, soil organic matter content showed significant variation among treatments. Treatment of compost (G) consistently displays higher levels compared to other treatments, especially over longer periods, while treatment of micronutrient fertilizers (C) and glyphosates (D) shows relatively lower organic matter content, particularly in extended durations, indicating limited organic inputs and microbial activity (Blanco-Canqui and Benjamin, 2013).

Compost amendments promote organic matter accumulation, stimulating microbial activity and enhancing soil productivity (Chen and Dixon, 2007). Conversely, treatment of micronutrient fertilizers and glyphosates shows relatively lower organic matter content, particularly in extended durations due to the chemical nature which may not contribute as significantly to organic matter accumulation as compost does (Baweja et al., 2020, Sebiomo et al., 2011) (Table 3.4).

Moreover, micronutrient levels (Fe, Zn, and Mn) displayed significant variation by the treatments. The application of compost enriches the soil with organic matter, which serves as a reservoir for micronutrients and promotes their release for plant uptake (Shu et al., 2022). Additionally, compost enhances soil microbial activity, facilitating the mineralization of organic matter and the mobilization of micronutrients bound to soil particles (van Beek et al., 2018). Moreover, chemical fertilizers and glyphosate applications may also contribute to micronutrient deficiencies by disrupting soil microbial communities involved in nutrient-cycling processes (Bàrberi, 2002).

Furthermore, glyphosate, a broad-spectrum herbicide, can form complexes with micronutrients in the soil through chemical interactions, reducing their bioavailability for plant uptake. Glyphosate can also chelate with micronutrients like Fe and Mn, leading to deficiencies in plants (Franz et al., 1997). Moreover, glyphosate usage alters microbial populations, impacting micronutrient uptake by plants, and inhibits soil microorganisms crucial for organic matter decomposition, thereby reducing mineralization essential for micronutrient availability (Khan et al., 2006).

Concerning the maize plant moisture and ash content the results support suggestions of maintaining a moisture level between 12 and 14% which is recommended for maize, as it ensures optimal conditions for storage (Bala, 2016). The moisture content observed in this study was lower

compared to some previous research (Ullah et al., 2010) (9.76 - 10.6%), (Ogunyemi et al., 2018) (12.01%), and (Tizhe et al., 2022) (30-34%), but higher than that reported for Pakistan's maize (Sagbo et al., 2017) (6.09 - 11.57%). This may be due to the compost treatment likely contributing to lower moisture content in maize due to improved soil structure and water retention capabilities (Adugna, 2016).

Conversely, the macronutrient fertilizer treatment may have resulted in higher moisture content in maize due to the specific nutrient composition and application method of the fertilizer. Furthermore, macronutrient fertilizers typically contain nitrogen, phosphorus, and potassium, which can influence plant metabolism and water uptake, potentially leading to higher moisture levels in harvested grains (Ray et al., 2020).

This variability in moisture and ash content can be attributed to differences in soil water retention capacity and the water-holding capacity of organic amendments like compost (Adugna, 2016), while the variation in ash content likely reflects differences in mineral content and soil fertility levels across treatments (Lal, 2015).

The ash content (lowest in the compost treatment) generally fell outside the range reported by several other studies, including (Enyisi et al., 2014)(1.1-2.95%), (Adegbite et al., 2016) (3.76 - 4.39%), and (Sagbo et al., 2017)(91.09 - 5.46%). The yield of ash content is often correlated with the presence of essential macro and micronutrients in food samples, as highlighted by (Ndukwe et al., 2015), and thus has significant implications for human health and well-being (Mohajan, 2022, Afata et al., 2023).

Furthermore, the inorganic fertilizer treatment may have led to higher ash content in maize due to the specific micronutrients provided, such as iron, zinc, copper, and manganese that are essential for various physiological processes in plants, including enzyme activation and metabolism, which can affect the mineral composition of maize grains. Additionally, the compost may have facilitated nutrient uptake and utilization, leading to increased mineral content and thus higher ash content in maize grains.

Maize yield quality parameters such as crude protein, crude fat contents, crude fiber, total carbohydrate, and gross energy indicated significant differences among the treatments. In terms of

crude protein content, the highest value was observed in maize flour from pots containing compost. These findings are in line with previous studies by (Adegbite et al., 2016) (9.24 - 11.58%), (Ogunyemi et al., 2018)(4.58 - 7.24%), and (Ullah et al., 2010)(7.71 - 14.60). This suggests that compost amendments may enhance nitrogen availability and promote higher protein synthesis in maize plants (Mäder et al., 2002) and genetic variability of maize seeds (Fahrurrozi et al., 2017). Furthermore, environmental factors, including soil type, climate, and agricultural practices can influence their nutritional composition (Bouis et al., 2011).

Also crude fat content was the highest in maize in the compost treatment and then in line with results from other studies (Ullah et al., 2010)(2.17- 4.43%), (Ogunyemi et al., 2018) (3.84 - 4.61%) and (Sagbo et al., 2017) (2.87 - 12.54%). The observed differences in nutrient levels may be attributed to various factors, including genetic variability of maize and environmental factors such as soil moisture and temperature, which can influence the fiber content of maize grains (xu et al., 2017).

Furthermore, the highest amount of crude fiber was found in maize from pots receiving inorganic micronutrient fertilizers and glyphosate, also in line with findings by (Adegbite et al., 2016) (64.02- 67.68), (Ogunyemi et al., 2018) (76.85- 80.31%), and greater than (Ullah et al., 2010)(69.66 - 74.55) and (Kabir et al., 2019)(82.40%). The variations in total fiber content (TF) may be associated with variances in soil organic matter content and microbial activity (Cumming et al., 2014). Carbohydrate and gross energy content varied significantly among treatment groups. Such variability could stem from differences in nutrient availability and soil microbial activity, ultimately affecting the carbohydrate content and energy content of maize grains (Majumdar et al., 2014).

Moreover, iron, manganese, copper, and zinc content differed significantly among treatment groups. This variation may be attributed to differences in soil pH and organic matter content (Abadía et al., 2011, Mukherjee and Kabata Pendias, 2007). Compost amendments positively impacted nutrient content and composition, emphasizing their importance in enhancing soil fertility and crop quality. Conversely, glyphosate treatment and micronutrient fertilizer treatment showed contrasting effects on nutrient availability and composition.

### **3.4. Conclusion**

The study emphasizes the substantial impact of inorganic mineral fertilizers and agrochemicals on soil properties, maize yield, and quality, including soil and plant micronutrient concentrations. Compost-treated soils exhibited the highest mesophilic bacterial and fungal count with higher Fe and Zn micronutrient concentrations. The glyphosate-treated soil showed the lowest micronutrient levels. Additionally, the presence of inorganic fertilizers and glyphosate resulted in a decrease in key soil parameters such as pH, electrical conductivity, and organic matter. Maize from the agrochemical-treated pots generally displayed low crude protein, total fat, total carbohydrates, gross energy, and total fiber levels.

These findings suggest that soil fertility in the western Ethiopia region, where small-scale farmers farm, may be compromised due to the extensive use of inorganic fertilizers and agrochemicals. To address this issue, it is recommended to implement sustainable agricultural practices that reduce reliance on agrochemical inputs, promote soil conservation measures, and adopt soil fertility enhancement techniques such as organic farming methods. Additionally, educating farmers on proper agrochemical usage through farmer education programs can help mitigate the adverse effects on soil health and crop productivity in the long term.

**Chapter four: Prevalence of pesticide use and occupational exposure among small-scale farmers in western Ethiopia**

Afata TN, Mekonen S, Shekelifa M, Tucho GT. Prevalence of Pesticide Use and Occupational Exposure Among Small-Scale Farmers in Western Ethiopia. *Environmental Health Insights*. 2022;16. doi:10.1177/11786302211072950

## **Abstract**

**Objective:** This study aims to assess the prevalence of pesticide use and its occupational exposure among small-scale farmers in the Kellem Wellega Zone of western Ethiopia.

**Methods:** A cross-sectional study design using a structured questionnaire was used to collect data from 249 small-scale farmers' households through face-to-face interviews. Statistical analysis such as descriptive statistics, Chi-square test, and binary logistic regression analysis was applied, and a p-value < 0.05 at 95%CI was considered statistically significant.

**Results:** The prevalence of pesticide use was 87.15%. About 40.16, 49.8, and 47.8% of the study participants were classified as having poor knowledge, poor practice, and negative attitude towards pesticide use, respectively. Thus, small-scale farmers whose age was greater than 40 years were 7.87 times more likely to be exposed to skin irritation than those whose age was less than 20 years (AOR = 7.87; 95% CI 1.75 - 35.45) and skin contact (AOR= 0.37; 95% CI 0.15 - 0.91). Most farmers who were directly involved in agriculture were 2.22 times more likely to be exposed to the inhalation of pesticide chemicals than those involved in another activity (AOR= 2.22; 95% CI 1.14 - 4.33). Based on educational level, small-scale farmers who have a primary school and above were 81% less likely to inhale pesticide chemicals than those who did not have formal education (AOR= 0.19; 95% CI 0.09 - 0.41). Furthermore, low-income small-scale farmers were 2.62 times more likely to be exposed to coughing (AOR= 2.62; 95%CI: 1.25 - 5.51) than high-income participants. Furthermore, farmers with good knowledge were 1.79 times more likely to be exposed to skin irritation than those with poor knowledge (AOR= 1.79; 95%CI: 1.0 - 3.17). Farmers with poor practice were 1.85 times more likely to show coughing symptoms than those with good practice (AOR=1.85; 95%CI: 1.08 - 3.2), and farmers with good practice were 48% less likely to be exposed to headache than those with poor practice (AOR= 0.52; 95%CI: 0.31- 0.88).

**Conclusions:** This study shows that small-scale farmers were exposed to pesticides through coughing, headache, skin irritation, inhalation, and skin contact. Due to low level of knowledge, poor practice, job, low income, older age, and educational level

**Keywords:** Ethiopia farmer, Pesticide exposure, Prevalence of pesticide use

#### 4.1. Introduction

Pesticides are any substance used to control certain forms of pests from plant or animal life (Bertomeu-Sanchez, 2019). On the other hand, the unprotected use of these chemicals can pose serious risks to human health and the environment.(Damalas and Koutroubas, 2016). The negative effects of exposure to pesticide chemicals during agricultural activities are high in farmers (Wang et al., 2016, Lebov et al., 2016).

According to World Health Organization (WHO) reports, more than 200,000 people are killed from pesticide poisoning each year in rural areas of developing countries (Damalas and Koutroubas, 2016). Most health problems are caused by long-term exposure to pesticides. Acute symptoms such as headaches, nausea, respiratory problems, vomiting, dermatitis, leukemia, mental disorders, brain tumors, and burns are widely experienced among farmers in African countries (Koh et al., 2017, Van Maele-Fabry et al., 2017, Chen et al., 2016, Malagoli et al., 2016, Lebov et al., 2015). Cognitive, motor, sensory, and neurological deficiencies were among the symptoms of chronic exposure of pesticide users (Muñoz-Quezada et al., 2016).

Evidence suggested that farmers' exposure could occur accidentally in the course of mixing, loading, spraying, in direct contact with treated vegetation by spraying, during cleaning up of spraying equipment, and vapor drift from volatilized deposits of pesticides because of not using PPE (Damalas et al., 2019, Ouedraogo et al., 2014).

Furthermore, the consumption of contaminated food, the proximity to agricultural fields, and the occupation of agriculture were some of the possible mechanisms of exposure to pesticides by small farmers (Mekonen et al., 2014, Akomea-Frempong et al., 2017, Akoto et al., 2015, Ali et al., 2018). However, the risk of exposure was based on the type, period, and route of exposure (Boccolini et al., 2017).

Occupational exposure to pesticides occurs commonly through inhalation, skin contact, and ingestion during the preparation of solutions and spraying conditions.<sup>19</sup> Thus, farmworkers are considered a primary risk group that receives a lot of exposure to pesticides (Jallow et al., 2017). Thus, farmworkers are considered a primary risk group that receives a lot of exposure to pesticides (Afata et al., 2022, Afata et al., 2021). The adverse effects of pesticides on health are increasing in

developing countries due to low educational levels and unfavorable working conditions (Sharifzadeh et al., 2019, Taghdisi et al., 2019).

Moreover, lack of knowledge, training, and unintentional application errors such as handling pesticides carelessly can pose serious health risks to farmers (Negatu, 2017, Afata et al., 2021). Since farmers' knowledge, practice, and attitude level of farmers on potential pesticide hazards is essential in preventing pesticide exposure (Gesesew et al., 2016, Taghdisi et al., 2019).

Finally, the health risks of farmworkers commonly concerned with agricultural activities were associated with occupational exposure to pesticides. To our knowledge, there are gaps in available data on the prevalence of pesticide use, knowledge and practice about pesticides, occupational exposure, and associated risks in small-scale farmers. Therefore, this study investigates the prevalence of pesticide use and its occupational exposure among small-scale farmers (SSFs) in the Kellem Wellega zone, western Ethiopia.

## **4.2. Materials and Methods**

### **4.2.1. Study site**

The study was carried out from May to June 2020 in the Kellem Wellega zone of the Oromia region, western Ethiopia. It was 672 km from Addis Ababa, the capital of Ethiopia. In ten districts in this region, there was a total population of 965,000. Of the total population, 51.3 % were men. The total number of households in the zone was 175000, with an average family size of 5.5 (EDHS, 2016).

It has a tropical highland climate with bimodal rainfall ranging from 1,200 to 2,000 mm annually. The topography is diverse, with elevations between 1,200 and 2,600 meters, featuring plains, hills, and mountains. Agriculture, mainly subsistence-based, is the key economic activity, with crops like maize, teff, sorghum, and coffee, the latter being a major cash crop (Ademe et al., 2020). To enhance agricultural output, farmers commonly employ pesticides including insecticides, herbicides, and fungicides to combat pests, weeds, and fungal infections, respectively. The zone's vegetation includes tropical highland forests, though deforestation for farming is widespread. Despite fertile Nitisol soils in the highlands, socioeconomic challenges such as limited infrastructure and market access hinder development (Asefa et al., 2020). The map of the study area was indicated in Figure 4.1.

