UNIVERSITY OF CAPE COAST

ASSESSMENT OF PESTICIDE USE AND IMPACTS AMONG SMALLHOLDER RICE FARMERS IN THE UPPER EAST REGION, GHANA

MUSAH IBRAHIM

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BY

MUSAH IBRAHIM

A thesis submitted to the Department of Environmental Science of the School of Biological Sciences, College of Agriculture and Natural Sciences, University of Cape Coast, in partial fulfilment of the requirements for the award of a Master of Philosophy degree in Environmental Science.

DECEMBER 2022

DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my original research and that no part of it has been presented for another degree in this university or elsewhere.

Name: Musah Ibrahim

Candidate's Signature…………………………… Date…………………

Supervisors' Declaration

I hereby declare that the preparation and presentation of the thesis were supervised with the guidelines on supervision of the thesis laid down by the University of Cape Coast.

Name: ……………………………………………………………………………..

Principal Supervisor's Signature………………..… Date……………..……

ABSTRACT

This study conducted an analysis among 388 smallholder rice farmers in the Upper East region, aiming to evaluate pesticide application practices and associated awareness. The research unveiled awareness of potential health risks associated with pesticides among the participants. The analysis revealed that diverse educational levels were observed among the farmers, with 33% having primary education and 27% admitting to not reading pesticide labels before use. The statistics indicated a higher utilisation of nose masks (70%) compared to protective coveralls (45%), implying potential inadequacies in protective measures during pesticide application. In addition, the study analysed the Environmental Impact Quotient (EIQ) values of various pesticides. The analysis revealed that Lambda, exhibiting a lower overall impact (EIQ 9.6), posed a higher risk to the ecosystem. Conversely, Dursban showcased a higher potential impact (EIQ 36.1) across all domains, particularly on the ecosystem. Furthermore, Confidor exhibited notably higher potential environmental impact (EIQ 50.4) compared to Lambda, emphasising the necessity for cautious usage. Additionally, the study focused on on how biochar contributes in reducing pesticide concentrations in soils. The results highlighted efficacy of rice husk biochar, notably the 1% rice husk effectively reduced pesticide concentrations in the soil. These findings underscore the need for targeted education, improved practices, and the potential application of biochar to ensure safer and more sustainable agricultural approaches among smallholder rice farmers in the region.

KEYWORD

Biochar

EIQ – Environmental Impact Quotient

Lambda-cyhalothrin

Pesticides

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DEDICATION

To the Divine Creator, the sustainer, my wellspring of strength, wisdom, and inspiration, I offer this project. On His wings, I ascend, grateful for His guidance throughout.

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To the seeker of knowledge, explorer of ideas, and embracer of learning's endless journey, your dedication to growth and understanding inspires and propels the quest for wisdom. May your curiosity spark new paths and illuminate the world. In the pursuit of enlightenment, may your endeavours continue to enlighten minds and open new horizons.

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LIST OF ABBREVIATIONS

A.I	Active Ingredients
AC	Activated Carbon
CCB	Corn Cob Biochar
CEC	Cation Exchange Capacity
EIQ	Environmental Impact Quotient
EIQ F. U	Environmental Impact Quotient Field Use
EI	Environmental Impact
EPA	Environmental Protection Agency
EPRIP	Environmental Potential Risk Indicator for Pesticides
FAO	Food and Agriculture Organization
GSS	Ghana Statistical Service
MC	Moisture Content
MoFA	Ministry of Food and Agriculture
NPAS	Northern Presbyterian Agricultural Services
PPE	Personal Protective Equipment
p-EMA	Environmental Performance Indicator of Pesticides
PVC	Polyvinyl Chloride
QA/QC -	Quality Assurance and Quality Control
RHB	Rice Husk Biochar
RT	Retention Times
SyPEP	System for Predicting the Environmental Impact of Pesticides
p-EMA	Environmental Performance Indicator of Pesticides

CHAPTER ONE

INTRODUCTION

There has been a discernible surge in the adoption of pesticides in the Ghanaian agricultural landscape attributed to their efficacy in pest control and their economic viability. Consequently, governmental regulations governing pesticide usage have been relaxed, aimed at invigorating agricultural productivity, fortifying food security, and expanding trade opportunities, as substantiated by Kwakye et al. (2018).

Nonetheless, the use of pesticides by smallholder farmers has raised concerns due to the possible risks posed by these chemicals, including risks to human health and the well-being of the environment, arising from instances of misapplication (Frimpong et al., 2012, Denkyirah et al., 2016). Lately, agricultural practices have encountered intensified scrutiny, primarily for their adverse consequences on the environment, spanning the deterioration of soil quality to water resource contamination, as evidenced by studies conducted by Anang & Amikuzuno, (2015), Herath et al. (2017), Hamsan et al. (2017) and AL-Ahmadi, (2019).

Pesticides constitute an essential tool for control of pest and disease in crop cultivation (Nicolopoulou-Stamati et al., 2016). This category of chemicals comprises herbicides, insecticides, fumigants, fungicides, and crop growth regulators, collectively representing the most widely deployed pesticides (Fianko et al., 2011). Regrettably, a significant proportion of these plant protection chemicals, when utilised in agricultural contexts, have the potential to exert detrimental impacts on non-target organisms and soil contamination, as observed in the research by Ogunfowokan et al. (2012).

In the specific context of Ghana, the extensive utilisation of pesticides by farmers serves as a vital strategy aimed at bridging the yield deficit within rice crop production, offering rapid resolutions to issues related to pests and diseases. It is imperative to underscore that this domain represents a crucial research gap, as these farmers occupy a position of heightened vulnerability to the adverse consequences associated with pesticide application. Thus, prioritising their risk assessment needs is paramount. Consequently, a critical facet of effective pesticide management hinges upon a broad comprehension of the behaviour of pesticides within the soil matrix, a factor that holds direct implications for the overall sustainability and safety of agroecosystems.

The subsequent studies shift the focus to the effectiveness of the Environmental Impact Quotient (EIQ) model in evaluating pesticide-related risks. These studies specifically highlight the applicability of the EIQ model in regions characterized by intensive pesticide use, particularly in cash crops like cocoa, found in the Western Region, Eastern Region, and Volta Region of Ghana. The research emphasizes the EIQ model's ability to provide a quantitative assessment of pesticide risks within the cocoa sector, stressing the importance of considering both environmental and human health factors. The studies cited (Kweku & Paintsil, 2017; Awusi et al., 2018; Kosivi, 2020) collectively support the efficacy of the EIQ model in assessing pesticide risks in these specific Ghanaian regions.

Nevertheless, variations in findings and research methodologies among these studies emphasise the need for context-specific risk assessments that take into account local conditions and pesticide characteristics. While the reviewed studies provide valuable insights into the EIQ model's application, there remains a scarcity of research on its implementation in specific regions or crop types. Consequently, it is important to recognise that the EIQ model's adaptability extends beyond cocoa and can also be applied to cereals such as rice.

The study contributes to our understanding of pesticide application, particularly in the context of cereals like rice, where the application of the Environmental Impact Quotient (EIQ) model has been less explored. It assesses farmers' familiarity with the types of pesticides used, their knowledge of safety precautions during application, and their proficiency in applying these substances. The research aims to evaluate potential pesticide-related hazards in agricultural soil, assess their toxicity employing a Risk Assessment model, such as the EIQ model, and investigate the leaching and removal of pesticides within the study areas, specifically Kassena Nankana East, Builsa North, and Builsa South Districts in the Upper East Region of Ghana.