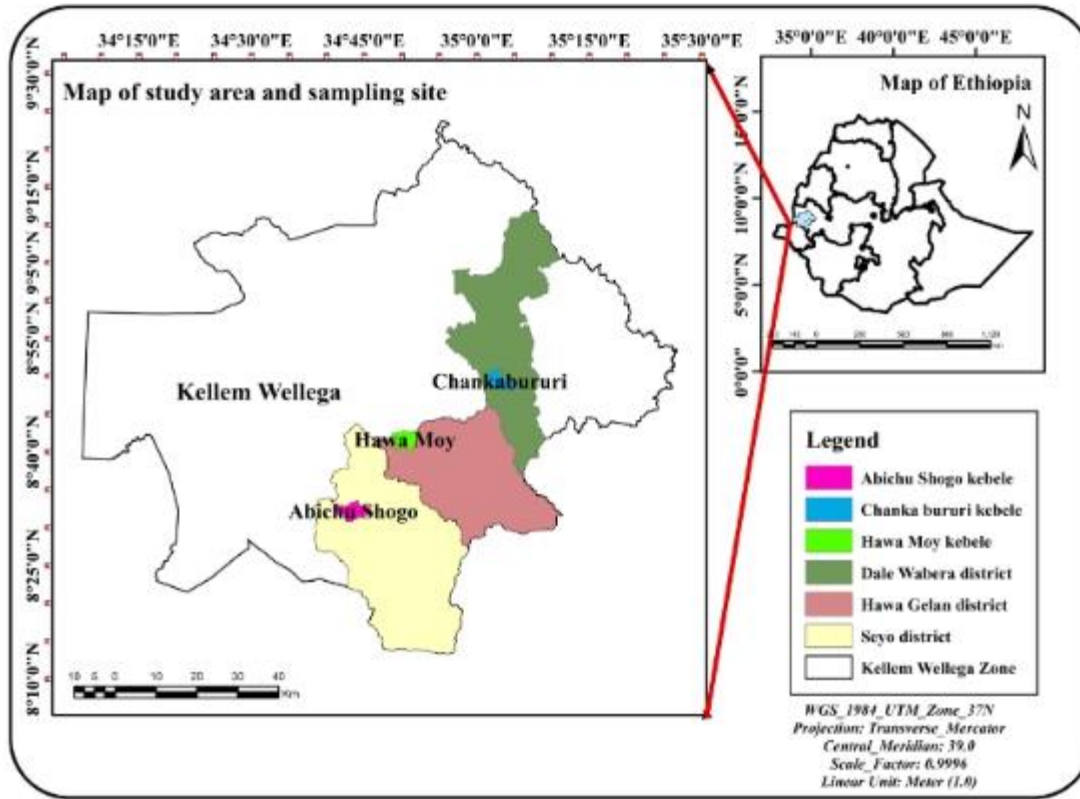


Figure 4.1. Study Area Map for Sayo, Hawa Gelan, and Dale Wabara districts in the Kellem Wellega Zone of western Ethiopia in 2020

#### 4.2.2. Study design

A cross-sectional study was conducted that included 249 households of SSFs from May to June 2020, in western Ethiopia. Following the verbal agreement, the heads of families were interviewed face-to-face using a standardized pretested questionnaire. When the head of the household was not available, the interviewer was asked if the first adult over 18 years of age met in the household.

#### 4.2.3. Sample Size Determination

The sample size was determined using a single population proportion formula for one point estimation by considering a confidence level of 95 %, a margin of error of 5%, and 82 % of small-scale farmers practice on pesticides (Ligani, 2016) with a non-response rate of 10%.

$$n = \frac{(Z\alpha/2)^2(p)(q)}{(SE)^2} = \frac{(1.96)^2(0.82)(1-0.82)}{(0.05)^2}$$

$$n = 227,$$

By adding a 10 % non-response rate to the calculated sample size, it becomes  $227 + (227 \times 10 \%) = 250$ , participants were designed to participate at the household level.

#### 4. 2.4. Operational Definitions

**Small-scale farmers (SFFs):** Farmers who can produce crops on a small piece of land without using advanced and expensive technologies

**Pesticides exposure:** an exposure that may occur through occupational exposure in the case of agricultural workers in open fields and house pests

**Pesticide Use:** are substances or mixtures of substances that are mainly used in agriculture or in public health protection programs to protect plants from pests, weeds, and diseases

**Self-reported symptoms:** is single, short-term exposure effects appear immediately and are often reversible. The self-reported symptoms related to coughing, headache, vomiting, skin irritation, and abdominal pain

**Exposed small-scale farmers (ESSFs):** Farmers who can produce crops using pesticide chemicals on their own for at least one year and more in the same area

**Non-Exposed Small-Scale Farmers (NESSFs):** Farmers practicing organic farming and having no history of chemical exposure to pesticide chemicals for at least one year before the study and who did not reside near a vegetable farm were also considered (Afata et al., 2021)

**Kebele(s):** (Amharic term standing for 'neighborhood') is a small administrative unit in urban and rural Ethiopia comprising around 500 households per unit.

#### 4.2.5. Sampling Techniques

Data were collected from three districts: Sayo, Hawa Galan, and Dale Wabara in the Kelleme Wellega zone in western Ethiopia. A three-stage sampling was used to select small-scale farmers for this study. First, three districts were purposively selected from the ten districts in the Kelleme Wellega zone based on their potential for agricultural products and the number of pesticides used per year. Second, three kebeles, namely Abichu Shogo from the Sayo district, Hawa Moy from the Hawa Galan district, and Chanka Bururi from Dale Wabara, were purposively selected in communication with zonal agricultural experts. According to the information from experts, most small-scale farmers in the study areas used pesticides. Third, each household was randomly selected from each kebele.

Therefore, a total of 249 households study participants were selected using the lottery method, and a systematic sampling method ( $k = N/n = 700/249 = 2.8 = 3$ ) was used to select the rest of the households.

#### **4.2.6. Data collection**

Face-to-face interviews were used to collect data using a standardized and pretested questionnaire (Afata et al., 2021, Gesesew et al., 2016). The questionnaire was written in English and then translated into Afan Oromo and then back into English to ensure that the translation was correct. The questions were pretested to ensure that the data collection instrument was complete. Sociodemographic factors, knowledge, practice, attitude, types of pesticides used, acute health symptoms (coughing, headache, vomiting, skin irritation, and abdominal pain) within 48 hours of exposure to pesticides and pesticide exposure routes such as ingestion, inhalation, and skin contact are included in the questionnaire. Those who had experienced this and reported two or more typical pesticide intoxication symptoms were considered.

Before being assigned to data collection, three agricultural extension workers and supervisors were trained for two days. Based on their reports, those participants who scored below the mean value of the responses for 10 items related to farmer knowledge about pesticide use were considered to have 'poor knowledge,' while those with scores above or equal to the mean value were considered to have 'good knowledge.' Participants who scored less than the mean value of responses to 10 questions related to farmer practices in pesticide use were labeled as having 'poor practice', while those who scored above or equal to the mean value were labeled as having 'good practice'. The level of farmer attitude towards pesticide use was evaluated for participants who scored less than the mean value of the response for 10 questions related to attitude towards pesticide use were considered as having a 'negative attitude' and those who scored more than the mean value were considered to have a 'positive attitude'.

#### **4.2. Data Analysis**

Data were checked and entered into SPSS version 23.0 (IBM Corp., Armonk, NY, USA). Descriptive analysis such as mean, standard deviation for continuous data, percentage, and frequency for categorical data. Chi-square tests and logistic regression analysis were performed to

determine the impact of the predicting variables (sociodemographic characteristics, knowledge, practice, and attitude) on the outcome variables (coughing, headache, vomiting, skin irritation and abdominal pain, ingestion, inhalation, and skin contact). Logistic regression analysis was used to adjust the confounders. All explanatory variables associated with the outcome variable in the bivariate analysis with a p-value of less than 0.25 were selected and further analyzed. The odds ratio and the 95% confidence interval were used to determine the effect of potentially associated variables on the outcome variable by controlling confounders. All variables with a P-value of < 0.05 were considered statistically significant associations with the exposure of small-scale farmers to pesticides.

### 4.3. Results

#### 4.3.1. Sociodemographic Characteristics

Of the two hundred forty-nine SSFs, the majority (88.4%) were male. The mean ages of the respondents were (40±0.45) years with 85.1% of them being married and 76.3 % being involved in farming activities. Additionally, approximately 39.8 % of the farmers were unable to write and read (Table 4.1).

Table 4.1: Sociodemographic status of SSFs in the Kellem Wellega Zone of western Ethiopia, 2020

Explanatory variables		Number	%
Sex	Male	220	88.4
	Female	29	11.6
Age	≤ 20 years	36	14.5
	21-40	128	51.4
	≥41	85	34.1
Head of the family	Yes	176	70.7
	No	73	29.3
Jobs	Farming only	190	76.3
	Other activities	59	23.7
Marital status	Single	28	11.3
	Married	212	85.1

	Divorced or Windowed	9	3.6
Educational level	Unable to write and read	99	39.8
	Primary school	111	44.6
	Secondary school and above	39	15.6
Total		249	100%

\*Other activities (daily laborers, private business, non-government and civil servants)

#### 4.3.2. Prevalence of pesticide use among small-scale farmers

The prevalence of pesticide use among farmers in Dale Wabara, Hawa Gelan, and Sayyo districts of the Kellem Wellega zone in western Ethiopia was 90 %, 83.3 %, and 87.7 %, respectively. The overall prevalence of current pesticide use was 217 (87.2 %) and 32 (12.8 %) of the study participants did not use chemical pesticides to increase agricultural productivity (Table 4.2).

Table 4.2: Previous and current use of pesticides used by SSFs in the Kellem Wellega Zone in western Ethiopia, 2020

Name of districts	Number	%
Dale Wabara	90	81 (90)
Seyo	81	71 (87.7)
Hawa Galan	78	65 (83.3)
Overall prevalence	249	217 (87.2)

Among the common pesticide chemicals used in the study area were 2, 4-D (69.1 %), glyphosate (41.4 %), diazinon (26.5 %), malathion (55.4 %), DDT (8.4%), mancozeb (25.7 %) and diazinon (26.5 %)(Table 4.3).

Table 4.3: Prevalence of pesticides used by SSFs in the Kellem Wellega Zone in western Ethiopia, 2020

Type of pesticides	Name of Districts			Total N(%)
	Dale Wabara (N= 90)	Hawa Gelan (N =78)	Sayyo (N= 81)	

2, 4-D*	69 (76.7)	45 (57.7)	58 (71.6)	172(69.1)
DDT**	4 (4.4)	11(14.1)	6 (7.4)	21(8.4)
Glyphosate	34 (37.8)	27 (34.6)	42 (51.9)	103 (41.4)
Diazinon	29 (32.2)	12 (15.4)	25 (30.9)	66 (26.5)
Malathion	59 (65.6)	37 (47.4)	42 (51.9)	138 (55.4)
Mancozeb	27 (30)	13 (16.7)	24(29.6)	64 (25.7)

\*2, 4-dichlorophenoxyacetic acid; \*\* Dichlorodiphenyltrichloroethane

### 4.3.3. Factors related to occupational exposure of SSFs

#### 4.3.3.1.. Knowledge of farmers on the safe use of pesticides

Although 87.2 % of small-scale farmers used pesticides for their agriculture, only 42.2 % know the safe use of pesticides. Most of them were used for weed control (52.6 %). Approximately 76.3 % of participants believed that pesticides are useful; however, they did not know the harmful effect of pesticides on humans and the environment in general. Most farmers did not have training (83.9 %) on handling and using pesticides.

Approximately 85 % of them were used above the recommended concentrations and purchased from private companies, illegally at low cost. Most of the participants (93.6 %) did not know the appropriate distance for mixing and loading pesticides from residential areas and water streams. Additionally, 67 % of farmers carelessly disposed of leftover pesticides in open fields, and 40.6 % stored in unsafe places, potentially exposing them. The mean score of knowledge on pesticide use was found to be  $49.03 \pm 0.5$ , which is summarized in Table 4.4. Consequently, 40.16 % of small-scale farmers who scored below the mean had poor knowledge about the safe use of pesticides.

Table 4.4: Knowledge of SSFs about the use of pesticides in the Kellem Wellega zone of western Ethiopia, 2020

Explanatory variables	Number	%
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Have you ever used pesticides?	Yes	217	87.2
	No	32	12.9
Know how to use pesticides safely?	Yes	105	42.2
	No	144	57.8
Pesticide retailers	Government	15	6.0
	Private	138	55.4
	Both government & private	72	28.9
	I don't use	24	9.6
Purpose of using pesticides	Fungi control	67	26.9
	Weed control	131	52.6
	Pest control	10	4.0
	Mixed-use	9	3.6
	I don't use	32	12.9
How can you consider pesticide chemicals?	Useful	190	76.3
	Harmful	40	16.1
	Both useful and harmful	19	7.6
Have you ever had any training on how to use and handle pesticides?	Yes	40	16.1
	No	209	83.9
Identifying the quantity of pesticides used?	Yes	37	14.9
	No	212	85.1
Knowing the distance of mixing from home, river?	Yes	16	6.43
	No	233	93.6
Pesticides storage	Stored everywhere	101	40.6
	Stored in the kitchen	57	22.9
	In mixed place	48	19.3
	In separate place	13	5.2
	I don't use	30	12.1
What are the trends in the amount and frequency of pesticides used in the last few years?	Increase	185	74.3
	Decrease	64	25.7

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Level of knowledge	Poor (< 49.03 %)	100	40.2
	Good ( $\geq$ 49.03 %)	149	59.8
Total		249	100%

#### 4.3.3.2. Practice pesticides use

Among farmers who have been using pesticides for more than 10 years (49%), still, 96.8% of them do not understand the instruction and labeling provided by the users in the pesticide containers (96.8 %). Small-scale farmers involved in spraying activities were more likely to be exposed to pesticides by eating and drinking (26.1 %), chewing chat (16.1%), smoking (26.9 %), performing different exposing activities (18.1%), and using damaged equipment during spraying (15.7 %). Around 40.6 % of farmers used more than four liters of pesticide chemicals for small land size. As Table 4.5 shows, the mean score of the farmers' practices for safe use of pesticides was found to be  $50.64 \pm 0.5$ . Almost half of them scored below mean values and had a poor practice that makes them more vulnerable to pesticide chemicals.

Table 4.5: Practice of SSFs towards pesticides use the Kellem Wellega Zone of western Ethiopia, 2020

Explanatory variables		Number	%
Working experience with pesticides	< 3 years	61	24.5
	3 - 10 years	34	13.7
	> 10 years	122	49
	I don't use	32	12.9
Understanding the labeled instruction	Yes	8	3.21
	No	241	96.8
Who sprays pesticides	Employ	78	31.3
	Father	99	39.8
	Mother	40	16.1
	I don't use	32	12.9
Activities performed during spraying	Eat and drink	65	26.1
	Chewing chat	40	16.1

	Smoking	67	26.9
	Mixed activities	45	18.1
	I don't use	32	12.9
Types of spraying equipment	Backpack	216	86.8
	Handhold	33	13.3
Condition of the equipment	Damaged	39	15.7
	Not damaged	178	71.5
	I do not use	32	12.9
Weather condition during pesticide spraying	Humid and cold	25	10.0
	Dry and hot	192	77.1
	I don't use	32	12.9
Crop area	0 - 2 hectare	203	81.5
	2.1-4 hectare	37	14.9
	> 4 hectare	9	3.6
Amount of pesticide	0- 2 liter	8	3.2
	2.1-4 liter	108	43.4
	> 4 liter	101	40.6
	I don't use	32	12.9
Frequency of application	Once times a year	83	33.3
	Two times a year	88	35.3
	Three times a year or more	46	18.5
	I don't use	32	12.9
Overall pesticide use practice	Poor (< 50.64%)	124	49.8
	Good ( $\geq$ 50.64%)	125	50.2
Total		249	100%

#### 4.3.3.3. Attitude of farmers towards the use of pesticides

Approximately 84.3 % of small-scale farmers did not use PPE during spraying. Some farmers mixed and washed their containers in the house (26.1%), and rivers (24.1%). About 47.39 % of small-scale

farmers never follow the instruction on the label of the pesticide containers. Regarding sprayer hygiene, (57.4 %) wash only hands, (22.9 %) bathe, and (6.8 %) change clothes before or after spraying. During mixing and spraying (71.1 %) mentioned that pesticides spill onto their body, (42.6 %) spraying against the wind, and (50.2 %) of the farmers were re-entered in a recently sprayed farmland. Some farmers did not know the final fate of pesticides (38.2 %) and (59 %) used pesticide equipment for other purposes.