Background to the Study

Rice, a staple crop for many regions, is susceptible to an array of pests, encompassing weeds, rodents, diseases, and insects. These pests pose a significant threat to agricultural production, capable of inducing substantial losses. Yield reductions of up to 40% of the harvested output have been documented, underlining the magnitude of this challenge (Savary et al., 2012). To combat these agricultural threats, farmers employ pesticide applications as a strategic response. Pesticides are instrumental in mitigating escalating pressures imposed by pests and diseases, seeking to bolster crop yields and mitigate post-harvest losses. Their potency, swift responsiveness, and ease of application underscore their role as indispensable tools in this endeavour(Anang & Amikuzuno, 2015; Jardim et al., 2014; Pano-Farias et al., 2017).

Despite their effectiveness, the widespread use of pesticides raises ecological and health concerns. Pesticides are extensively deployed in both developing and developed nations, but this practice carries substantial environmental, occupational, and consumer-related hazards. Pesticides are extensively employed in both developing and developed nations, thereby imparting noteworthy environmental, occupational, and consumer-related hazards (Popp et al., 2013; Bonner & Alavanja, 2017; Akter et al., 2018). Furthermore, the quest for heightened agricultural productivity, which involves the utilisation of chemical agents and other substances, has indeed led to increased operational efficiency and enhanced farm output, a phenomenon corroborated by Rasool et al. (2022). Nevertheless, this enhanced productivity has come at a cost, as it has concurrently engendered elevated levels of soil and water contamination (Claeys et al., 2011; Hjorth et al. 2011). Even in minor quantities, pesticides have exhibited adverse ecological effects and have contributed significantly to elevated groundwater contamination, as detailed in the research conducted by Agrawal et al. (2010).

In the year 2012, a comprehensive survey conducted by the Northern Presbyterian Agricultural Services (NPAS) encompassed 14 rural communities within the Upper East Region of Ghana. This research investigation revealed that a significant proportion of pesticide applicators, approximately constituting 25% to 33% of the total sample size, comprising 183 respondents, had acknowledged instances of inadvertent pesticide exposure. These inadvertent exposures predominantly manifested through inhalation and dermal contact, resulting in direct contact with chemical agents. These exposures were attributed to suboptimal handling practices and were indicative of a concerning pattern in pesticide management (NPAS, 2012, Okonya et al., 2019).

Of noteworthy concern is the pronounced effects of pesticides on agricultural workers. The suboptimal application and misuse of pesticides, coupled with the inadequate adoption of safety precautions, like the use of protective gear during handling and application, considerably heighten the risks faced by farmers (Imoro et al., 2019; Issahaku & Abdulai, 2020). Particularly concerning is the practice of manually mixing pesticides with bare hands, further underscoring the lack of adequate safety precautions in pesticide handling (Ndayambaje et al., 2019).

A significant observation is that only a small fraction of farmers sought pesticide application advice from public sector extension personnel, with the vast majority opting to obtain guidance from pesticide dealers or retail establishments (Rahaman et al., 2018). This choice of information sources may have contributed to problematic pesticide application practices. Notably, research indicates that farmers in Ghana were applying pesticides at rates varying from 1.3 to 13 times higher than the approved dose, pointing to a concerning pattern of misuse and overuse (Onwona-Kwakye et al., 2020). Such negligent behaviour has the potential to expedite the emergence of pests, increase their influence, and engender secondary insect infestations. Additionally, it poses environmental contamination risks with potentially long-lasting and deleterious consequences.

The global landscape of pesticide marketing and consumption presents a significant challenge in terms of data availability. Despite these limitations, estimates indicate that in 2007, global pesticide consumption reached approximately 2363 million kilograms. Herbicides constituted the largest share, accounting for roughly 950.7 million kilograms, followed by insecticides at 404.6 million kilograms, and fungicides at 262.17 million kilograms (Sushma et al., 2015). These estimates underscore the substantial quantities of pesticides utilised worldwide, with consumption steadily increasing over time. This pattern is not confined to global scales, as it is similarly observed in the African context, where fungicides, herbicides, insecticides, and bactericides rank among the most commonly employed and effective pesticides.

China's pesticide export data to African markets from January to November 2015 reveals the extent of this global trend. During this period, pesticide exports to Africa accounted for 13.9% of China's total pesticide exports (Bertrand, 2019). Notably, the Republic of South Africa, Nigeria, Ivory Coast, Egyptian Republic, Kenya, Cameroun, Ethiopia, the Republic of Tanzania, the Republic of Guinea, and Ghana feature prominently among top ten countries in terms of export value. These countries collectively contribute to 85% of China's export earnings in the African market (Bertrand, 2019). However, pesticide consumption patterns display substantial variability on a country-by-country basis. For instance, Taiwan records an average consumption of approximately 17 kilograms per capita, while Korea and Japan report consumption figures of 14 kilograms and 12 kilograms, respectively. The Netherlands and the United States follow, with per capita consumption rates of 9.4 kilograms and 7 kilograms, respectively (Gyawali, 2018). This variability highlights the significance of region-specific factors in shaping pesticide usage trends.

All the same, pesticides affect more than just farmers. Pesticide concentrations in the overall population can be observed as a direct consequence of contamination of the environment or work-related pesticide application (Mostafalou, et al., 2013). The homes of farm laborers are also susceptible to this toxic substance. Since they are situated so close to farmlands and spend a lot of time in areas where pesticides are used.

Pesticide exposure, whether occurring acutely or chronically, presents a multifaceted environmental risk that carries profound and enduring consequences for human health. Tragically, pesticide-related fatalities claim a significant number of lives globally each year, with an estimated annual exposure of 1 to 41 million individuals (Gyawali, 2018). Clinical symptoms of pesticide exposure often manifest within a few hours of contact and typically subside within days or weeks (Aryal et al., 2016). The primary avenues through which individuals are exposed to pesticides encompass the consumption of contaminated water and food. However, noteworthy exposure can also occur within or nearby areas. This exposure can lead to a diverse range of symptoms, ranging from mild afflictions such as ocular irritation and skin rashes to more severe and life-threatening conditions, including respiratory and neurological disorders, cancer, congenital malformations, and, in certain instances, fatality (Corvaro et al., 2017; Mew et al., 2017; Bassil et al., 2007; Sanborn et al., 2007). Globally, pesticide poisoning affects an alarming three million individuals and claims the lives of over 200,000 people each year (Sheikh et al., 2011).

Despite the drawbacks associated with pesticide usage, it remains the predominant method for managing rice insect pests. However, the lack of comprehensive health monitoring programs and environmental regulations for farm workers and farmers is a source of concern. Additionally, the scarcity of data on monitoring, pesticide exposure, and incidents of poisoning highlights a substantial research and oversight gap in this field (Donkor et al., 2016). Consequently, the need for rigorous scientific safety evaluation is paramount to safeguarding both individual health and ecological systems from the potential adverse ramifications of contact with pesticides. A comprehensive understanding of farmers' experiences, knowledge, and the potential consequences associated with pesticide usage holds particular importance in the development of sustainable and economically viable methods for environmental remediation, which, in turn, may serve to reduce health risks among farmers and enhance rice quality.