Regarding the container of pesticides that uses them as home utensils (53.4 %), thrown into fields (7.6 %), sold to others (8.8 %), disposed of in streams (12.4%), mixed-use (4.4%), buried, and burned (1.6 %) and returned to a disposing agent (2 %). In general, Table 4.6 shows that the mean score of farmers' attitudes towards pesticide use was  $47.8 \pm 0.49$ . About 47.8% of the participants who scored below the mean had a negative attitude toward pesticides.

Table 4.6: Attitude of SSFs toward pesticide use in the Kellem Wellega Zone of western Ethiopia, 2020

Explanatory variables		Number	(%)
Can you understand the information written on the pesticide packages?	Yes	131	52.6
	No	118	47.4
Should you wear protective equipment during spraying?	Yes	39	15.7
	No	210	84.3
Appropriate locations for mixing pesticide or washing container	House	65	26.1
	River	60	24.1
	Farmland	53	21.3
	Mixed	39	15.7
Have you ever spilled pesticides on your body?	I don't use	32	12.9
	Yes	177	71.1
How can you prevent the splash of pesticides during spraying?	No	72	28.9
	Washing only hands	143	57.4
Practices after spraying	Bathing	57	22.9
	Changing clothes	17	6.8

	I don't use	32	12.9
Spraying against the wind	Yes	106	42.6
	No	143	57.4
Entering recently sprayed farmland	Yes	67	26.9
	No	182	73.1
Did farmers use empty pesticide equipment for other purposes?	Yes	147	59.0
	No	102	41
Do you think pesticides empty materials can harm your health?	Yes	154	61.9
	No	95	38.2
What solutions do you suggest for the empty pesticide container disposal methods?	Home use reuse at home	133	53.4
	Thrown into fields	19	7.6
	Sold to others	22	8.8
	Thrown into streams	31	12.5
	Mixed-use	11	4.4
	Buried or burned	4	1.6
	Return to disposing agent	5	2.0
	I don't use	24	9.6
Level of attitude	Poor (< 47.89 %)	119	47.8
	Good ( $\geq$ 47.89 %)	130	52.2
Total		249	100%

#### 4.3.3.4. Acute health symptoms of SSFs

The results of this study showed that nearly all agricultural farmers have symptoms of acute health after using pesticides. The most often symptoms linked to pesticides use includes coughing (61 %), headache (62.7%), vomiting (41.8 %), skin irritation (29.3 %), and abdominal pain (28.1 %)(Table 4.7).

Table 4.7: Acute health symptoms of SSFs during pesticide application of SSFs in the Kellem Wellega Zone in western Ethiopia, 2020

Outcome variables	Yes	%	No	%
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Coughing	152	61	97	39
Headache	156	62.7	93	37.3
Vomiting	104	41.8	145	58.2
Skin irritation	73	29.3	176	70.7
Abdominal pain	70	28.1	179	71.9

#### 4.3.3.5. Determinant of health symptoms

The formulation of pesticides was an essential factor in human exposure to pesticide chemicals. The liquid mist was the predominant type of farmers' exposure that takes place during the production, transportation, preparation, and application of pesticides in the workplace. In the study area, agricultural occupations pesticide exposure occurs via through the main route of inhalation (51.4%), ingestion (59.8 %), and skin contact (58.6 %).

Thus, SSFs whose age was greater than 40 years were 7.87 times more likely to be exposed to skin irritation than those whose age was less than 20 years (AOR = 7.87; 95% CI 1.75 - 35.45) and skin contact (AOR= 0.37; 95% CI 0.15 - 0.91). Most farmers who were directly involved in agriculture were 2.22 times more likely to be exposed to the inhalation of pesticide chemicals than those involved in another activity (AOR= 2.22; 95% CI 1.14 - 4.33). Based on educational level, small-scale farmers who have a primary school and above were 81% less likely to be inhaled than those who did not have formal education (AOR= 0.19; 95% CI 0.09 - 0.41).

Furthermore, low-income SSFs were 2.62 times more likely to be exposed to coughing (AOR= 2.62; 95%CI: 1.25 - 5.51) than high-income participants. Additionally, farmers with good knowledge were 1.79 times more likely to be exposed to skin irritation than those with poor knowledge (AOR= 1.79; 95%CI: 1.0 - 3.17). Farmers with poor practice were 1.85 times more likely to show symptoms of coughing than those with good practice (AOR=1.85; 95%CI: 1.08 - 3.2), and farmers with the good practice were 48% less likely to be exposed to headache than those with poor practice (AOR= 0.52; 95%CI: 0.31- 0.88)

Table 4.8 shows the bivariate analysis of exposure to pesticides with sociodemographic characteristics, knowledge, practice, attitude, route of exposure, and self-reported symptoms of exposure to pesticides. In the analysis: age, job, educational level, knowledge, and practice were significantly associated with a p-value < 0.05 with the outcome variables of coughing, headache,

skin irritation, inhalation, and skin contact. The remaining variables were not significantly associated with the outcome variables. The results of the logistic regression analysis of the exposure of farmers to pesticide use and associated factors are summarized in Table 4.8. In study jobs, educational level, knowledge, practice, coughing, headache, skin irritation, inhalation, and skin contact are significantly associated with the exposure of farmers to pesticide chemicals.

. Thus, SSFs whose age was greater than 40 years were 7.87 times more likely to be exposed to skin irritation than those whose age was less than 20 years (AOR = 7.87; 95% CI 1.75 - 35.45) and skin contact (AOR= 0.37; 95% CI 0.15 - 0.91). Most farmers who were directly involved in agriculture were 2.22 times more likely to be exposed to the inhalation of pesticide chemicals than those involved in another activity (AOR= 2.22; 95% CI 1.14 - 4.33). Based on educational level, small-scale farmers who have a primary school and above were 81% less likely to be inhaled than those who did not have formal education (AOR= 0.19; 95% CI 0.09 - 0.41).

Furthermore, low-income SSFs were 2.62 times more likely to be exposed to coughing (AOR= 2.62; 95%CI: 1.25 - 5.51) than high-income participants. Additionally, farmers with good knowledge were 1.79 times more likely to be exposed to skin irritation than those with poor knowledge (AOR= 1.79; 95%CI: 1.0 - 3.17). Farmers with poor practice were 1.85 times more likely to show symptoms of coughing than those with good practice (AOR=1.85; 95%CI: 1.08 - 3.2), and farmers with the good practice were 48% less likely to be exposed to headache than those with poor practice (AOR= 0.52; 95%CI: 0.31- 0.88).

Table 4.8: Results of the logistic regression analysis of self-reported symptoms of SSFs and associated factors in the Kellem Wellega zone of western Ethiopia, 2020

Explanatory variables		Coughing		Headache		Skin Irritation	
		Yes	No	Yes	No	Yes	No
		152 (61 % )	97 (39 %)	156(62.7 %)	93(37.3%)	73 (29.3 %)	176(70.7%)
		COR	AOR	COR	AOR	COR	AOR
Age	≤ 20 years	0.45 (0.19- 1.08)	0.46 (0.19-1.12)			1	1
	21-40	0.93 (0.53-1.62)	1.0 (0.56- 1.79 )			9.27 (2.08 - 41.30)*	7.87 (1.8-35.5)*
	≥41Years	1	1			1.16 (0.65 -2.07)	1.23 (0.68- 2.21)
Jobs	Farming	1	1			1	1
	Other activities	0.68 (0.37 -1.27)	1.41 (0.73-2.71)			2.13 (1.12- 4.05 )*	0.89 (0.44-1.78)
Education	Non-formal Primary school			1 1.59 ( 0.74- 3.43 )	1 2.25 (0.94-5.4)		
	Secondary school and above			1.15 ( 0.54- 2.48)	1.89 (0.8-4.5)		
Income	<1000 birr	0.49 ( 0.1- 2.48 )	0.52 (0.1-2.66)				
	1000 - 2000	2.84 (1.37-	2.62 (1.25 -				

		5.92)*	5.51)*		
	2000 -	1.35	1.38		
	3000	(0.66-2.73 )	(0.64 -2.81)		
	> 3000	1	1		
Level of	Poor	1	1	2.15	1.79
				(1.24- 3.75)*	(1.0 -3.17)*
knowledge	Good	0.66(0.39-1.1)		1	1
Level of	Poor	0.48	1.85	1.91	0.52
Practice		(0.28-0.81)*	(1.08 - 3.2)*	(1.14-3.22)*	(0.31-0.88)*
	Good	1	1	1	1

Table 6 continued...

Explanatory variables		Inhalation		Skin contact	
		Yes	No	Yes	No
		149 (59.8%)	100 (40.2%)	158 (63.5%)	91 (36.5%)
		COR	AOR	COR	AOR
Age	≤ 20 years			0.37 (0.2 -0.90)*	0.37 (0.15 -0.91)*
	21-40 (128)			0.73(0.41 -1.27 )	0.73(0.42-1.28)
	≥ 41 Years			1	1
Jobs	Farming	2.13(1.12-4.05)*	2.22(1.14 -4.33)*		
	Other activities	1	1		

Educational level	Non-formal	0.32(0.15 -0.68 )*	0.31(0.14 - 0.68)*
	Primary school	0.19 (0.09-0.42)*	0.19 (0.09 - 0.41)*
	Secondary school and above	1	1
Level of knowledge	Poor		1.5(0.89 -2.52)
	Good		0.71(0.41 -1.22)
			1
			1

SSFs: Small-Scale Farmers; COR: Crude Odd ratio; AOR: Adjusted Odd Ratio; CI: Confidence interval, \* < 0.05; \*\*< 0.01, other activities (daily laborers, private business, non-government and civil servants)

#### 4.4. Discussion

This study assessed the prevalence of pesticide use and occupational exposure of small-scale farmers in the Kellem Wellega zone of western Ethiopia. Therefore, 87.2% of small-scale farmers have used at least one or more pesticide chemicals for agricultural purposes (Table 2). This is higher than the study report from southern Ethiopia (83.3%) and southwest (82%) of Ethiopian farmers (Gesese et al., 2016, Ligani, 2016). This showed that there is an increasing trend in the use of chemical pesticides among small-scale farmers (Afata et al., 2022).

Thus, SSFs whose age was greater than 40 years were 7.87 times more likely to be exposed to skin irritation than those whose age was less than 20 years (AOR = 7.87; 95% CI 1.75 - 35.45) and skin contact (AOR= 0.37; 95% CI 0.15 - 0.91)(Table 8). This reveals that younger groups would be convenient for the recommended PPE on pesticides use as compared to older SSFs who could use more pesticides to maximize their products (Jallow et al., 2017) and due to bioaccumulation of pesticides from past exposure and decreasing rates of excretion with increasing age for small-scale farmers (Afata et al., 2021, Ben Hassine et al., 2014).

Additionally, the educational level of small-scale farmers who have a primary school and above was 81% less likely to be inhaled than those who did not have formal education (AOR= 0.19; 95% CI 0.09 - 0.41). In this study, about 47.4 % and 96.8 % of the participants never followed and understood the labeled instruction, respectively. This is due to their low educational level and their instructions, often written in foreign languages (Table 5).

A study conducted in Pakistan revealed that 48.2 % of farmers did not follow the labeled instructions and in Kuwait, over 70 % of farmers did not read or follow the instructions on the pesticide label. Furthermore, low-income SSFs were 2.62 times more likely to be exposed to coughing (AOR= 2.62; 95%CI: 1.25 - 5.51) than high-income participants. These suggest that farmers in the study area were exposed to pesticide chemicals due to not using complete PPE since they cannot afford the price and are not easily available on market (Negatu, 2017).

On the other hand, farmers with good knowledge were 1.79 times more likely to be exposed to skin irritation (AOR=1.79; 95%CI: 1.0 -3.17) than those with poor knowledge and skin contact (AOR= 0.37; 95% CI 0.15 - 0.91). This was lower than the study reported from Egyptian (Mohammed et

al., 2018) and southern Ethiopian farmers (Ocho et al., 2016). This is due to the low awareness of the harmful effects of pesticides on humans and the environment (Ocho et al., 2016).

Additionally, the level of knowledge of farmers on the safe use of pesticides is very inadequate (Öztaş et al., 2018). Moreover, some farmers who had a sufficient level of knowledge of the safe use of pesticides did not implement their knowledge into practice (Taghdisi et al., 2019, Sankoh et al., 2016). Furthermore, exposure can occur through skin contact with contaminated hands after pesticide-related work (Jallow et al., 2017, Taghdisi et al., 2019).

Similarly, farmers with the poor practice were 1.85 times more likely to be exposed to coughing than those with good practice (AOR=1.85; 95%CI: 1.08 - 3.2), and farmers with the good practice were 48 % less likely to be exposed to headaches than those with poor practice (AOR= 0.52; 95% CI 0.31- 0.88). A similar report from the Philippines revealed that the most common self-reported symptoms were headache (64.1 %), cough (45.5 %), weakness (42.4 %), eye pain (39.9 %), and chest pain (37.4 %) (Lu, 2017).

Furthermore, 90% of the respondents to the Rwandan study show adverse health effects on farmers, such as intense headache, dizziness, stomach cramps, skin pain, itching, and respiratory distress after using pesticides (Ndayambaje et al., 2019). This could be due to practicing everyday activities without worrying during spraying, such as eating, drinking, smoking, chewing, and even using damaged backpack sprayer equipment to increase exposure (Gesese et al., 2016, Ocho et al., 2016).

In addition spraying within the hot and dry conditions usually results in rapid evaporation of pesticide chemicals (Ndayambaje et al., 2019) that can distract the proper spraying man and take the chemical off-target (Lu, 2017). Moreover, mixing the pesticides with bare hands, not wearing PPE, and carelessly disposing of leftover pesticides (Satya Sai et al., 2019) causes high exposure of SSFs to pesticide chemicals (Afata et al., 2021).

Some limitations are worthy of note, however, sample size and self-reported symptoms when spraying pesticides might introduce recall bias and may have difficulty recalling them a whole year or even a month previously. Furthermore, there may be inaccuracies in reporting on pesticide

chemical use history, frequency, training, and experience from both exposed and non-exposed SSFs that affect the result of past exposures.

#### **4.5. Conclusions**

The prevalence of pesticide use among small-scale farmers in western Ethiopia was 87.2%. In this study, small-scale farmers were exposed to coughing, headache, skin irritation, inhalation, and skin contact with pesticide chemicals due to low level of knowledge, practice and education, age, work, and low income. Finally, it is recommended that the Ministry of Agriculture and Rural Development, the Ministry of Health, and the Environmental Protection Authority work on integrated and continuous awareness creation programs that increase knowledge and practice on pesticide safety for small-scale farmers in Ethiopia.

**Chapter five: Evaluating the level of pesticides in the blood of small-scale farmers and its associated risk factors in western Ethiopia**

Redrafted from : Afata TN, Mekonen S, Tucho GT. Evaluating the Level of Pesticides in the Blood of Small-Scale Farmers and Its Associated Risk Factors in Western Ethiopia. *Environmental Health Insights*. 2021;15. doi:10.1177/11786302211043660

## Abstract

**Background:** The presence of agricultural pesticide residue can cause adverse health effects. The main objective of this study was to evaluate the level of pesticides in the blood of small-scale farmers (SSFs) and associated risk factors in western Ethiopia.

**Methods:** Across cross-sectional study was conducted in June 2020 using 240 blood samples, 140 from the exposed small-scale farmers (ESSFs) and 100 from non-exposed small-scale farmers (NESSFs).

The blood sample analysis was made for five organochlorines (OCs) and three synthetic pyrethroids (SPs) pesticides by gas-liquid chromatography with an electron capture detector (GC-ECD) method. Extraction and clean-up of the samples were made by using standard analytical methods. To define the relationships between the outcomes and explanatory variables, logistic regression models were used.

**Results:** The results shows that p,p'-DDT, heptachlor and deltamethrin were the most frequently detected pesticides with 96.4 , 95 and 100% in both ESSFs and NESSFs, respectively. The ESSFs blood samples have shown the highest mean concentrations of permethrin and p,p'-DDT( $1.26 \pm 0.15$ ) and ( $0.28 \pm 0.4$ )  $\text{mgL}^{-1}$ , respectively. SSFs under the age of 40 were 21% less likely to be exposed to permethrin than those above the age of 40 (Adjusted Odd Ratio, AOR, 0.21; 95% CI: 0.1- 0.44). Male SSFs were 17 times more likely to be exposed to heptachlor than females (AOR, 17.36; 95%CI: 7.34-41.09) and farmers with no formal education were 18 times more likely to be exposed to deltamethrin than those with primary schools and beyond (AOR, 18.1; 95 %CI: 4.53-72.06). Furthermore, SSFs that did not use PPE appropriately were 3.6 and 6.21 times more likely to be exposed to cypermethrin (AOR, 3.6; 95%CI: 1.94- 6.54) and p,p'-DDE(AOR, 6.21; 95%CI: 3.38-11.41) blood levels than those who did, respectively. SSFs that perform different activities like eating and drinking (11%), chewing (10%), and diverse activities (8%) were more likely to be exposed to p,p'-DDT than those farmers who didn't use pesticides.

**Conclusions:** This study identified a high concentration p,p'-DDE, p,p'-DDT, heptachlor, cypermethrin, permethrin, and deltamethrin in the blood of small-scale farmers. Older age, less education, and farmers with inappropriate PPE use are more likely exposed to pesticides.

Keywords: Blood, Ethiopia, Farmers, Pesticide residues, Risk factor

## 5.1. Introduction

Pesticides are any substance or combination of substances used to prevent, eliminate, repel, or mitigate pests (Us, 2018, Marrs and Ballantyne, 2004). Chemical pesticides are classified into families, including organochlorine pesticides (OCPs), organophosphates, and synthetic pyrethroids (SPs) (Huong et al., 2020, Gildden et al., 2010). These chemicals are mostly used in public health, agriculture, and forestry (Gildden et al., 2010, Coats, 1990). However, OCPs are persistent insecticides that have been worldwide regulated, and their widespread usage causes severe health and environmental problems (Lushchak et al., 2018, Ecobichon, 2001).

Furthermore, farmers in low and middle-income countries have been exposed by misuse, lack of understanding, poor application techniques, and a lack of personal protective equipment (PPE) during application (Khan et al., 2020, Donkor et al., 2016, Ecobichon, 2001). Some reviewed studies revealed that pesticides and their metabolites cause health risks problems. Those reported risks might be due to occupational pesticide exposure, a lack of post-registration monitoring mechanisms, or farmers' lack of awareness of pesticide storage, application, and disposal (Negatu et al., 2021, Elibariki and Maguta, 2017).

Additionally, the use of pesticides without knowing their toxicity and dosage might result in a severe of health problems (Barrón Cuenca et al., 2020). For instance, the excessive use of pesticides against pests has been found in the blood of vegetable-producing farmers, causing adverse health effects like headache, loss of consciousness, dark vision, blood pressure, cancer, diabetes, infertility, and Parkinson's disease (Prudence et al., 2019, Jalilian et al., 2018, Neghab et al., 2014).

Since occupational exposures to OCPs and SPs occur primarily by inhalation and dermal contact (Arcury et al., 2001). Families living near farms may be more exposed than the usual because of agricultural application drift (Dereumeaux et al., 2020). Its hydrophobic nature allows it to easily bind the biological membranes of phospholipid bilayers, implying bioavailability in human tissues (Lushchak et al., 2018). As a result, assessing the concentrations of OCPs and SPs in the blood reveals the level of exposure (Ramesh and Ravi, 2004).

Small-scale farmers (SSFs) may be exposed to pesticides through occupational exposure, formulation, handling, storage, transportation, and inappropriate application in the agricultural fields or through the food chain (Sankoh et al., 2016). Farmers are also exposed to pesticides through the

consuming of contaminated food with cypermethrin, permethrin, heptachlor, and deltamethrin (Huong et al., 2020, Ingenbleek et al., 2019, Akomea-Frempong et al., 2017, Mekonen et al., 2014, Akoto et al., 2013). Correspondingly, pesticide residues found in wheat and bovine milk samples were higher than permissible residue limits (Gill et al., 2020, Pirsahab et al., 2017, Gebremichael et al., 2013).

On the other hand, farmers engaged in the poor practice of pesticide handling activities have the risk of being exposed to pesticides (Ligani, 2016) and accumulate OCPs and SPs concentrations. Since humans hold the top place in the trophic level and become more prone to its harmful effects (Qiu et al., 2019). For this investigation, blood, plasma, milk, and adipose tissue samples were used to track the degree of exposure of small-scale farmers to lipophilic pesticides (Hardell et al., 2010). Human blood is the most accessible body fluid for determining pesticide concentration levels (Al-Daghri et al., 2019).

Ultimately, the blood assessment offers evidence of body pesticide exposure and provides indicators of body load of pesticide concentrations in small-scale farmers for OCPs and SPs. To our knowledge, there are gaps of data available on the level of OCPs and SPs with their associated factor with higher levels of pesticides in blood samples of small-scale farmers (SSFs) in Ethiopia that this study aims to fill in. Therefore, the objective of this study was to determine the blood level of pesticides in small-scale farmers in the Kellem Wellega zone, western Ethiopia.

## **5.2. Materials and Methods**

### **5.2.1. Study setting**

The study was conducted in the Kellem Wellega zone of the Oromia region, western Ethiopia. It is 672 km away from Addis Ababa, the capital city of Ethiopia. The zone is divided into 10 districts, with a total population of 965000 people, 49.75% of them are females (PSA, 2008). The zone has 175000 households, with an average household size of 5.5 (EDHS, 2016). The present study purposely selected three districts, namely Sayo, Hawa Gelan, and Dale Wabara considering their population, density, access to pesticide use, and convenience for the study. The study was conducted in June 2020.

It has a tropical highland climate with bimodal rainfall ranging from 1,200 to 2,000 mm annually. The topography is diverse, with elevations between 1,200 and 2,600 meters, featuring plains, hills, and mountains. Agriculture, mainly subsistence-based, is the key economic activity, with crops like maize, teff, sorghum, and coffee, the latter being a major cash crop (Ademe et al., 2020). To enhance agricultural output, farmers commonly employ pesticides including insecticides, herbicides, and fungicides to combat pests, weeds, and fungal infections, respectively. The zone's vegetation includes tropical highland forests, though deforestation for farming is widespread. Despite fertile Nitisol soils in the highlands, socioeconomic challenges such as limited infrastructure and market access hinder development (Asefa et al., 2020). The map of the study area was indicated in Figure 5.1.

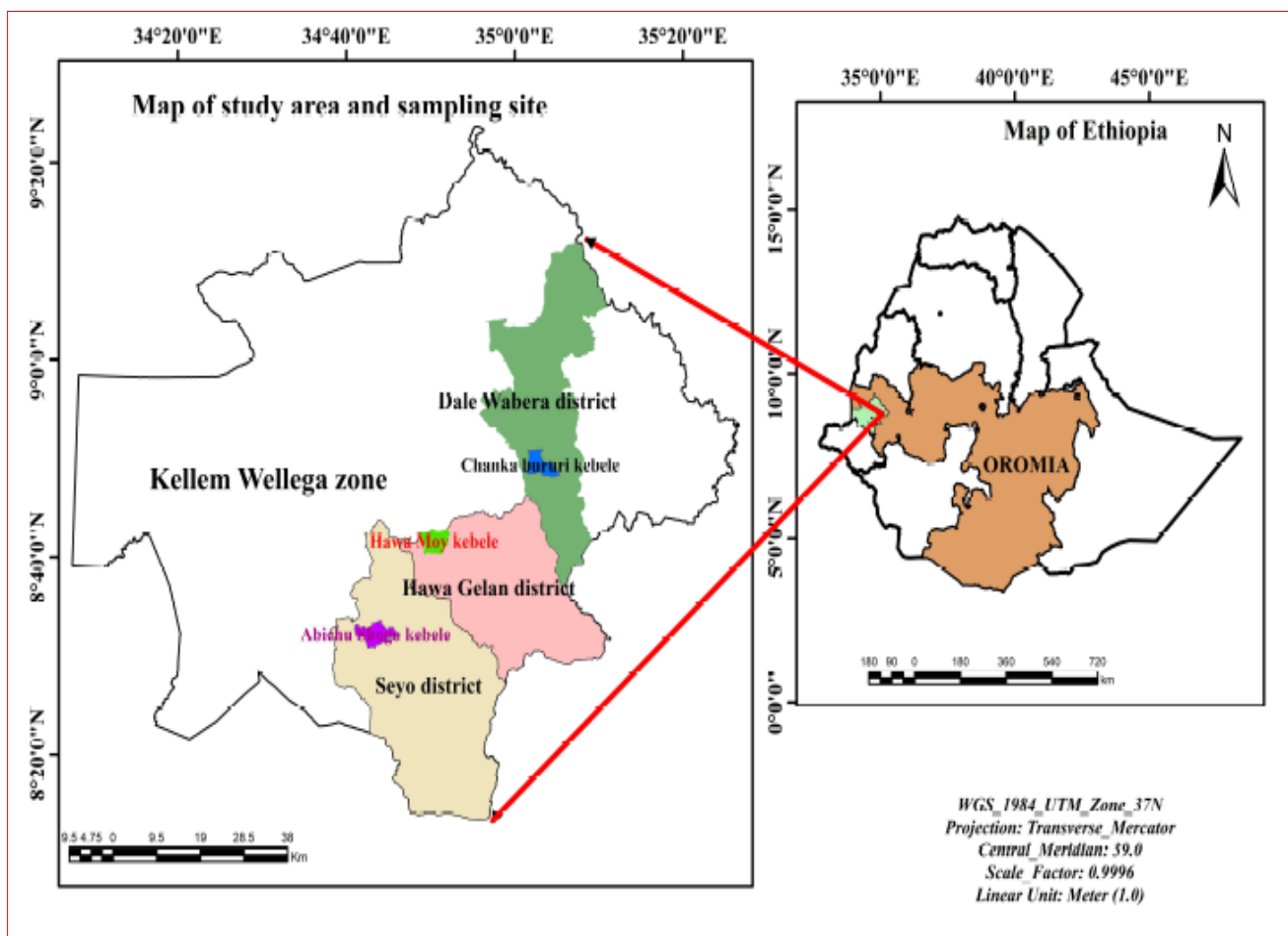


Figure 5.1. Study Area Map for Sayo, Hawa Gelan, and Dale Wabara districts in the Kellem Wellega Zone of western Ethiopia

### 5.2.2. Sample size determination

The sample size was determined using a single population proportion formula by considering 82% of small-scale farmers engaged in the poor practice of pesticide handling activities have the risk of being exposed to pesticides (Ligani, 2016), 95% confidence level, and 5% margin of error with a 10% non-response rate.

$$n = \frac{(Z\alpha/2)^2(p)(q)}{(SE)^2} = \frac{(1.96)^2(0.82)(1-0.82)}{(0.05)^2} = 227, \text{ by adding 10\% non-response rate, it becomes } 227 +$$

$(227 \times 10\%) = 250$  participants were intended to participate at the household level.

### 5.2.2. Sampling techniques

The data were collected from three districts: Sayo, Hawa Galan, and Dale Wabara in the Kellem Wellega zone of western Ethiopia, through a household survey, covering 250 small-scale farmers using pesticides. A three-stage sampling was used to select small-scale farmers for this study. First, three districts were chosen purposively out of ten districts in the zone based on their potential for agricultural products and pesticide use. Second, three kebeles, namely Abichu Shogo from the district of Sayo, Hawa Moy from the district of Hawa Galan, and Chanka Bururi from Dale Wabara, were again purposely selected by considering similar criteria and in consultation with zonal agricultural experts. Finally, households were selected by proportionally allocating the sample size to each kebele. The considered households from each kebele were randomly chosen for the study.

### 5.2.3. Operational definitions

**Small-scale Farming (SFFs):** is the production of crops on a small piece of land without using advanced and expensive technologies

**Exposed small-scale farmers (ESSFs):** Those farmers that must have used pesticides on their own for at least one year and above in the same area

**Non-exposed farmers (NESSFs):** After training the non-exposed grouped farmers were categorized by organic farming, no chemical exposure background because of using complete PPEs, following the labeled instruction, did not perform any activities during spraying, less frequency of pesticides usage per year, condition of the equipment was not damaged, and never spraying against the wind. Additionally, those farmers who did not use pesticides for at least one year before this research, and did not live near vegetable farming were considered.

#### **5.2.4. Inclusion and exclusion criteria**

Individuals under 18 years and those unwilling to give their consent were excluded from the study. SSFs chosen for exposed groups must have used pesticides for at least one year and above in the same area. In addition, for the non-exposed farmers, those who did not use pesticides for at least one year before the onset of this research and did not live near pesticides applied farming were considered. Moreover, participants with experiences of smoking and alcohol drinking were not considered (Prudence et al., 2019).

#### **5.2.5. Data collection and blood sampling**

Data on the blood level of pesticides for SSFs in the Kellem Wellega zone was collected using a structured and pretested questionnaire via face-to-face interviews. A standard questionnaire with some modifications was prepared in the English version, translated to Afan Oromo for a clear understanding, and translated back to confirm the correctness of the translation. During this study, the data collectors explained ambiguous questions to the participants that would not be apparent.