The State authorities in Ghana acknowledges the pivotal role of agriculture in poverty alleviation, emphasising the imperative for environmentally friendly pesticide use that can yield positive socio-economic outcomes. In Ghana's Upper East Region, there is an evident dearth of studies focused on farmers' comprehension of Personal Protective Equipment (PPE) use, the consequences of contact with pesticides, and the application of the Environmental Impact Quotient (EIQ) as an educational tool to underscore the hazards of pesticide usage for both consumers and the environment. The EIQ model, with its field rating values, may be harnessed by extension agents to make informed choices regarding the selection of the most environmentally benign pesticides. Additionally, it can serve as a valuable resource for the Farmer Training Center-Rice Sector Support Project (FTC-RSSP) within the research area, assisting in the evaluation of agricultural production and policies related to pesticides and the examination of continuous efforts in pest control adopted by farmers.

Statement of the Problem

Dichlorodiphenyltrichloroethane (DDT) is banned in developed nations but available in economically constrained countries, revealing a global disparity in pesticide regulation (Allsop et al., 2015, Wahab et al., 2016, Gesesew et al., 2016). Additionally, organochlorines exhibit substantial resistance to microbial degradation (Ruiz-Toledo et al., 2018). These raise concerns due to their potential to enter the human body through pathways such as diet, indoor/outdoor exposure, and occupational contact (Allsop et. al., 2015) thereby prompting food safety concerns among consumers and environmental groups (Thompson et al. 2017).

Despite pesticides' harmful effects on health, water, soil, and the environment, both applicators and the public lack awareness of these hazards. (Ogunfowokan et al., 2012) with regional variations in awareness of pesticide impacts on human health adding complexity (Allahyari et al., 2017; Denkyirah et al, et al., 2016) with many applicators exhibiting poor attitudes toward wearing personal safety gear during pesticide application (Okoffo et al., 2016).

This investigation discusses a research gap in pesticide use, Environmental Impact Quotient (EIQ) modeling, and soil cleanup in Ghana's Upper East Region. It integrates social and mathematical modeling with experimental approaches to comprehensively investigate the risks of pesticides, focusing on transformation and leaching in soils. The study, conducted in specific districts, also examines the use of adsorbents like corn cob and rice husk biochar for remediating pesticide-contaminated soils.

Aims and Objectives of Research

The research sought to examine farmers' depth of understanding concerning the application of pesticides and use the data to quantify the dangers of pesticide usage among rice farmers, in addition, the research aims at identifying useful amendments capable of adsorbing remnants of pesticides that leach into soil.

The specific objectives of the research are:

1. to examine the knowledge, attitudes, and practices of farmers regarding pesticide usage on rice farms in the study location.
2. using the EIQ method to evaluate the potential dangers of chemical control
3. to evaluate the effects of soil amendment (using rice husk and corn cob biochar) in remediating pesticide-contaminated areas, the following proposed hypotheses were tested in the study:

Hypotheses

1. Farmers understand how to apply pesticides to rice during outbreaks of pests and diseases.
2. The EIQ model would determine the potential risks pesticides posed to farmers, end consumers, and the ecosystem.
3. Applying rice husk-derived biochar and corn cob would effectively adsorb pesticides that may drain into the soil.

Statistical Hypotheses

1. H_{01}: There is no significant difference between farmers' knowledge and the application of pesticides on rice farms.

   H_{A1}: There exists a significant difference between knowledge of farmers and the actual application of pesticides on rice farms.

H_{02}: There exists no significant difference in the risk of pesticide use to farmers and the environment using the EIQ risk assessment model.

H_{A2}: There exists a significant difference in the risk of pesticide use to consumers, farmers and the environment using the EIQ risk assessment model.

2. H_{03}: The use of biochar (corn cob and rice husk) will assist pesticide draining in the soil.

   H_{A3}: Incorporating biochar (corn cob and rice husk) will not assist pesticide draining in the soil.

Research Significance

Pesticide use in rice farming is a familiar convention to combat pests and diseases that cannot be managed through organic methods, but it poses a significant risk of environmental pollution. Ecological policymakers and decision-makers require solid scientific data to underpin policies aimed at mitigating the adverse impacts of pesticides. Moreover, the diversity in socioeconomic and cultural backgrounds, along with varying resource availability among farmers in different agroecological regions, significantly influences their resource utilisation efficiency.

As a consequence, farmers exhibit considerable variation in their understanding, behaviour, and practices related to pesticides across communities, districts, and regions. This research aims to illustrate how farmers' knowledge and behaviour patterns affect pesticide application methods and alternative pest suppression approaches, with a singular attention on the potential threats faced by rice farmers and the surrounding ecosystem.

Smallholder farmers in Ghana heavily rely on rice cultivation for both economic stability and ensuring their families' food security. However, incorporating pesticides in rice cultivation methods, while effective in controlling harmful pests, has been linked with adverse environmental consequences and issues impacting human well-being. The Environmental Impact Quotient (EIQ) has been a valuable tool employed by scientists, economists, and environmentalists to quantify the relative impacts of different pesticides and food production techniques.

The study's results contribute to advancing the existing knowledge pertaining to the prevalence of pesticide traces in paddy soils. These findings underscore the significance of raising awareness and providing education about the dangers related to excessive use of pest-control chemicals in rice farming. The study reveals that farmers may not always employ the requisite preventive measures while working with pesticides, often due to their lack of familiarity with the active ingredients and the normalization of pesticide use.

Furthermore, the research highlights the serious consequences of pesticide use in communities, including health issues and environmental harm. This study provides valuable insights that can assist the Ghanaian government in developing targeted public health promotion efforts to address the challenges associated with pesticide application, benefiting both consumers and farmers.

Delimitations

This study focuses on investigating the risks associated with pesticide application among rice farmers. The research was constrained in its geographic scope, encompassing solely three districts within the Upper East Region: Kassena-Nankan, Builsa North, and Builsa South. These districts were purposively chosen due to their notable rice production, enabling the collection of relevant data concerning pesticide usage and its impacts on farmers. The long-standing management of rice farms across generations in these areas offers a unique opportunity to gain insights into pesticide utilisation, potential health risks, and the behaviour of pesticides in soil. It is assumed that what happens in these three districts is indicative of those in other districts within the Upper East Region.

Research Limitations

The research investigation was limited to three specific locales within the Upper East Region, primarily as a result of funding constraints. The collection of data was further complicated by challenges related to language and cultural differences, as well as difficulties in obtaining access to the subjects from whom data was sought.

Definitions of Terms

Pesticide: A pesticide is a chemical or biological substance designed to regulate pests, repel, or kill pests, which comprise insects, fungi, weeds, rodents, and varied organisms that can harm crops, animals, structures, or humans. Pesticides are used in agriculture, forestry, public health, and various other fields to protect crops, livestock, and human health by managing and reducing the damage caused by pests. They can come in various forms, including insecticides, herbicides, fungicides, and rodenticides, each targeting specific types of pests.

Smallholder rice farmers: The specific farm size considered for smallholder farmers can vary depending on the context and region. No universally agreed-upon farm size categorically defines smallholder farmers because it depends on local conditions, agricultural practices, and government policies. However, a smallholder farmer refers to an individual or family engaged in agricultural activities on a relatively small scale, typically with limited resources and land holdings. Smallholder farmers in Ghana typically operate farms of less than 5 acres (approximately 2 hectares) in size. Some definitions consider farm sizes of up to 5 hectares (about 12 acres) as falling within the smallholder category. It is significant to point out that the farm size alone is not the only criterion for defining smallholder farmers. Factors such as resource constraints, income levels, and subsistence farming practices also play a role in this classification.

Environmental Impact Quotient (EIQ): It is a technique used to determine how commonly used pesticides affect the environment including insecticides, fungicides, and herbicides in agricultural farming.

Organization of the Research

The part of the thesis is divided into different sections. First, we review the literature as well as a conceptual and theoretical framework in chapter two. In the third chapter, the research methodology will be described. Then, an in-depth analysis of the results is provided in Chapter 4. In Chapter 5, the results will be discussed. In conclusion, overarching summaries and potential avenues for future research will be outlined.

Summary of the Chapter

This section serves as an introduction to the research. It has given information about the research by summarizing its background, purpose, hypotheses, problem description and importance of the research, key terminologies operationally defined, and a breakdown of the sections within the chapter.

CHAPTER TWO

LITERATURE REVIEW

Introduction

The expansion of pesticide markets in West Africa has seen a significant acceleration, especially after 2005. From 2005 to 2015, the collective pesticide imports into the region experienced a threefold increase, with notably swift expansion observed in the three predominant agricultural markets, namely Côte d'Ivoire, Ghana, and Nigeria (FAOSTAT, 2020). The application of pesticides in farming has effectively lowered production costs and significantly mitigated losses in crop yield. This approach aims to enhance food production to meet the demands of the growing global population (Thompson et al., 2017). In Ghana, herbicide use resulted in a substantial 94% reduction in weed control expenses, while the combined approach of herbicide application and manual weeding led to a 53% to 60% reduction in weed control costs compared to relying solely on manual weeding. Controlling weeds in peanut cultivation for a season typically demands an average of 66.6 days of manpower per hectare. However, when herbicides are used either alone or in combination with manual weeding, the labour required is significantly reduced to 1.3 man-days per hectare and 36 to 41 days of labour per hectare, respectively (Arthur et al., 2016)

Continual utilisation of these substances results in the accumulation of harmful residues on agricultural products (Donkor et al., 2016). This buildup of toxic residues can potentially have detrimental impacts on human health (Tutu et al., 2011) and disrupt the local ecosystem (Ali et al., 2021). This issue is particularly severe in the context of rice production, given that it involves a substantial number of smallholder farmers operating on extensive areas of land.

To provide the necessary context for this study, it is essential to conduct a review of existing information.

This section of the research presents a comprehensive overview of the relevant literature, serving as the foundational framework for the research. The researcher has synthesized information from various sources, including journals, abstracts, online materials, books, and existing research, specifically addressing the application of pesticides among rice farmers. The examination of existing literature has been thoughtfully organised into three distinct sections.

The first section delves into key topics related to rice production in Ghana, pesticide usage, its consequences, pesticide exposure, and the recognition of farmers regarding the impacts of pesticides on both the physical well-being of humans and the ecosystem. This section provides a well-rounded understanding of the context in which pesticide application occurs.

The second section shifts the focus to the environmental impact of pesticide usage, considering various risk assessment models. Particular attention is given to the Environmental Impact Quotient (EIQ) model, which serves as a valuable risk indicator. This section aims to review the environmental implications of the use of pesticides and the methodologies employed for such assessments.

The final section offers an in-depth exploration of soils and the persistence of pesticides. It encompasses discussions on soil types, structure, and the adsorption of pollutants, emphasising the role of soil amendments in mitigating pesticide impacts on the environment. This section deepens our understanding of how pesticides interact with soil and persist in agricultural ecosystems.

In conclusion, this literature review not only provides valuable insights into the factors surrounding pesticide application among rice farmers but also lays the groundwork for subsequent research. It highlights the significance of evaluating the environmental and health impacts of pesticide use while emphasising the importance of an environmentally-friendly and informed agricultural practices.

Rice Production in Ghana

Rice farming plays a pivotal role in the economic landscape of Ghana, contributing significantly to its financial state, offering job opportunities to approximately 10 per cent of households (Anang, 2017). The northern regions of Ghana are crucial in rice production, accounting for 67.8 per cent of the overall rice output in the nation (Angelucci et al., 2013). This underscores the importance of rice not only for the national economy but also for local employment and livelihoods, particularly in the northern regions.

However, the rising demand for rice, driven by population growth, has outstripped domestic production, necessitating heavy reliance on imports (Van Oort et al., 2015). The per-person consumption of rice has significantly risen in Ghana over the past two decades, rising from 17.5 kilograms to 48 kilograms. The current per capita consumption stands at 48 kilograms, translating to approximately 1.42 million metric tons of rice consumed in the country (Archibald & Taylor, 2020). The need for imports to cover this deficit comes at a significant cost, exceeding US$600 million annually, which strains foreign currency reserves (USDA, 2018).

To address these issues, the Ghanaian government is committed to reducing its reliance on rice imports by promoting domestic rice production.

This strategy focuses on enhancing productivity and efficiency, aiming to decrease the expenditure on rice imports. The initiative not only seeks to bolster food self-sufficiency but also holds the potential to increase farmers' yields and income levels, ultimately leading to an improved standard of living. Additionally, it will create employment opportunities for farmers, processors, and marketers, benefiting the economy.

The application of pest control agents in Ghana, particularly within the scope of agriculture, has increased significantly over the past few decades (Donkor et al., 2016). Pesticides play a crucial role in crop protection and disease vector control in the public health sector (Dzobo, 2016). These pesticides vary in composition and target organisms, falling into categories like inorganic, synthetic, and biological pesticides (Zacharia, 2011). Farmers continue to employ specific pesticides due to their effectiveness in pest control, causing the occurrence of pesticide traces in various crops, such as okra, garden eggs, pepper, and tomatoes (Abagale et al., 2019). These residues include organochlorine pesticides, with Lindane and Aldrin showing notable concentrations.

Persistent Organic Pollutants (POPs) fall into a category of chemical substances with specific properties that make them stable and long-lasting in the environment. They disperse widely through natural processes, accumulating in the fatty tissues of organisms, with the inclusion of humans, and posing risks to both human health and wildlife (Afful et al., 2010; K. C. Jones, 2021). Pesticide residues refer to the amount of pesticide that remains in products after contact with the treated area (Quansah et al., 2015; K. C. Jones, 2021). These residues are influenced by various environmental factors and may undergo degradation, evaporation, binding to soil, or transport by means of surface runoff and leaching mechanisms (Vryzas, 2018).

In conclusion, the importance of rice in Ghana's economy, especially in the northern regions, is significant for employment and local livelihoods. However, the rising demand for rice has led to heavy reliance on imports, straining foreign currency reserves. The government's initiative to promote domestic rice production is expected to enhance self-sufficiency, increase farmer incomes, and create employment opportunities. Meanwhile, the growing use of pesticides in Ghana has raised alarms about the existence of pesticide remnants in crops, which can have implications for both the health conditions of people and the ecological balance. Addressing these issues requires a balanced approach that ensures food security while safeguarding environmental and human well-being.

The Impact of Pesticide Usage on Humans and the Environment

The escalation of pesticide usage in many developing nations has given rise to increasingly severe environmental challenges, manifesting in issues such as water pollution, disruption of ecosystems, and habitat contamination (Marquis, 2013). Despite pesticides playing crucial roles in managing pests and diseases to economically acceptable levels, their application is frequently linked to unintended adverse effects on both the environment and the health of individuals (Owombo et al., 2014; Dankyi et al., 2014).