Most of the questions were dichotomous, with a yes and no option. Prior to the interview, verbal informed consent was obtained from the study participants after explaining the purpose of the study. Blood samples were simultaneously collected from one hundred forty ESSFs and one hundred of NESSFs. The trained lab technician collected 4ml of blood samples with a sterilized syringe, transferred them into polyethylene tubes, and then kept them in the ice-cold box, transported them to the Department of Environmental Health Science and Technology at Jimma University, and stored them at - 20°C for analysis.

#### **5.2.7. Extraction and cleanup of pesticide residues**

OCPs (*p,p'*-DDD (para para 1,1-dichloro-2,2-bis(4-chlorophenyl)ethane), *p,p'*-DDE (para para 1,1-dichloro-2,2-bis(4-chlorophenyl)ethylene), *o,p*-DDT (ortho para 1,1,1-trichloro-2,2-bis(4-chlorophenyl)ethane, and *p,p'*-DDT (para para 1,1,1,Trichloro-2,2-bis(4-chlorophenyl)ethane and heptachlor) and SPs (permethrin cypermethrin and deltamethrin) pesticides from blood samples were extracted using a method stated by Agarwal (Agarwal et al., 1976). A 4ml of blood samples were diluted with 25ml of distilled water and 2ml of saturated brine solution and then transferred to a 60ml separator funnel. The extraction was made by adding 10ml of acetone, 10ml of n-hexane in

the same ratio, shaking three times for about three minutes with occasional releasing pressure, and kept until it forms separate layers. After that, the upper (non-polar) layers were obtained by repeatedly removing the lower (polar) layers three times. The three combined extracts were passed through anhydrous sodium sulfate to eliminate residual polar solvents.

The extracts' cleanup was made using the USEPA(USEPA, 1980), 3620B method and activating florisil overnight at 130<sup>0</sup>C and cooled in desiccators until used. One gram of florisil was predetermined and packed into column chromatography by calibration. Anhydrous sodium sulfate was added to 0.5 cm to the top of the florisil column, washed with n-hexane, and discarded. Then the extracts were added to the top of the columns slowly. A 10 and 8.5 ml of hexane was added continuously and followed by a 1.5ml of diethylether. Then another 5ml of hexane was added with 5ml of the diethylether turn by turn into column chromatography. Finally, the eluent was contained in a single container and evaporated into dryness through the rotary vacuum evaporator. Samples were finally prepared in hexane 1.5ml and analyzed by GC-ECD for pesticides.

#### **5.2.8. Chemicals and reagents**

High purity grade of organic solvents (acetone- 99.85%, diethyl ether- 99%, and n-hexane - 99%), saturated brine solution-99%, anhydrous sodium sulfate 99.0%, and florisil or magnesium silicate with 60 -100 mesh size used were purchased from Heparin Chemical Private limited company, Addis Ababa, Ethiopia. The standards for permethrin (98%), cypermethrin (98%), deltamethrin (99%), heptachlor (98%), *p,p'*-DDD (99.3%), *p,p'*-DDE (99.9%), *o, p*-DDT(100%), and *p, p'*-DDT (99%) OCPs and SPs chemicals were obtained from Sigma Aldrich, Germany. In addition, gas chromatography techniques were used to determine pesticide concentration.

#### **5.2.9. Chemical analysis**

The gas chromatography-electron capture detector has determined the pesticides with an auto sampler (GC-ECD, Agilent Technologies7890A). HP-5 capillary column of 30 m x 0.25 mm i.d. x 0.25 $\mu$ m film thickness was used in combination with the following oven temperature program: The initial temperature was 80 $^{\circ}$ C, ramp at 30 $^{\circ}$ C min<sup>-1</sup> to 180 $^{\circ}$ C, ramp at 3 $^{\circ}$ C min<sup>-1</sup> to 205 $^{\circ}$ C, held for 4 min, ramp at 20 $^{\circ}$ C min<sup>-1</sup> to 290 $^{\circ}$ C, held for 8 min, ramp at 50 $^{\circ}$ C min<sup>-1</sup> to 325 $^{\circ}$ C. The total time of the GC run was 27.92 min. Helium (99.999% purity) was used as a carrier gas at a flow rate of 20mL min<sup>-1</sup> and high purity nitrogen (N<sub>2</sub> = 99.999%) as a makeup gas at a flow rate of 60mL min<sup>-1</sup>.

An aliquot of 1 $\mu$ L was injected in split mode with a 50:1 split ratio and a 280°C injection temperature. The pesticide residues were identified with an electron capture detector ( $\mu$ -ECD) at a temperature of 300°C.

#### **5.2.10. Quality assurance and quality control**

For quality control, procedural blanks were analyzed every five samples to check for interferences or contamination from solvent, glassware, and equipment used during the entire analytical procedure. Quantification of the selected OCPs and SPs was performed by the external standard addition method. The calibration curves were obtained by spiking five different concentrations of the pesticide standards in the range of 10, 1, 0.1, 0.01, and 0.001mgL<sup>-1</sup>. The regression coefficient of the standard curve was greater than 0.9994 for all pesticides under study. The detection limit was estimated as the analyte concentration in the sample producing a peak with a signal-to-noise ratio of three. Limits of quantification (LOQ) were calculated from signal-to-noise ratios 1:10, which were obtained from the measurement of the samples with the lowest concentration level where peaks of studied pesticides were detected (Nassar et al., 2016).

#### **5.2.11. Statistical analysis**

The data were cleaned and entered into SPSS software version 24.0 (IM Corp., Armonk, NY, US) for analysis. First, a descriptive analysis was performed using a frequency distribution to understand the characteristics of the study population, followed by further statistical analysis. Given the low proportion (<15%) of individuals with detectable concentrations of OCPs and SPs pesticides, we did not apply any method for dealing with values below the evaluated LOD. However, mean values, detection frequencies, and selected percentiles were used for descriptive analysis. Detection frequencies were calculated separately for the entire samples collected from both ESSFs and NESSFs.

The distributions of the participants' socio-demographics and other explanatory variables were explored using the Chi-square test and parametric tests to examine differences among the ESSFs and NESSFs. The  $p$ ,  $p'$ -DDT/ $p$ ,  $p'$ -DDE ratio was calculated as an indicator for environmental exposure to DDT (Antonio et al., 2013). The Chi-square test was used to examine the association between exposed and non-exposed SSFs with their socio-demographics and other descriptive variables. A

logistic regression analysis was performed to identify explanatory variables of pesticide residues of OCPs and SPs in blood samples. Regression analysis was conducted only for compounds detected in at least 15% of the study population: *p,p'*-DDE, *p,p'*-DDT, heptachlor, cypermethrin, and permethrin, and deltamethrin (Freire et al., 2017). Factors associated with dependent variables (*p,p'*-DDE, *p,p'*-DDT, heptachlor, cypermethrin, permethrin, and deltamethrin) were determined at a significant level of p-value less than 0.20, and chosen in the bivariate were included in regression models. Finally, a stepwise backward elimination was performed based on p-values of less than 0.20 on the variables kept in the model one-by-one until only variables with p-values below 0.05 remained for analysis.

### **5.2.12. Ethical consideration**

The ethical approval letter was obtained from the Institute of Health Institutional Review Board (IRB) of Jimma University on 18/10/2019 (No. IHRPGD/407/2019). Participants have ensured confidentiality of their personal information and were given a chance of leaving the study at any time. Moreover, written informed consent was obtained from the study participants.

### **5.3. Results**

This study included 240 SSFs, i.e., 140 participants from the ESSFs and 100 from the NESSFs. The response rate was 96.4% for ESSFs and 100% NESSFs. The study showed that male SSFs whose age was greater than forty years and involved in farming activities were significantly exposed to pesticide chemicals (p-value < 0.00).

Farmers with greater or equal to five years of working experience in the complete use of PPEs and farmers who sprayed pesticide chemicals against the wind were significantly exposed to pesticide chemicals (p-value < 0.00). SSFs that were not trained on pesticide chemicals and used frequency of pesticides used per year (p-value < 0.01) had a significant association with exposure to pesticide chemicals.

In addition following the labeled instruction (p-value < 0.04) and activities like drinking, chewing, and eating food while spraying had a significant association with exposure to pesticides (p-value < 0.02) (

Table 5.1)

Table 5.1: Descriptive statistics for SSFs in Sayo, Hawa Gelan, and Dale Wabara districts of Kellem Wellega zone, western Ethiopia (n = 240).

Characteristics of the respondents		ESSFs (%)	NESSFs (%)	p- value
Sex	Male	70(50)	90(90)	0.00
	Female	70(50)	10(10)	
Age	< 40 Years	15(10.7)	50(50)	0.00
	> = 40 Years	125(89.3)	50(50)	
Marital status	Married	105(75)	70(70)	0.7
	Single and others	35(25)	30(30)	
Educational level	Non-formal education	125(89.3)	80(80)	0.36
	Primary school and above	15(10.7)	20(20)	
Occupation	Farming	130(92.9)	60(60)	0.00
	Farming and others	10(7.1)	40(40)	
Working experience	< 5 Years	6(4.3)	20(20)	0.00
	> = 5 Years	59(42.1)	55(55)	
	I don't use	75(53.6)	25(25)	
Training	Yes	59(42.1)	26(26)	0.01
	No	101(72.1)	7(7)	
Complete PPEs use	Yes	81(57.7)	93(74)	0.00
	No	39(27.7)	93(93)	
Following the labeled instruction	Yes	50(35.7)	49(49)	0.04
	No	90(64.3)	51(51)	
Activities performed during spraying	Eating food/drinking	33(23.6)	34(34)	0.02
	Chewing	15(10.7)	12(12)	
	Mixed activities	30(21.4)	29(29)	
	Nothing	62(44.3)	25(25)	
Frequency of used per year	0- 2 times	6(4.3)	1(1)	0.01
	3-4 times	56(40)	32(32)	

	Greater than four times	53(37.9)	30(30)	
	I don't use	25(17.9)	37(37)	
Condition of the equipment	Damaged	18(12.9)	19(19)	0.35
	Not damaged	105(75)	67(67)	
	I don't use	17(12.1)	14(14)	
Spraying against the wind	Yes	66(47.1)	24(24)	0.00
	No	57(40.7)	34(34)	
	I don't use	17(12.1)	42(42)	

ESSFs: Exposed Small-Scale Farmers; NESSFs: Non-Exposed Small-Scale Farmers

### 5.3.1. Detection of OCPs and SPs in human blood

The analytical results of OCPs and SPs in the blood are shown in 5.2. For OCPs, *p,p'*-DDT (96.4%), and *p,p'*-DDE (85.7%) in ESSFs and heptachlor (95%) in NESSFs were the most frequently detected species, whereas *o,p*-DDT, and *p,p'*-DDD were detected less frequently in both ESSFs and NESSFs, respectively. *p,p'*-DDT has the highest mean concentration ( $0.28 \pm 0.4$ ) and ( $0.25 \pm 0.45$ )  $\text{mgL}^{-1}$  for both ESSFs and NESSFs, respectively. As for ESSFs, deltamethrin (100%) was detected most frequently then followed by cypermethrin (90%) and permethrin (78.6%). Deltamethrin was primarily detected in 60% of the NESSFs and the rest all went under 20%. The highest mean concentration for ESSFs was permethrin ( $1.26 \pm 0.15$ ) followed by cypermethrin ( $0.53 \pm 0.09$ )  $\text{mgL}^{-1}$ .

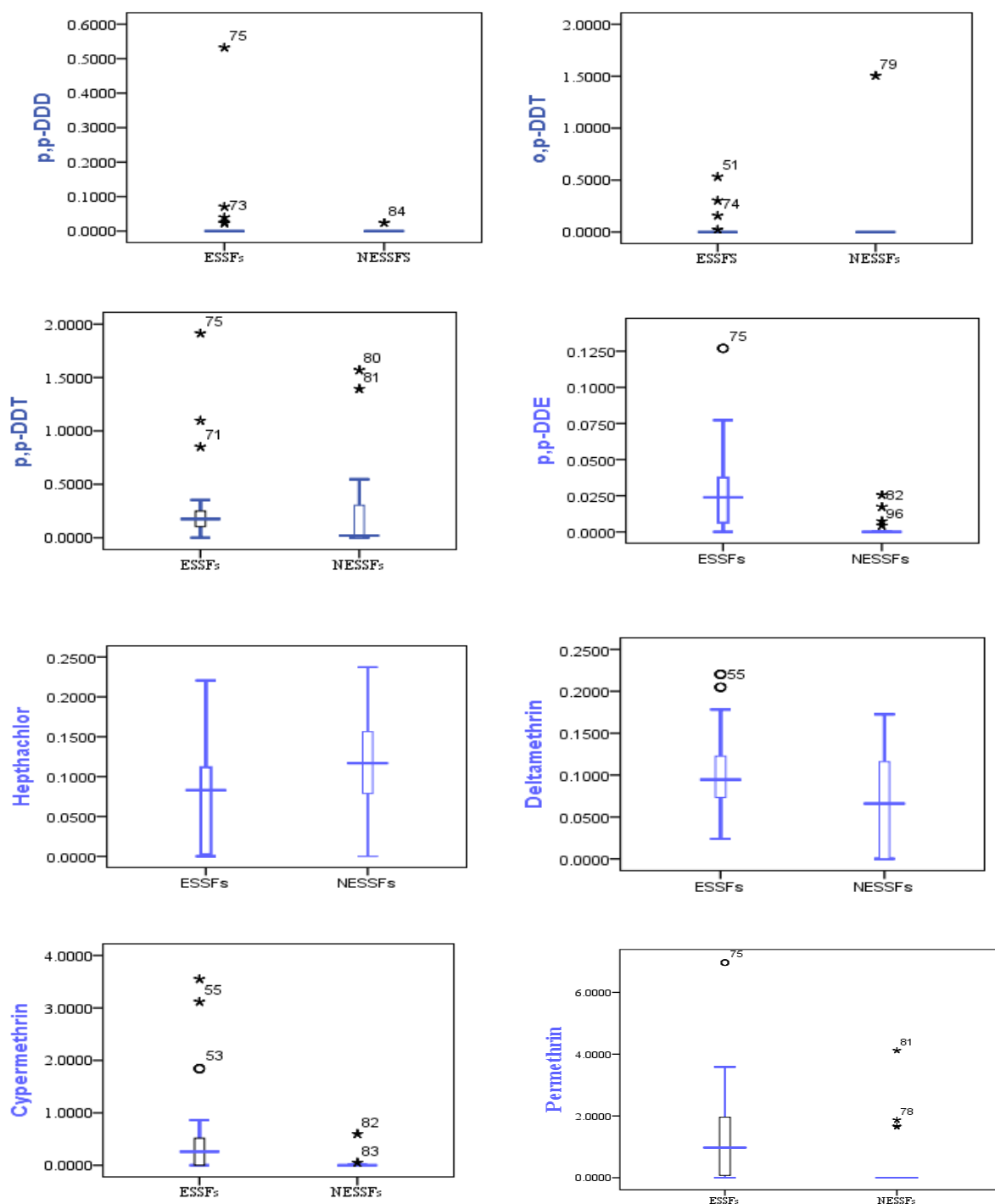


Figure 5.2: Box plot for some selected OCPs and SPs pesticide residues concentration ( $\text{mgL}^{-1}$ ) in the blood of ESSFs and NESSFs

Abbreviation: ESSFs: Exposed small-scale farmers; NESSFs: Non-exposed small-scale farmers; *o,p*-DDT: ortho para1,1,1-trichloro-2,2-bis(4-chlorophenyl)ethane; *p,p'*-DDD: para para 1,1-dichloro-2,2-bis(4-chlorophenyl)ethane ; *p,p'*-DDE: para para 1,1- dichloro-2,2-bis(4-chlorophenyl)ethylene; and *p,p'*-DDT: para para 1,1,1, Trichloro-2,2-bis(4-chlorophenyl)ethane.