The environmental effects of pesticides depend on the extent of exposure and the specific pesticide's toxicity attributes (Li et al., 2015). The detection of pesticides in various environmental components in Ghana has raised significant concerns regarding the safety of remaining traces in crops, soils, and water, and possible detrimental outcomes on both humans and the natural surroundings (Mohammed et al., 2019).

Exposure occurs when individuals come into contact with various environmental factors, including the atmosphere, water, soil, dust, food, and items. This exposure can take different forms, such as ingesting contaminated food, inhaling polluted workplace air, or touching contaminated surfaces. It can transpire via breathing and physical contact with the skin, or oral consumption (Lorenz et al., 2012).

However, the consequences of pesticide usage extend to various stakeholders in the food supply chain, affecting consumers, farmers, and traders (Onwona Kwakye et al., 2019). Pesticide application has far-reaching effects, including harm to domestic animals, the depletion of beneficial predators and parasites, air pollution, reductions in fishery and aquatic populations, and environmental degradation. Furthermore, it leads to inadvertent pesticide exposure in crops, the lethal impact on birds and honeybees, and the presence of unwanted residues in food items. It is well-established that pesticide residues pose a substantial threat to numerous endangered species (Brain et al., 2015).

In conclusion, increasing application of pest control agents in many developing countries has led to widespread environmental and health challenges. These issues are closely linked to exposure levels, the toxicity of pesticides, and their far-reaching consequences on various aspects of the ecosystem, including crops, wildlife, and human health. Addressing these concerns is essential to mitigate the unfavorable outcomes of pesticide usage on both the environment and human well-being.

Farmers' Knowledge, Attitudes, and Practices Regarding Pesticide Use

Knowledge, attitudes, and practices (KAP) surveys have proven invaluable in assessing people's understanding, attitudes, and behaviours concerning specific subjects (Lorenz et al., 2012). A research initiative conducted in Rwanda revealed that the overwhelming majority of participants held the belief that personal protective equipment (PPE) implementation and consistent pesticide safety training could insulate them from the harmful health outcomes resulting from pesticide exposure (Ndayambaje et al., 2019). The task of the pesticide applicator's behaviour in accurately assessing risks, emphasizing the crucial importance of farmer awareness and knowledge about pesticide risks for enhancing safety. Safety behaviours are influenced by perceptions, attitudes, and self-efficacy in pesticide use (Damalas & Koutroubas, 2018).

Pesticide use behaviour exhibits regional disparities within Ghana. In the Western region, Paintsil (2017) identified low levels of education and a negative attitude towards using personal protective equipment (PPE). Additionally, Ansah (2019) found that a significant percentage of farmers (89.8%) combined multiple types of pesticides. Conversely, in the Volta region, farmers demonstrated good knowledge of pesticide usage but often mishandled pesticides, as observed in a study by Kosivi (2020).

These regional discrepancies in pesticide use behaviour in Ghana can be attributed to the limited knowledge among farmers about pesticide types, their proper use, and associated risks, as well as ineffective government regulation enforcement. These conditions have led to the widespread use of low-cost and frequently adulterated pesticides (NPAS, 2012). These circumstances were further explored in studies that delved into how farmers situated in the northern sector of Ghana manage pesticides (Imoro et al., 2019).

In contrast to Palestine, most individuals demonstrated a strong understanding of the pesticides they used, with those having higher education levels tending to adopt safer pesticide practices (Zyoud et al., 2010). However, even among those with greater knowledge, some individuals neglected to implement protective measures. In Uganda, small-scale farmers often disregarded safety precautions, despite being aware of the health risks (Oesterlund et al., 2014). Similarly, in Brazil, even though farmers were aware of the risks and regularly read label instructions, they frequently failed to implement adequate safety measures. This failure was often attributed to their attitudes and education levels (Remoundou, 2014). These findings underscore the importance of education in enhancing safety practices among farmers (Dey Nepal, 2010).

In conclusion, these studies highlight the significance of education, attitude, and regional variations in pesticide use behaviour. They emphasise that increasing knowledge and promoting safe practices are essential steps toward reducing the dangers linked to the utilisation of pesticides in different regions in the midst of various farming communities.

Disposal and Transportation of Pesticides

Disposing of and moving pesticide containers is important because it can harm the environment. Researchers have looked at what farmers typically do with these containers, and it is not always good. Pesticides are used a lot, and this creates a lot of empty pesticide containers. These containers can have pesticide leftovers in them, and they can be harmful to the environment. The containers include things like bottles, tanks, barrels, and bags that hold pesticides or have pesticide residues (Li et al., 2015; Li & Huang, 2018).

In Ghana, a study unveiled that agriculturists often get rid of their empty pesticide bottles in environmentally harmful ways, a practice that regrettably many farmers do not adhere to the recommended instructions (Okoffo et al., 2016; Wumbei et al., 2019). Even though farmers claim to follow pesticide label instructions, these claims often don't translate into actual practice (Miyittah et al., 2020). However, their methods pertaining to storage, getting rid of, and cleansing these bottle containers post-usage are unsuitable and could pose risks to both human well-being and the ecosystem (Miyittah et al., 2020). These containers are sometimes thrown into fields or placed near water sources used for irrigation, and occasionally, they are even burned in open fires. Furthermore, some farmers repurpose these containers for storing water and oil, raising significant concerns because of their potential to harm the natural environment and impact individuals' well-being (Okoffo et al., 2016). As efforts are made to boost agricultural production, the handling of these pesticides by farmers has become a growing concern(Northern Presbyterian Agricultural Services and Partners, 2012).

However, there's some good news too. In some developed countries, they've initiated programs to promote awareness about the proper disposal of old pesticides. These countries have stringent regulations, such as following global standards like good agricultural practices (GAP), which mandate farmers to safely store leftover pesticides, empty bottle containers, and various waste associated with pesticides. Capable institutions are responsible for collecting and ensuring the safe disposal of these materials. In contrast, in many developing countries, farmers tend to handle leftover pesticides and empty bottles in the same manner, as noticed (GAP, 2016).

In conclusion, addressing the disposal and transportation of pesticide containers is critical for safeguarding both the environment and human health. This issue requires a multi-faceted approach, including education and awareness programs, the creation and implementation of rules, and the promotion of responsible practices among farmers. Efforts in this area are essential to mitigate the adverse consequences associated with improper disposal and transportation of pesticide containers. To keep pesticides safe, we must prevent spills and leaks. If an accident happens, using plastic materials to catch the spills is crucial. When moving pesticides, especially in open trunks or the back of vehicles, make sure to store and cover them securely. These steps protect both people and the environment from harm. By following these safety measures and implementing responsible practices, we can work towards a safer and more sustainable approach to pesticide use to benefit everyone.

Storage of Pesticides, and use of Personal Protective Equipment.

Personal Protective Equipment (PPE) is all about getting rid of dangers, no matter how you do it. It is about keeping safe habits and good health at work, making sure the environment is safe, and not putting the lives of farmers, consumers, and others at risk (Raimi et al., 2020). In many developing countries, farmers and operators frequently employ unsafe methods when dealing with pesticides. This can lead to potential harm to both the environment. It is important to raise awareness and provide education on safer pesticide handling practices in these regions to prevent these risks.

Storing pesticides in bedrooms is a dangerous practice observed among farmers. According to Raimi and colleagues' findings in 2020, 29.1% of farmers chose to store pesticides in their bedrooms (Raimi et al., 2020). Abubakar and his team's research in 2015 also discovered a similar trend, with 26.6% of farmers misusing pesticides by storing them in their family bedrooms. Notably, the majority, approximately 96% consider the improper disposal of pesticide containers as a form of misuse

Furthermore, the study revealed that 38.5% of farmers stored pesticides outside their houses, and an additional 32.5% stored pesticides inside their houses (Raimi et al., 2020). These statistics illustrate potentially harmful practices that pose risks to farmers, their households, and the environment. It is crucial to promote safer and more responsible pesticide storage practices to safeguard both human health and the surroundings.

A different research study focused on how cocoa farmers in southwestern Nigeria interact with insecticides and their understanding of precautionary measures. The results of this research showed that around 61% of these farmers kept pesticides in their houses, while 31% had a designated storage area for pesticides, and 8% kept the pesticides directly on their farms (Dzobo, 2016).

These findings highlight the significance of paying attention to how pesticides are stored. It is essential to address and improve pesticide storage practices to enhance the safety of agricultural communities. Storing pesticides in homes can pose risks to both farmers and their families, and thus, there is a need to raise awareness and encourage safer methods of pesticide storage to protect the well-being of those involved in agriculture.

In one study conducted by Raimi and colleagues in 2020, it was revealed that 47.0% of surveyed individuals get rid of pesticide bottle containers by simply discarding them into open fields. Additionally, 38.7% of respondents discard these containers in the garbage, while 14.2% choose to return them to the seller (Raimi et al., 2020).

This contrasts with the findings of another study led by Ricco and his team. In their research, they discovered that a majority of their participants, approximately 90.8%, reported having a designated place for storing pesticides, either near their homes or on their farms. Surprisingly, only a small percentage, specifically 10.0%, mentioned storing these pesticide products inside their houses (Riccò et al., 2018).

The initial research unveiled that a substantial proportion of individuals employ unsafe methods for the disposal of pesticide containers, including the improper discarding of containers in open fields, and waste receptacles, or returning them to the vendor. In contrast, the subsequent study demonstrated that the majority of participants adhered to safer practices by designating appropriate storage locations for pesticides, either in proximity to their residences or within agricultural premises. This distinction underscores the critical need for advocating and endorsing secure procedures for the disposal of pesticide containers.

In conclusion, the proper keeping of pesticides and the adoption of Personal Protective Equipment (PPE) are integral components of safe and responsible agricultural practices. Storing pesticides correctly ensures the safeguarding of both the well-being of people and the ecosystem. It prevents the potential hazards associated with pesticide contamination, leakage, or mishandling. Furthermore, the utilisation of PPE, such as protective clothing, masks, and gloves, acts as a vital shield against pesticide exposure, offering a critical layer of defence for farmers and workers.

The studies discussed underscore the importance of promoting awareness and education on the appropriate storage of pesticides, not only to ensure safety but also to prevent harmful practices, such as storing pesticides in bedrooms. The discrepancies in pesticide storage practices, as highlighted in different research findings, emphasise the need for a standardized approach to ensure safety in agricultural communities. Ultimately, safeguarding the well-being of those involved in agriculture, as well as preserving the environment, necessitates the consistent adoption of responsible pesticide storage and the use of Personal Protective Equipment. These measures are pivotal in reducing the risks associated with pesticide handling, benefiting both agricultural workers and the broader ecosystem. As we move forward, it is imperative to prioritise and enforce safe pesticide storage and PPE usage to ensure a future that is both healthier and more sustainable for everyone.

Risk Assessment of Pesticides

In a changing world characterised by enhanced data sharing and accessibility, the challenges of gathering data for comprehensive pesticide risk assessments remain a significant concern. These assessments are crucial for evaluating the potential dangers of pesticide exposure, especially when assessing risks within the confines of a region or nation (Lewis et al., 2016).

To conduct these assessments, safety experts employ advanced mathematical tools and ecological risk assessment models (such as PRZM – Carsel et al. 1985, GLEAMS – Leonard et al. 1987, EIQ - Kovach et al. 1992, EUROPOEM – Van Hemmen, 2001, MACRO – Larsbo et al. 2005) to estimate pesticide risks (Schwarzenbach et al., 2016). These tools enable them to make educated guesses about pesticide exposure and its environmental presence. They compare these estimates to established safety regulations and consider the repercussions of pesticides on living organisms.

Pesticide risks are shaped by the properties of the pesticides themselves, such as their movement in soil and breakdown characteristics, in conjunction with the environmental settings and the presence of microorganisms (Beesley et al., 2010). This means that the way a pesticide behaves in the environment, including how it spreads in the soil and how quickly it degrades, plays a significant impact on establishing the risks it poses to ecosystems and organisms. Additionally, specific environmental variables, namely temperature, moisture, and the types of microorganisms present, can further influence the manner in which pesticides interact with the environment and potentially lead to adverse effects on ecosystems and human health. Understanding these complex interactions is crucial for effective pesticide risk assessment and management.

In recent years, the European Food Safety Authority (EFSA) has been at the forefront of updating pesticide hazard assessment practices, focusing particularly on understanding the impact of pesticides on various bee species, notably honey bees and bumble bees. The imperative for these revisions became evident in 2013 as concerns over declining global pollinator populations escalated. Responding to these concerns, EFSA introduced a new set of guidelines tailored for conducting comprehensive hazard assessment concerning honey bees, bumble bees, and solitary bees (EFSA, 2013).

A primary objective of this innovative approach was to enhance the protection of honeybee communities, particularly those established on periphery of fields subject to pesticide applications. This marked a pivotal shift towards preserving the well-being of these essential pollinators. EFSA's commitment to this cause persisted in 2014 when the authority released supplementary guidance accompanied by a specialized tool aimed at assessing the exposure of various demographic groups, encompassing operators, workers, residents, and bystanders, within the framework of threat evaluation for products that protect plants (EFSA, 2014).

Building upon these efforts, EFSA has further refined these guidelines in 2023, introducing a two-tiered system. The first tier addresses the assessment of pesticide exposure, while the second tier delves into understanding the consequences of pesticides on bee populations. Mathematical models are harnessed to estimate bee exposure, and dose-response curves provide valuable insights into how pesticides influence these crucial insect species. These adjustments underline the growing recognition of the pivotal role that safeguarding bee populations plays in the broader context of pollination and environmental well-being (EFSA, 2023).

Pesticide risk assessments serve purposes beyond regulatory compliance. They are utilised by governments for pollution management, policy development, and monitoring, and by water companies to safeguard drinking water supplies. Large retailers also employ them to ensure consumer safety and promote sustainable farming practices. In non-regulatory applications, simpler techniques established on the physical and chemical properties of pesticides are often used, making them particularly relevant in resource-constrained developing countries (Feola et al., 2011).

These assessments play a pivotal role in managing the potential hazards associated with pesticide use. While challenges in data collection persist, the precision of these assessments is essential to safeguarding the responsible use of pesticides, protecting both the wellness of individuals and the surroundings (Adejumo et al., 2014). In a world where pesticide use is widespread, understanding and managing these risks are more critical than ever.