### **5.3.2. Factors associated with some SP pesticides**

Table 5.5.2 show the logistic regression analysis results for permethrin, cypermethrin, and deltamethrin concentration in the blood of ESSFs and NESSFs. After backward elimination age, marital status, education, occupation, working experience, training, and complete PPE used were significantly associated with some residues of SPs found in the blood of both ESSFs and NESSFs. Thus, SSFs whose ages were less than 40 years were 21% less likely to be exposed to permethrin than those whose age was older than 40 years (AOR, 0.21; 95%CI: 0.1- 0.44).Most of the SSFs that did not use complete PPE were 3.6 times more likely to increase cypermethrin exposure than those using complete PPEs. Finally, according to educational level, farmers who did not have formal education were 18.1 times more likely to be exposed to deltamethrin than those having primary school were and above.

Table 5.2: Results of logistic regression model for SPs pesticides detected in n > 15% of the study population of both ESSFs and NESSFs

Explanatory variables	Permethrin		Deltamethrin		Cypermethrin		
	COR(95%CI)	AOR (95% CI)	COR (95%CI)	AOR(95% CI)	COR (95%CI)	AOR(95% CI)	
Age	≤ 40 years	1	1	1	1	1	
	> 40 years	0.16(0.08-0.3) <sup>*</sup>	0.21(0.1- 0.44) <sup>*</sup>	0.05(0.02-0.12) <sup>b</sup>	0.04(0.01-0.11) <sup>*</sup>	0.19(0.09-0.4) <sup>*</sup>	0.24(0.11-0.54) <sup>*</sup>
Marital status	Married	0.42(0.23-0.77) <sup>*</sup>	0.32(0.15-0.67) <sup>*</sup>				
	Single and others	1	1				
Education	Non-formal education			4.4(2.17-8.91) <sup>*</sup>	18.1(4.53-72.1) <sup>*</sup>		
	Primary school & above			1	1		
Occupation	Farming	6.86(3.23-14.56) <sup>*</sup>	4.27(1.8-10.14) <sup>*</sup>				
	Other activities	1	1				
Training	Yes	1	1	1	1		
	No	1.96(1.13-3.37) <sup>a</sup>	2.13(1.08-4.19) <sup>*</sup>	3.02(1.33-6.83) <sup>*</sup>	4.68(1.5-14.63) <sup>*</sup>		

PPEs use	Yes	1	1	1	1	1	1
	No	5.08(2.90-8.90) <sup>b</sup>	4.74(2.47-9.1) <sup>*</sup>	3.54(1.66-7.54) <sup>*</sup>	2.59(0.88-7.6)	4.38(2.52-7.6) <sup>*</sup>	3.56(1.94-6.54) <sup>*</sup>
Working practice	≤ five years			0.07(0.02-0.23) <sup>*</sup>	0.1(0.02-0.46) <sup>*</sup>	0.06(0.01-0.25) <sup>*</sup>	0.09(0.98-0.42) <sup>*</sup>
	> five years			0.21(0.08-0.52) <sup>*</sup>	0.31(0.1-0.99) <sup>*</sup>	0.27(0.15-0.48) <sup>*</sup>	0.27(0.15-0.51) <sup>*</sup>
	I don't use			1	1	1	1

Abbreviations: AOR: Adjusted odds ratio; COR: Crude odds ratio; CI: Confidence interval; Other activities: (daily laborers, privately business, non-Government and civil servants), and \* represent the level of significance at p-values less than 0.05.

### 5.3.3. Factors associated with some OCPs in blood samples

Table 5.3 shows the logistic regression analysis for *p,p'*-DDE, *p, p'*-DDT, and heptachlor concentrations in the blood of both exposed and non-exposed SSFs. After backward elimination, age, sex, marital status, educational level, working practice, training, complete PPE, activities performed during spraying, and condition of the equipment used were significant.

Thus, SSFs whose age was less than 40 years were 80% less likely to be exposed to *p, p'*-DDT concentration in blood than those whose age was greater than 40 years old. Females SSFs were 70% less likely to be exposed to *p,p*-DDT concentration in blood than males, and small-scale farmers who did not have non-formal education were 23.37 times more likely to be exposed to *p,p'*-DDT than those having primary schools and above.

In addition, SSFs that perform different activities like eating and drinking (11%), chewing (10%), and diverse activities (8%) were more likely to be exposed to *p,p'*-DDT than those farmers who didn't use pesticides. Likewise, damaged and not damaged equipment is more likely to cause exposure of SSFs to *p,p'*-DDT in 32.4 and 13.93 times than those who did not use pesticides. Moreover, SSFs not using complete PPE were 6.21 times more likely to increase the exposure to *p,p'*-DDE blood levels than those who were using complete PPE.

Table 5.3: Results of logistic regression model for OCPs detected in n >15% of the study population of both ESSFs and NESSFs

Explanatory variables		p,p'-DDT		p,p'-DDE		Heptachlor	
		COR (95%CI)	AOR (95%CI)	COR (95%CI)	AOR(95%CI)	COR (95%CI)	AOR
Sex	Male	0.11(0.04-0.29)*	0.3(0.09-0.83)*			11.67(5.36-25.4)*	17.36(7.34-41.09)*
	Female	1	1			1	1
Age	≤ 40 years	1	1			1	1
	> 40 years	0.18(0.1-0.33)*	0.2(0.09-0.48)*			3.56(1.34-9.46)*	3.62(1.17-11.21)*
Educational level	Non-formal education	10.31(4.59-23.2)*	23.37(6.97-78.49)*	3.46(1.29-9.3)*	4.22(1.49-11.99)*		
	Primary school & above	1	1	1	1		
Working practice	≤5 years	0.24(0.07-0.89)*	0.24(0.06-0.89)*				
	> 5years	1.95(0.83-4.57)	1.95(0.83-4.57)				
	I don't use	1	1				
Training complete	Yes	1	1				
	No	2.8(1.42-5.51)*	4.68(1.5-14.63)*				
PPEs use	Yes	1	1	1	1		
	No	4.75(2.42-9.34)*	6.15(2.23-16.95)*	5.8(3.2-10.5)*	6.21(3.38-11.41)*		

Activities performed during spraying	Eating and drinking	0.5(0.24-1.04)*	0.11(0.02-0.51)*		
	Chewing	0.58(0.22-1.54)	0.1(0.02-0.55)*		
	Mixed activities	0.55(0.26-1.19)	0.08(0.02-0.41)*		
	I don't use	1	1		
Condition of the Equipments	Damaged	3.73(1.21-11.5)*	32.41(4.22-26.3)*		
	Not damaged	1.98(0.9-4.36)*	13.93(2.5-77.23)*		
	I don't use	1	1		
Marital status	Married			0.28(0.11-0.75)*	0.09(0.03-0.28)*
	Single & others			1	1

Abbreviations: AOR: Adjusted odds ratio; COR: Crude odds ratio; CI: Confidence interval and \* represent the level of significance at p-values less than 0.05.

#### 5.4. Discussion

This study observed that *p,p'*-DDE, *p,p'*-DDT, heptachlor, cypermethrin, permethrin, and deltamethrin compounds had been detected in more than 15% of all blood samples. As a result, the mean concentration of *p,p'*-DDE, *p,p'*-DDT, heptachlor, cypermethrin, permethrin, and deltamethrin in blood samples of both ESSFs and NESSFs was 0.02, 0.27, 0.09, 0.32, 0.32, and 0.93 mgL<sup>-1</sup>, respectively.

The mean values of *p,p'*-DDE in this investigation were greater than the levels reported on pesticide residues in human blood samples from India (Bedi et al., 2015) and Mexico (Ruiz-Suárez et al., 2014). Similarly, the mean concentrations of *p,p'*-DDT and heptachlor in blood were greater in Libyan agricultural workers (Al salhen et al., 2019), serum levels of blood donors of Brazil (Freire et al., 2017), and malaria epidemic populations of blood plasma in Mexico (Ruiz-Suárez et al., 2014) (Figure 6.2).

This exposure to high-level pesticides by small-scale farmers is associated with some alterations in the hematological parameters and abnormalities in the urine (Neghab et al., 2018) and oxidative stress that may cause severe diseases in the exposed populations (Abbasi-Jorjandi et al., 2020). Due to persistence, and bioaccumulation, the mean concentration of SPs in blood samples of SSFs was higher than that of the same samples of Taiwan (Simaremare et al., 2019) and Benin (Prudence et al., 2019).

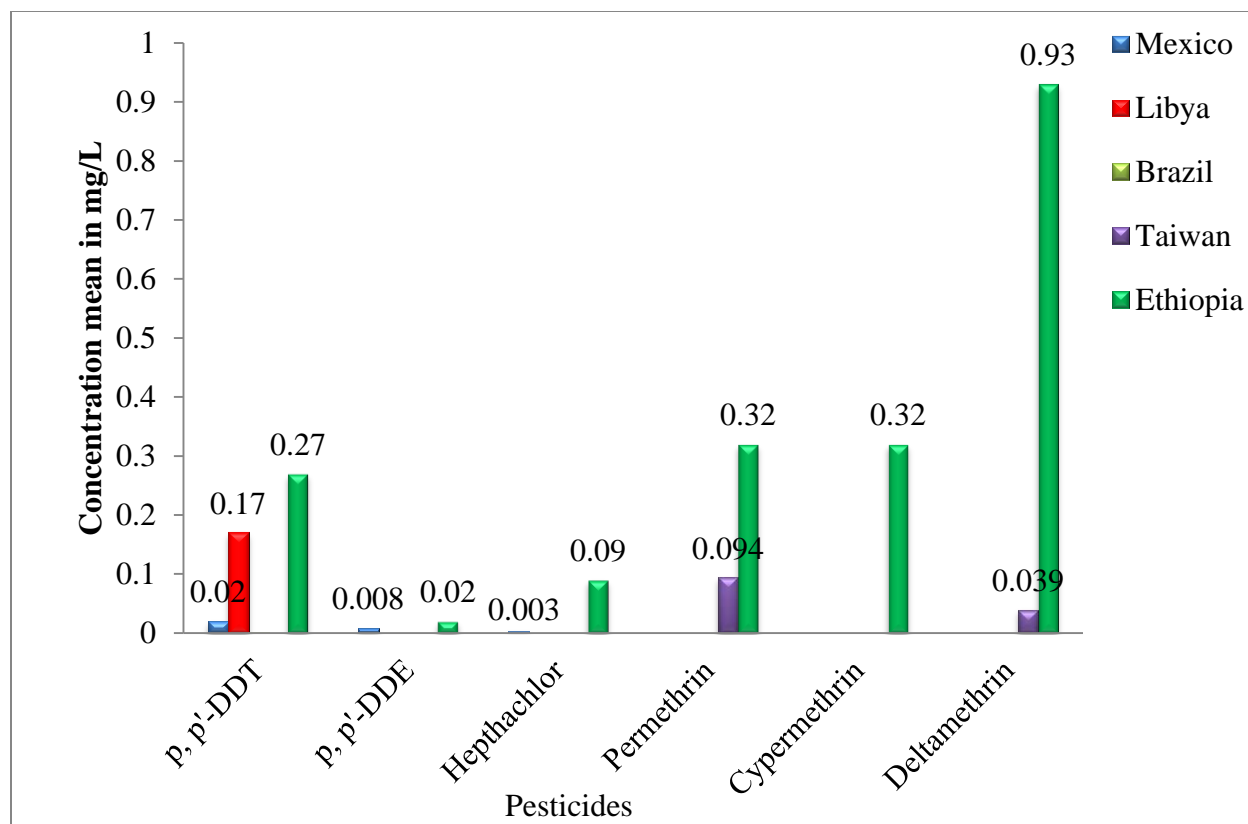


Figure 5.3: Comparison of OCPs and SPs concentration means level ( $\text{mgL}^{-1}$ ) in blood with different countries (Reference for Mexico (Ruiz-Suárez et al., 2014), Libya (Al salhen et al., 2019), Brazil (Freire et al., 2017), and Taiwan (Simaremare et al., 2019)).

A plausible reason for this difference is the extensive use of DDT for controlling malaria among farmers currently, and (Ruiz-Suárez et al., 2014) used to distinguish between current and historical exposure to DDT. Suppose the ratio of p,p'-DDT/p,p'-DDE is less than one. In that case, it indicates high persistence in the environment and ongoing bio-magnifications, whereas if it is greater than one, it implies both continuous and continued exposure to DDT (Antonio et al., 2013).

The mean ratio across the entire blood samples was 9.33, which supports the hypothesis of an active and continuous source of the banned pesticides; despite the considerable legal restrictions introduced against the use of DDT in Ethiopia. Because of their convenience and effectiveness in controlling pests, prohibited pesticides are still in demand from some farmers. Studies have shown that compounds were still being illegally imported without the formal Ethiopian

registration process (Negatu et al., 2016). Furthermore, the remaining stockpiles of DDTs in Ethiopia are stored under inadequate conditions and are currently a source of severe pollution.