Environmental Impact Assessment and Pesticide Risk Indicators

Worldwide, people are very worried about pesticides because they can be harmful. Almost everywhere, governments have rules before pesticides can be sold to make sure they don't cause problems. Scientists check if pesticides might be dangerous to people and other creatures (Streissl et al., 2018). Pesticide risk indicators play a crucial role in evaluating the potential environmental harm caused by pesticides. Farmers and people who make rules use these indicators to decide which pesticides are better for the environment. They help choose the best ways to control pests while causing the least harm to the environment (Paintsil, 2017).

Despite the abundance of data on pesticides and the use of established risk assessment methods, there is increasing evidence of unanticipated environmental consequences. For example, impacts on birds, pollinators and aquatic organisms have come to light, even though current methods did not predict such outcomes (Hallmann et al., 2014; Goulson et al., 2015; Woodcock et al., 2016; Sánchez-Bayo et al., 2016). Lots of pesticide indicators only look at toxicology information (such as risk index, bioconcentration factor, risk index persistence, groundwater distribution score, and Hasse diagram) and physical properties of the chemicals, hence disregarding the consideration of exposure (Muhammetoglu et al., 2010).

The current methods for assessing risks primarily concentrate on local impacts and do not take into account broader regions, multiple pesticides, and crucial elements like landscape structure and the extent of pesticide usage, raising concerns about achieving the envisioned standard of environmental guardianship (Streissl et al., 2018).

Additionally, evidence indicates that pesticide levels within the surface water systems may surpass the bounds established by regulations (Stehle & Schulz, 2015). As a response to this concern, some experts propose implementing pesticide surveillance initiatives similar to those used for pharmaceuticals (Milner & Boyd, 2017). Monitoring serves multiple purposes, including regional assessments, as long as the sampling covers sufficient time and space, and the right analytical methodologies are put into practice (D. Wang et al., 2016). For larger-scale assessments, the most effective approach involves a combination of model predictions and targeted monitoring, as outlined by Ippolito et al., 2015.

Certain indicators, like how often it is administered, hectare doses and the Environmental Impact Quotient (EIQ), can offer a worldwide perspective when assessing environmental risks. Pesticide risk indicators can be categorized based on how they affect humans, plants, and animals. These indicators are then blended to devise systems for assessing the impact of pesticides, helping us assess the risks of using pesticides on a larger scale. Some acknowledged examples of pesticides risk evaluation models include SyPEP, EYP, EIQ, SYNOPS, p-EMA, IPest and Pesticide Environmental Risk Indicator (PERI) (Adejumo et al., 2014).

In conclusion, a global perspective on pesticide risks is crucial for understanding their effects on the environment, humans, plants, and animals. By utilising these assessment systems, we can better evaluate and mitigate the risks associated with pesticide use on a larger scale, ultimately promoting environmental protection and safety.

The Environmental Impact Quotient (EIQ)

The Environmental Impact Quotient (EIQ) was created in 1992 at Cornell University in the United States. Its purpose was to gather the available knowledge about the environmental influence of pesticides and make it more accessible. This was done to aid crop producers and other Integrated Pest Management (IPM) practitioners in making pesticide choices that are more environmentally friendly (Kovach et al., 1992). The EIQ serves as a methodology for quantifying the environmental repercussions of pesticides. The observed values derived from these assessments enable the comparison of distinct pesticides and pest control strategies, ultimately aiding in the determination of which program or pesticide is more inclined to yield a reduced environmental impact. This approach tackles numerous environmental issues commonly encountered in agricultural systems, encompassing concerns related to farm workers, consumers, wildlife, health, and safety (Kovach et al., 1992). A differentiation is established between "EIQ values" and "Field Use EIQ." The EIQ value represents a numerical measure calculated for a particular active ingredient. It forms the foundation for computing the "Field Use EIQ," which offers insights into the potential environmental impact of distinct pesticide formulations when used at recommended dosages.

The EIQ value for a specific active ingredient is computed based on a formula that takes into consideration factors like toxicity (covering dermal, chronic, bird, bee, fish, and beneficial arthropod effects), soil half-life, systemicity, leaching potential, and plant surface half-life. Each of these factors is assigned a rating of 1, 3, or 5 to indicate its potential to cause harm. Six of these ratings depend on facts and measurements, while the other five rely on judgments about whether the impact is low, medium, or high.

These factors are employed to figure out eight indicators for environmental impact. This is done through math equations that involve the numerical ratings and the importance of each effect. The effects considered include the impact on pesticide applicators, pickers, consumers, groundwater, fish, bees, and beneficial arthropods. These scores are combined to show how much of an impact the pesticide has on three main areas: the farmer, the consumer, and the environment. The overall EIQ score is the average of these three scores, and it is calculated for each pesticide ingredient.

EIQ Related Issues

Risk assessors rely on indicators because they help simplify the vast amount of data and numbers related to pesticide impact on the environment. The Environmental Impact Quotient (EIQ) was designed to compile data on risks and toxicity into a single numerical value, where higher numbers indicate greater risk. However, condensing extensive data into one value can lead to the loss of important details. The accuracy of this approach hinges on its underlying assumptions and mathematical data combination (Peterson & Schleier, 2014).

Within the EIQ formula, there are factors like plant surface half-life and runoff potential that serve as proxies for potential exposure. For instance, fish toxicity is multiplied by the surface runoff potential in the EIQ formula. While these factors are indicative of exposure potential, they do not provide precise estimates of actual exposure. Assigning specific scores to risks in the EIQ system suggests a lack of acknowledgment of the uncertainty surrounding exposure and toxicity. This can be problematic because these scores are meant to represent the likelihood or probability of exposure and toxicity occurring (Peterson & Schleier, 2014).

The EIQ was developed to address a specific issue - the use of the weight of applied pesticides as an environmental indicator. When you only consider the amount of pesticides used and ignore information about toxicity, possible exposure, and how long the pesticide sticks around, it leads to significant limitations (Benbrook, 2012). In this context, the oversimplification of pesticide impact, which results from exclusively focusing on quantity, renders the assessments incomplete and potentially misleading. A comprehensive evaluation of the environmental consequences of pesticide application necessitates the incorporation of these previously disregarded facets (Benbrook, 2012).

No previous criticisms and evaluations of the EIQ have particularly concentrated on herbicides. Despite this, the Field EIQ is still applied in weed science research to compare herbicide use, especially in the context of herbicide-resistant crops and weeds (Brookes & Barfoot, 2012; Green, 2012; Beckie et al., 2014). Users of the EIQ often acknowledge its limitations during its application, but the calculation method employed may not be as suitable for comparing herbicides as it is for other categories of pesticides. In the context of herbicides, there are two specific anomalies in the EIQ calculation. The "systemicity" risk factor (SY) consistently receives a value of 1 for herbicides, resulting in no contribution to herbicide EIQ values. SY, according to the definition by Kovach et al. (1992), represents "the pesticide's capacity to be taken in by plants." Herbicides, in general, can be taken in by plants to a certain degree, and systemic herbicides can move within the plant. It remains uncertain why SY was regarded as significant for various pesticide types but was essentially excluded from the EIQ calculation for herbicides.

In summary, while indicators like the EIQ offer valuable tools for simplifying complex data, users must be aware of their limitations and uncertainties. Careful consideration and refinement are necessary for accurate and comprehensive pesticide risk assessment, particularly in the context of herbicides.