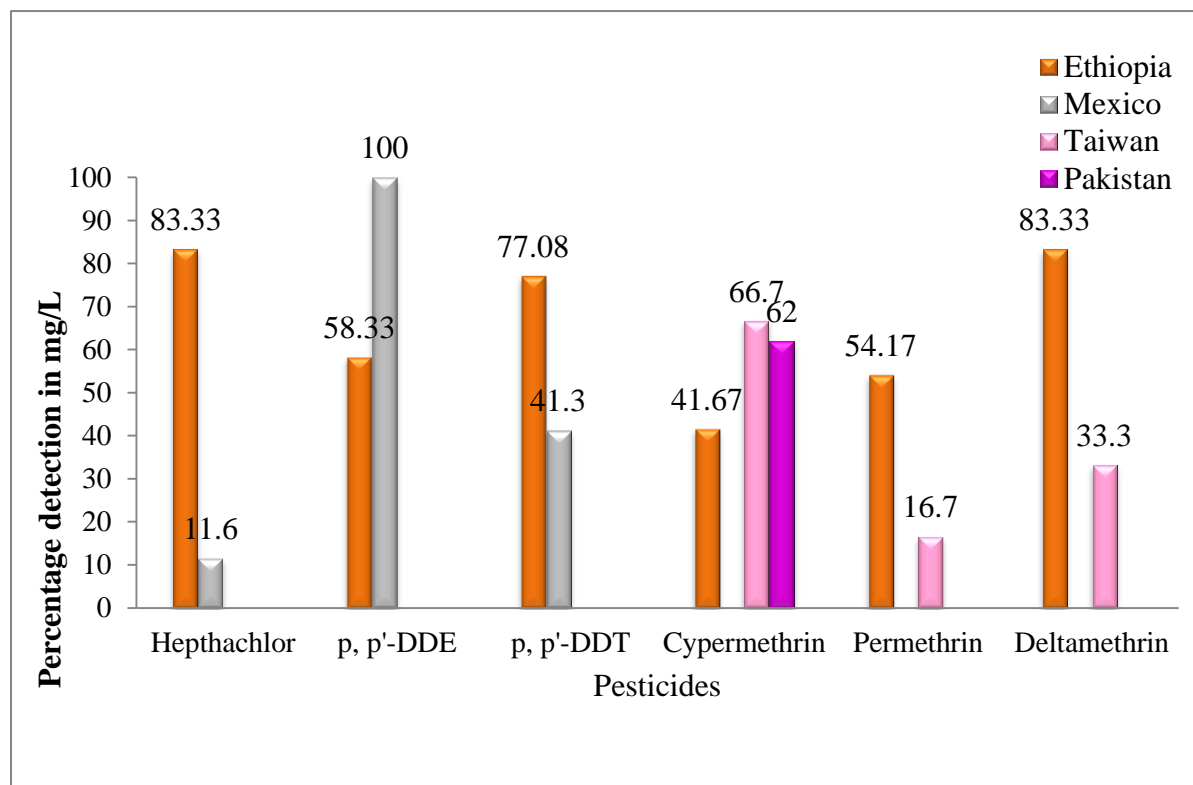


Figure 5.4: Comparison of OCPs and SPs percentage detection in blood samples ( $\text{mgL}^{-1}$ ) of different countries (References for Taiwan(Simaremare et al., 2020, Simaremare et al., 2019), Pakistan (Khan et al., 2008), and Benin(Prudence et al., 2019))

The high detection rate of heptachlor, p,p'-DDT, permethrin, and deltamethrin in Figure 6.3 implies that the individuals were exposed to pesticides from surrounding agricultural regions or simply by dietary digestion of contaminated food (Gebremichael et al., 2013, Mekonen et al., 2014). Moreover, this study depicts that SSFs whose age was less than 40 years were less likely to be exposed to p,p'-DDT, p,p'-DDE, heptachlor, permethrin, cypermethrin, and deltamethrin than those above 40 years. This is due to the bioaccumulation of pesticides from past exposure and decreasing excretion rates with increasing age for SSFs (Ben Hassine et al., 2014, Al-Daghri et al., 2019). In another way, the younger groups would be more convenient for the recommended PPE on pesticide use compared to older SSFs who could use more pesticides to maximize their products (Jallow et al., 2017).

Moreover, male SSFs dominate farming activities than females due to the hardness and difficulty of work that might naturally limit the involvement of females. Comparatively, males are more of a household leader and energetic than females and they are more actively involved in farming practices than female SSFs. This causes a distinct accumulation of pesticide chemicals at the workplace, which typically differs by gender, as men and women (Ruiz-Suárez et al., 2014, Al-Daghri et al., 2019, Abou-Elwafa Abdallah et al., 2017). This might be related to breastfeeding and the menstrual cycle, which can cause significant variations in OCP levels between males and females, resulting in lower blood concentrations in females (Thomas et al., 2017, Barrón Cuenca et al., 2020).

In addition, SSFs who got training regarding handling pesticides were more aware of how to use PPE, understand the side effects, and observe the weather conditions before spraying. Since educated farmers are more knowledgeable about pesticide safety, they can better understand, follow the labeled instructions, and conceptualize the side effects of poor practices on pesticide chemicals (Wang et al., 2017, Jallow et al., 2017, Gayatri and Amarjeet, 2020, Abbasi-Jorjandi et al., 2020).

Furthermore, this study found that farmers who spent more time working with pesticides were exposed to more pesticides than those who spent less time working with pesticides, i.e., the experience of pesticide use influences the exposure to SSFs. The finding of this study was consistent with studies done in Brazilian blood donors and Cameroon tomato farmers in which occupational exposure was associated with previously used pesticides (do Nascimento et al., 2017, Tambe et al., 2019).

Furthermore, the hand pump was the most often used pesticide spraying device, which exposes sprayers to health hazards through skin contact, inhalation, and ingestion. Due to the limited use of PPE, farmers spray pesticides by dressing T-shirts, shorts, and slippers that offer little protection (Afata et al., 2022), (Mengistie et al., 2017). In addition, SSFs may be exposed to pesticides occupationally during spraying, loading, maintaining, cleaning equipment, and entering sprayed farmland. This is due to knowledge gaps among respondents, poor practice, and inadequate safety measures (Cramer et al., 2017, Jallow et al., 2017, Taghdisi et al., 2019).

The study has several drawbacks. The data from non-exposed households of SSFs had a higher level of pesticide concentrations leading to a positive bias in our estimates of pesticide levels. In addition, we did not have information on food intake from animal origin and body mass index (BMI) to adjust our estimates of OCPs and SPs concentration levels. Likewise, there might be poor reporting on the history of previous use, frequency, training, and working experience of pesticide chemicals. Additionally, past exposure assessed by using a questionnaire might be subject to recall bias and lack of consistent reporting from both ESSFs and NESSFs. Due to the inabilities of instruments, the organophosphate pesticides were not included in this report.

## **5.5. Conclusion**

This study identified a high concentration of *p,p'*-DDE, heptachlor, cypermethrin, permethrin, and deltamethrin in the blood samples of small-scale farmers. Older age, less educated, and farmers with inappropriate PPE use are more likely exposed to the identified pesticides. The study identified a high concentration of pesticides from potentially exposed and non-exposed farmer blood samples. Since this study is the first report on pesticide use and its concentration in the blood of small-scale farmers in the study area, we recommend further studies with larger sample sizes focusing on identifying the sources of exposure to pesticides.

**Chapter six: General discussion, conclusions, and future research prospects**

## **6.1. General Discussion**

The study investigates various determinants of micronutrient deficiencies among small scale farmers through emphasizing agrochemical utilizations. The study highlights significant differences in the quality characteristics and proximate composition of crop yield samples collected from small-scale farmers. Soil water content influences plant nutrient availability and uptake, explaining the higher moisture content in crops such as potatoes, which require more water (Marschner, 2012). High ash content in crops indicates a high mineral content, linked to soil fertility and the plant's ability to accumulate minerals (Brady et al., 2008). Variations in mineral content among crops can be attributed to differences in soil composition, cultivation practices, and plant genetics (Khoshgoftarmanesh et al., 2010).

In the general discussion, the impact of chemical fertilizers and glyphosate on agricultural ecosystems is profound, affecting soil health, nutrient dynamics, crop productivity, and food quality. Understanding these effects is crucial for sustainable agricultural practices that balance productivity with environmental stewardship. Chemical fertilizers provide plants with vital nutrients like nitrogen, phosphorus, and potassium. However, their overuse can lead to soil acidification, nutrient imbalances, and adverse effects on soil microbial communities. Glyphosate, a widely used herbicide, disrupts soil microbial populations and nutrient cycling processes, thereby affecting overall soil fertility and ecosystem resilience.

## **6.2. Soil Micronutrient Content and Crop Composition of Small-Scale Farming Communities in Western Ethiopia**

### **6.2.1. Micronutrient Contents in Local Soil**

The plant availability of micronutrients like zinc (Zn) is strongly influenced by soil pH. Higher pH levels can reduce Zn availability, explaining the lower Zn levels in some crops (Noulas et al., 2018). Iron (Fe) availability is also affected by soil pH, which can vary widely between different crops and regions (Colombo et al., 2014). Similarly, manganese (Mn) availability decreases in soils with high pH levels, accounting for the lower Mn levels in certain crops (Sparrow and Uren, 2014). Soil texture and organic matter content also influence copper (Cu) availability, as Cu tends to bind strongly with organic matter, reducing its bioavailability (Bravin et al., 2012).

The pH levels of soil significantly affect the solubility and availability of micronutrients. In this study, 76.7% of the soil samples had acidic conditions, known to facilitate the solubility and uptake of micronutrients. Increasing soil acidity can exacerbate micronutrient deficiencies, posing significant challenges to agricultural productivity (Abate et al., 2017).

Agricultural practices such as frequent tillage, removal of crop residues, and continuous cropping can degrade soil quality, reducing its capacity to buffer hydrogen ions (Bhattacharyya et al., 2022, McCauley et al., 2009). Moreover, the use of ammonia-N-containing fertilizers like urea and DAP contributes to soil acidity by releasing hydrogen ions during plant uptake or nitrification (Yadav et al., 2020, Fageria and Baligar, 2008). In Ethiopia, the widespread use of urea as a nitrogen source and sulphate-containing fertilizers has further compounded soil acidity and nutrient leaching (Gurmessa, 2021, Goulding, 2016).

### **6.2.2. Micronutrient Level in Crop Yields**

The study found significant variations in the micronutrient levels of crops, influenced by soil properties and agronomic practices. Manganese (Mn) levels in crops like sorghum, millet, and onion are notably lower than FAO guidelines, attributed to soil pH and organic matter content (Sparrow and Uren, 2014). Copper (Cu) content in crops is highly variable, influenced by soil texture and organic matter (Bravin et al., 2012). Iron (Fe) concentrations in crops like maize, millet, and onion were significantly lower than FAO guidelines, as Fe solubility decreases in well-drained, aerated soils (Colombo et al., 2014).

Zinc (Zn) levels in maize and sorghum were below FAO guidelines, influenced by soil pH and phosphate levels. High soil pH and phosphate fertilization can reduce Zn availability, leading to deficiencies (Alloway, 2008a). Bean seeds, however, show higher levels of Mn, Cu, Fe, and Zn compared to other crops, attributed to the legumes' ability to fix nitrogen and improve soil organic matter, enhancing micronutrient availability (Virk et al., 2021).

The total mesophilic bacterial count (TMBC) and total microbial fungal content (TMFC) also play roles in nutrient cycling and availability. Higher TMBC and TMFC in soils with optimal Zn and Fe levels indicate more active microbial processes that enhance nutrient dynamics (Smith, 2018, Dotaniya and Meena, 2015).

Additionally, the study highlights the importance of organic matter in improving soil structure and micronutrient retention. Only 3.3% of the organic matter in soil samples was deemed beneficial, while an alarming 86.7% of the ash content was considered unwanted, indicating poor organic matter return and decomposition (Ai et al., 2018, Tefera et al., 2018).

The study's findings underscore the need for incorporating a variety of yields into the human diet to meet micronutrient requirements for optimal health. Improving soil management practices and addressing soil acidity and nutrient leaching are crucial for enhancing crop yield quality and micronutrient content (Adamu et al., 2021, Afata et al., 2023, Bedassa et al., 2017).

### **6.3. Effect of agrochemicals on soil microbiological activity, micronutrient availability, and the uptake of these nutrients**

The study elucidates the profound influence of commonly utilized agricultural inputs on soil microbiological activity, micronutrient availability, and nutrient uptake by maize plants. Notably, the excessive application of inorganic fertilizers and glyphosate demonstrates pronounced effects on soil biological and physicochemical properties, as well as maize yield and quality. The investigation reveals that the use of chemical fertilizers and glyphosate leads to alterations in soil microbial communities, diminishing the population of beneficial soil microorganisms and disrupting the functional diversity of the soil microbial community. Specifically, treatments involving compost exhibit the highest counts of mesophilic bacteria and fungi, indicative of a positive impact on soil bacterial populations. Conversely, the introduction of inorganic fertilizers and glyphosate leads to declines in mesophilic bacterial and fungal counts, attributed to their disruptive effects on soil microbial communities.

Moreover, the study underscores the temporal dynamics of microbial populations in response to glyphosate and inorganic fertilizer treatments, with initial increases followed by significant declines over time. This pattern suggests a selective promotion of certain microbes and inhibition of others by these chemicals, leading to shifts in microbial diversity and overall abundance. Additionally, glyphosate and chemical fertilizers contribute to soil acidification, negatively impacting soil microbial activity and nutrient availability. In contrast, compost amendments promote alkaline conditions favorable for microbial activity and nutrient uptake by plants.

Furthermore, the study highlights the influence of agricultural inputs on maize yield and quality parameters. Compost amendments enhance crude protein and fat content in maize, while treatments involving glyphosate and micronutrient fertilizers show contrasting effects on crude fiber content. These variations in nutrient composition are attributed to differences in soil pH, organic matter content, and microbial activity. Overall, the findings underscore the critical role of agricultural inputs in shaping soil microbiological activity, nutrient availability, and maize yield and quality, emphasizing the importance of sustainable agricultural practices to mitigate adverse effects on soil health and crop productivity.

### **6.3.1. Effect of Chemical Fertilizer and Glyphosate Use on Soil Biological and Physicochemical Properties**

Chemical fertilizers and glyphosate alter soil biological properties by reducing microbial diversity and biomass. Studies have shown that inorganic fertilizers decrease populations of beneficial soil microorganisms such as mesophilic bacteria and fungi (Onet et al., 2019; Ashworth et al., 2017). This disruption impacts soil nutrient cycling, organic matter decomposition, and overall soil health. In contrast, compost amendments promote microbial diversity and activity, enhancing soil structure and nutrient availability (Aulakh et al., 2022).

Physicochemical properties of soil are also influenced by these inputs. Compost amendments increase soil pH due to organic matter's buffering capacity, supporting nutrient availability and microbial function (Lehmann and Kleber, 2015). Conversely, chemical fertilizers and glyphosate tend to lower pH levels, primarily through the release of ammonium ions and herbicidal effects on microbial communities (Hassink, 1997, Wolmarans, 2013). These changes in pH affect soil nutrient solubility and availability, influencing crop growth and yield.

### **6.3.2. Effect of Chemical Fertilizer and Glyphosate Use on Soil Micronutrient Concentration**

The application of chemical fertilizers and glyphosate impacts soil micronutrient concentrations, critical for plant growth and development. Compost amendments enhance micronutrient availability by fostering microbial mineralization processes that release bound nutrients (Shu et al., 2022). In contrast, chemical fertilizers may disrupt these processes, leading to reduced micronutrient availability in soil (Bàrberi, 2002). Glyphosate specifically can form complexes

with soil micronutrients such as iron (Fe), zinc (Zn), and manganese (Mn), rendering them less accessible to plants (Franz et al., 1997). This interference can lead to nutrient deficiencies in crops, impacting overall yield and quality. Understanding these interactions is crucial for sustainable soil management practices that maintain optimal nutrient levels for agricultural productivity.

### **6.3.3. Effect of Chemical Fertilizer and Glyphosate Use on Maize Yield and Quality**

Maize yield and quality parameters are significantly influenced by the application of chemical fertilizers and glyphosate. Compost amendments enhance maize quality by increasing crude protein and fat contents, indicative of improved nutrient uptake and utilization (Mäder et al., 2002). This enhancement is attributed to enhanced soil fertility and microbial activity supported by organic inputs.

Conversely, chemical fertilizers and glyphosate treatments may alter nutrient composition and content in maize grains, affecting nutritional value and overall crop quality (Ray et al., 2020). The impacts can vary from changes in moisture content, and ash content, to the levels of crude fiber, carbohydrates, and gross energy. These variations underscore the importance of balanced nutrient management practices in achieving sustainable agricultural productivity while preserving soil health.

In summary, the effects of chemical fertilizers and glyphosate on soil properties, micronutrient concentrations, maize yield, and quality highlight the complexities of agricultural management. Integrating compost amendments alongside judicious use of chemical inputs can mitigate adverse effects on soil health and enhance crop productivity sustainably.

### **6.4. Prevalence of pesticide use and occupational exposure**

Chapter 4 of the study delves into the prevalence of pesticide use and occupational exposure among small-scale farmers in western Ethiopia. The findings reveal that a staggering 87.15% of small-scale farmers in the Kellem Wellega zone have utilized one or more pesticide chemicals for agricultural purposes. This prevalence falls between reports from southern and southwest Ethiopian farmers, suggesting variances influenced by factors such as knowledge, attitude, practice, and socio-demographic factors. Moreover, the study highlights a concerning reality:

farmers engaged in agricultural practices are 2.2 times more likely to be exposed to pesticide chemicals than those in other activities.

This heightened risk is attributed to poor knowledge, leading to direct exposure during various agricultural tasks like spraying and mixing. Additionally, the study identifies lapses in adherence to labeled instructions, with 47.4% of participants not following and 96.8% not understanding them due to low educational levels and language barriers. Conversely, farmers with good knowledge exhibit a 58% lower likelihood of exposure. However, poor-practice farmers are 1.84 times more likely to be exposed, often engaging in everyday activities during spraying and using damaged equipment. These findings underscore the urgent need for targeted interventions to enhance education, safety practices, and awareness among small-scale farmers.

. The high levels of pesticide use among small-scale farmers (SSFs) are largely driven by the need to protect crops and sustain agricultural productivity. As noted by (Negatu, 2017) , this heavy reliance on pesticides is a significant factor in the observed prevalence. Small-scale farmers involved in agricultural activities face a 2.2-fold higher risk of pesticide exposure compared to individuals in other professions. This elevated risk is due to the extensive use of pesticides throughout different stages of crop production, including spraying, mixing, loading, and equipment maintenance. These tasks expose farmers directly to pesticides, while indirect exposure can occur through contaminated water, food, and environmental residues.

Moreover, the exposure to pesticides among SSFs occurs through multiple pathways, highlighting the extent of occupational hazards faced in agricultural practices. Direct contact during pesticide application activities, as noted by (Negatu, 2017), includes spraying and handling pesticides without adequate protective measures. Indirect exposures further contribute to SSFs' overall chemical burden, encompassing activities like entering recently sprayed fields, consuming contaminated food, and inhaling airborne particles during application. Studies (Taghdisi et al., 2019, Cramer et al., 2017, Jallow et al., 2017) emphasize how knowledge gaps and poor safety practices exacerbate these exposure risks among SSFs.

## **6.5. Effect of Pesticide Use Among Small-Scale Farmers**

The effect of pesticide use on the health of SSFs is profound and multifaceted. Studies consistently report adverse health outcomes associated with pesticide exposure, ranging from acute symptoms like headaches, coughs, and skin irritation to chronic conditions such as neurological disorders and reproductive health issues (Lu, 2017, Ndayambaje et al., 2019).

The presence of pesticide residues such as p, p'-DDE, p, p'-DDT, heptachlor, and various pyrethroids in SSFs' blood samples underscores the bio-accumulative nature of these chemicals and their potential long-term health impacts (Negatu et al., 2018, Abbasi-Jorjandi et al., 2020). Age and gender disparities also influence exposure levels, with younger SSFs generally less exposed but vulnerable due to cumulative risks over time, while male SSFs typically face higher exposure due to their predominant roles in farming activities (Ruiz-Suárez et al., 2014).

## **6.6. Conclusions**

This study provides a detailed examination of various challenges confronting small-scale farmers in the western region of Ethiopia. It explores critical issues such as nutrition deficiencies, health impacts of pesticide exposure, soil quality concerns, and the effects of agricultural practices on crop productivity and human health. By uncovering these interconnected dynamics, the study underscores the need for integrated approaches to improve both agricultural sustainability and community well-being in the region.

Crop and soil analyses demonstrate deficiencies in essential nutrients like iron, zinc, manganese, and copper, as well as poor soil health indicators such as acidity and low microbial counts. These findings underscore the critical need for sustainable agricultural practices that enhance soil fertility and crop nutrition. Developing region-specific guidelines and promoting innovative farming techniques will be crucial in improving agricultural productivity and enhancing food security in the region.

Additionally, the study examines the effects of inorganic fertilizers and agrochemicals on soil properties and maize quality, highlighting detrimental impacts on soil health and crop nutrient content. Chapter three and four emphasizes the importance of transitioning towards sustainable agricultural practices that reduce reliance on chemical inputs and promote organic farming

methods. Educating farmers on proper agrochemical usage and soil conservation measures will play a pivotal role in preserving soil fertility and improving long-term crop productivity.

The study uncovers widespread pesticide use among small-scale farmers, revealing inadequate safety knowledge and practices that lead to significant health risks. In Chapter four, symptoms reported by farmers, such as coughing, headaches, and skin irritations, underscore the urgent need for comprehensive pesticide safety education and improved regulatory measures. Effective strategies should be implemented to safeguard farmer health and environmental sustainability in agricultural communities.

Furthermore, analysis of pesticide concentrations in farmer blood samples reveals alarming levels of exposure to chemicals like p,p'-DDE, heptachlor, cypermethrin, permethrin, and deltamethrin. Chapter five notes, those factors such as age, education level, and improper use of personal protective equipment (PPE) contribute to heightened exposure risks. Further research is imperative to understand the sources and long-term health impacts of pesticide exposure, informing better safety protocols and policies to protect farmer health.

## **6.7. Recommendations**

### **6.7.1. Important actions for improvement of problems related to agrochemicals' effects on micronutrient deficiencies of small-scale farmers**

Improving the issues related to agrochemicals' effects on micronutrient deficiencies among small-scale farmers requires a strategic approach that integrates education, regulation, and sustainable agricultural practices. Here are some important actions that can be taken:

#### **6.7.2. Education and Awareness Programs**

Implement comprehensive education programs to increase awareness among farmers about the risks associated with agrochemical use. Provide training on safe handling, application methods, and the proper use of personal protective equipment (PPE) to minimize exposure to pesticides.

### **6.7.3. Regulatory Measures**

Strengthen and enforce regulations on the sale, distribution, and use of agrochemicals to ensure compliance with safety standards. Monitor pesticide residues in crops and soil to assess contamination levels and enforce permissible limits.

### **6.7.4. Promotion of Integrated Pest Management (IPM)**

Encourage the adoption of IPM practices that prioritize biological control methods, crop rotation, and pest-resistant varieties to reduce reliance on chemical pesticides. Provide support for farmers to access and implement IPM strategies through training and subsidies for alternative pest management techniques.

### **6.7.5. Enhancing Sustainable Agriculture through Research, Innovation, and Soil Health Support**

Research and innovation are crucial for developing safer alternatives to hazardous pesticides, such as bio pesticides and organic farming methods. Investing in studies on the impact of agrochemicals on soil health and micronutrient availability is essential for creating sustainable farming practices that improve nutrient uptake by crops. Support for soil health and fertility is equally important. Promoting soil testing and analysis helps assess nutrient deficiencies and pH levels, enabling farmers to receive tailored recommendations for soil amendments. Encouraging the use of organic fertilizers, compost, and cover crops can significantly improve soil structure, fertility, and microbial activity, thereby enhancing nutrient availability to crops.

### **6.7.6. Capacity Building and Farmer Empowerment**

Provide technical assistance and training programs to small-scale farmers on sustainable soil management practices and nutrient-balanced crop cultivation. Empower farmer cooperatives and associations to advocate for sustainable agricultural policies and access markets for organic produce, incentivizing environmentally friendly practices.

### **6.7.7. Partnerships and Collaborations**

Foster partnerships between government agencies, NGOs, research institutions, and private sector stakeholders to leverage expertise and resources in addressing agrochemical-related challenges. Establish platforms for knowledge sharing and best practices dissemination to facilitate continuous learning and adaptation of sustainable farming techniques. By implementing these actions collectively and collaboratively, stakeholders can mitigate the adverse effects of agrochemicals on micronutrient deficiencies among small-scale farmers. This holistic approach aims to promote sustainable agriculture practices that safeguard human health, preserve environmental integrity, and enhance agricultural productivity in the long term.

### **6.8. Future research prospects**

In the future, longitudinal studies could investigate the long-term health effects of pesticide exposure on small-scale farmers and their communities. Simultaneously, exploring alternative farming practices and integrated pest management strategies might offer sustainable solutions to reduce reliance on chemical pesticides, thus protecting the health and environment of farming communities.

Moreover, future research could further explore the causal relationships between micronutrient deficiencies and various socioeconomic factors, possibly through interventional studies. Addressing these underlying factors comprehensively could enable policymakers and healthcare providers to effectively address the nutritional challenges faced by pregnant women in the region, thereby enhancing health outcomes for both mothers and their babies.

Furthermore, future research should delve deeper into the specific mechanisms linking pesticide exposure to micronutrient deficiencies and explore potential interventions to mitigate these risks. Larger-scale studies involving diverse populations could offer a more comprehensive understanding of the prevalence and contributing factors of micronutrient deficiencies, paving the way for targeted interventions and policies to enhance maternal and child health outcomes.

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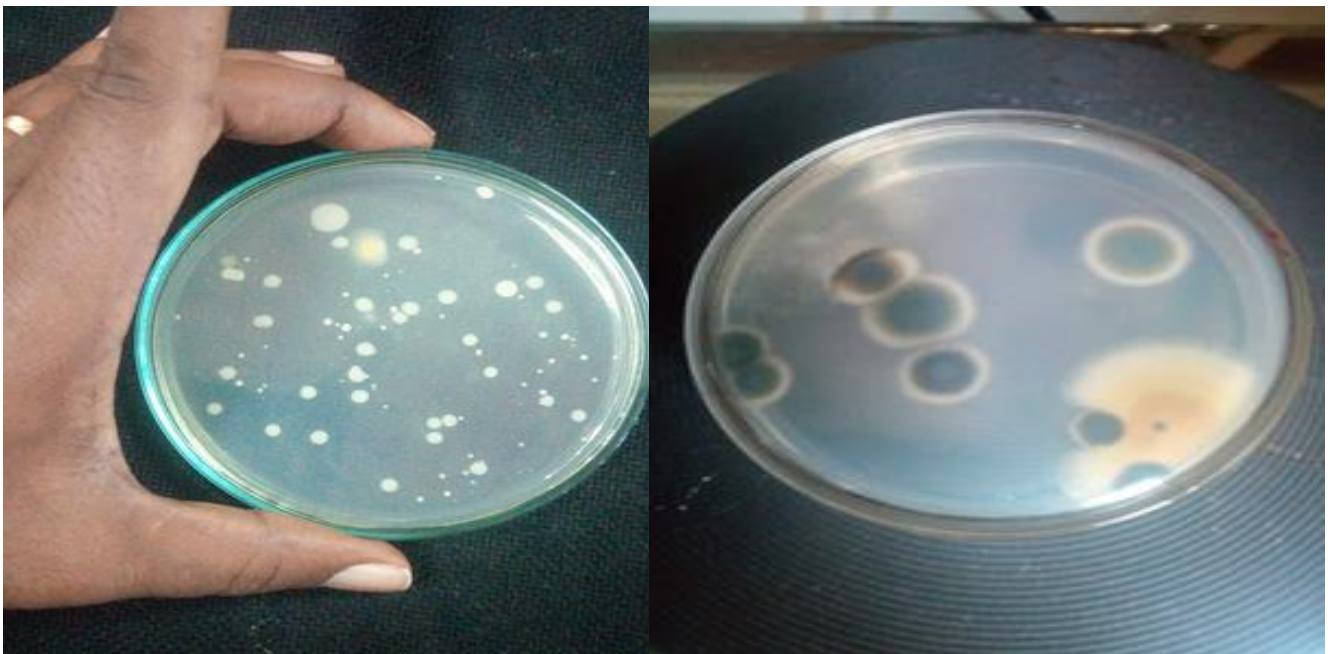
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## Annexes

### Annex1: Detecting the effect of glyphosate on soil micronutrients and nutritional quality of maize



**Annex2: Detecting the effect of glyphosate on soil microbiological activity**



**Annex 3: Pesticide residues detection from blood of small scale farmers**



## **Annex 4: Curriculum Vitae**

### **1. Personal detail**

Name: Tariku Neme Afeta

Birth date: 1975 EC

Sex: Male

Marital status: Married

Email: tarikun2001@gmail.com

Qualification: MSc in organic chemistry

Institution: Haramya University

From May 2004

Qualification: Bachelor degree Chemistry

Institution: Jimma University

From In Semp2000

### **2. Experience**

From 2005 - 2010

Position: Lecture ring, Teaching and research in Dambi Dollo Teachers college (DDCT) of Oromia, Ethiopia

### **3. Workshop/conference**

#### **Presentation**

*Tariku Neme Afeta* has presented research finding in Ethiopian Environmental Health 5th Annual scientific conference held from May 27-28/2022 at Dilla University, Dilla

### **4. Short term Training**

- Acquired research writing skills from the Norwegian University of Life Sciences from January 1, 2024, to June 30, 2024
- Attending training on climate and energy changes that was held in Silesian University of technology of Poland in July 2021
- Attended training on how to write proposal, grant and manuscript writing knowledge and skill enhancing given by Africa One Health University Network (AFROHUN) Formerly One Health Central and Eastern Africa (OHCEA) in June 2021 at Jimma University College of Agriculture and Vet Medicine (JUCAVM) campus
- Attending Comprehensive Systematic Review Training Program that was held in between Joanna Briggs Institutes and Jimma University in 2020

#### **5. List of Publications (More than 16): some of them are listed below**

- ✚ Prevalence of pesticide use and occupational exposure among small-scale farmers in Western Ethiopia
- ✚ Phytochemical investigation, physicochemical characterization, and antimicrobial activities of Ethiopian propolis
- ✚ Evaluating the level of pesticides in the blood of small-scale Farmers and its associated risk factors in western Ethiopia
- ✚ Serum concentration of zinc, copper, iron and its associated factors among pregnant women of small-scale farming in western Ethiopia
- ✚ Chemical composition and antimicrobial effect of western Ethiopian propolis
- ✚ Analysis of iodine from human urine and other food samples
- ✚ Analysis of Pesticide Chemicals from Human Blood Samples
- ✚ Review of blue-green infrastructure concepts for some selected countries
- ✚ Prevalence and associated factors of noise-induced hearing loss among workers in Bishoftu Central Air Base of Ethiopia
- ✚ Risk detection and assessment in small-scale metalworking industries of southwest Ethiopia