Persistence of Pesticides in Soil

The breakdown of Dichlorodiphenyltrichloroethane (DDT) in soil can vary considerably, ranging from 4 to 30 years, and a similar pattern is observed for other chlorinated organic substances, often referred to as Organochlorine pesticides (OCPs). These OCPs have the capacity to endure within the soil environment for extended durations even after their initial application (Afful et al., 2010). The reason behind this extended persistence is their resistance to natural breakdown, with chemical, physical, biological, and microbiological processes proving to be ineffective in hastening their degradation (Afful et al., 2010).

Even though DDT was banned in the 1980s, it continues to persist in the environment and can be found in different environmental sources (Xu et al., 2013). Once pesticides enter the soil, they have the potential to enter the human body through soil ingestion, inhaling soil particles, or coming into contact with the skin. Due to their harmful effects, many pesticides can have adverse impacts on both the environment and human health (Aiyesanmi & Idowu, 2012). Pesticides, especially those that were initially included in the 2001 Stockholm Convention and those subsequently added to the convention's list in 2009 and 2011, are a source of worry (Jennings & Li, 2015).

Pesticides can contaminate agricultural soils in multiple ways. This contamination may result from direct soil applications of pesticides or, alternatively, through indirect means like runoff from plants, drift during spraying, and even transportation and disposal via the air. When pesticides are carried by runoff or flooding, they can unintentionally spread to areas where they weren't originally intended, causing contamination of non-target environments (Wong et al., 2017). The rate at which pesticides attach to different parts of the soil, particularly organic matter, is linked to the particle size of the pesticides in the formulation. Smaller pesticide particles tend to attach faster (Kumi & Daymond, 2015).

The behavior of pesticides in soil is determined by a multitude of factors encompassing physical, chemical, and photochemical processes, as well as biological transformations (Dirbaba et al., 2018; Jorfi et al., 2019). Pesticides in soil are primarily influenced by how they evaporate, get taken up by plants, leach and wash away, attach to soil components, break down chemically through processes like hydrolysis and oxidation-reduction, break down when exposed to light, and degrade through the actions of soil microorganisms (Nieder et al., 2018). These processes are linked to environmental factors such as soil properties (like texture), chemical attributes (such as pH, organic material, and metal ions), and weather conditions (Jorfi et al., 2019). The pace and path of pesticide changes are what eventually decide how much of them remains and how stable they are in the soil (Dirbaba et al., 2018; Jorfi et al., 2019). The way pesticides behave and how they react with soil can be significantly altered by their chemical properties and their interaction with other chemicals often added to commercial products. These additional compounds, like surfactants, coagulants, decomposition inhibitors, buffers, and synergic substances, can have a notable impact on how pesticides interact with soil components and their ability to breakdown (Dirbaba et al., 2018).

In summary, understanding the persistence and contamination pathways of pesticides in soil is crucial for mitigating their environmental and health impacts. Further research and effective management strategies are needed to address these challenges and minimize the long-term effects of pesticide use in agriculture.

Biochar as Pesticide Adsorbent in Soil

Pollution caused by human activities harms the quality of soil and presents environmental risks that are deemed unacceptable for both living organisms and humans (AL-Ahmadi, 2019). Data on pesticide leaching are essential to prevent chemical contaminants from entering water ecosystems, including sources of drinking water. Several techniques have been devised to immobilize contaminants within soil. These methods include electrokinetics (Rezaee et al., 2017), encapsulation (Shen et al., 2019), and the use of sorbent materials, such as organophilic clays, ferrous sulfate, and carbon sorbents (Zhang et al., 2010; Shen et al. 2019). Biochar, a carbon-based sorbent, is derived from the pyrolysis of plant materials at temperatures below 700°C with limited oxygen supply (Lehmann & Joseph, 2015).

The potential influence of biochar materials on pesticide leaching is a complex matter, with outcomes significantly dependent on different soil types and the sorption characteristics of the specific compounds involved (Larsbo et al., 2013). Biochar has been utilised for many centuries and is often linked to charcoal, which was initially created from biomass feedstock (Adejumo et al., 2014). The use of biochar, a finely textured substance, distinguishes it from charcoal in its role in soil cleanup since it is produced from pyrolytic organic substances (Zhu et al., 2017). Soil amendments are well-known for their ability to remove pollutants from soil (Miyittah et al., 2011). In addition to their role in soil remediation, biochar and related materials serve various other purposes, such as heat and power generation, as well as fuel production. These versatile materials are also essential for managing waste materials, addressing the challenges of climate change, and producing sustainable energy sources (Ahmad et al., 2014). Biochar exhibits exceptional adsorption capabilities for a wide range of pollutants, encompassing both organic and inorganic substances. Its remarkable resistance to degradation, whether chemical or biological, makes it a robust soil amendment (Lehmann et al., 2011). By employing biochar, pollutants are effectively trapped within the soil, thereby reducing their potential to infiltrate groundwater or affect crops.

Biochar, according to Yang et al. (2010), reduces pesticides in agricultural soil, resulting in less pesticide uptake by plants. Biochar additions may influence pesticide fate and function in the environment. The power of biochar to trap toxic substances was related to its sorption abilities. This differed widely based on the biomass used as a feedstock and pyrolysis conditions (Keiluweit et al., 2010). The use of agro-waste biochar is a significant approach to reducing pesticide leaching. Because of its high porosity, it has a greater ability to bind with nutrients (Ahmad et al., 2014). As a result, it can effectively reduce pesticide loss due to leaching (Inyang & Dickenson, 2015). It improves soil airflow, water storage capabilities, as well as crop nutrition(Atkinson et al., 2010).

Economical adsorbents are not only efficient but also cost-effective for removing organic and inorganic contaminants from water solutions. These adsorbents can be sourced from diverse materials such as marine resources, fungi, industrial waste, agricultural products, organic residues, wood shavings, vegetation, and mineral substances. Their affordability and effectiveness make them valuable tools for water purification. These adsorbents are highly proficient in eliminating a wide array of pesticide contaminants from water-based solutions. In terms of structural composition and properties, biochar closely resembles activated carbon (AC).

While biochar shares similarities in composition and properties with activated carbon (AC), activated carbon boasts a significantly larger surface area, often measuring in the hundreds or thousands of square meters per gram (m2/g). Biochar production is considered cost-effective compared to activated carbon (AC) due to the minimal energy consumption during the manufacturing process, especially since it doesn't require activation (Adejumo et al., 2014). Due to its low energy demands in the operational processes and absence of activation, the production of biochar is a more cost-efficient alternative compared to activated carbon (AC) (Adejumo et al., 2014). Biochar produced from materials like sunflower seeds, rice husks, and composted sewage sludge has been applied to eliminate contaminants such as atrazine, alachlor, endosulfan sulfate, and trifluralin from aqueous solutions (Rojas et al., 2014).

Moreover, in the context of leachate phosphorus (P) concentration levels, biochar derived from switchgrass demonstrates a noteworthy capacity for reduction when pyrolyzed at two different temperatures (250°C and 500°C). The biochar produced at the lower temperature is notably more effective in lowering P concentrations in leachate compared to the biochar generated at the higher temperature, as supported by studies (Ippolito et al., 2012; Hass et al., 2012).

The rice industry significantly contributes to the generation of agricultural waste. Across the paddy cultivation cycle, a diverse range of agricultural wastes is produced, including the husk, bran, straw, and broken rice. Rice Husk (RH) denotes the outer protective layer of rice, which is segregated from the rice grains during the milling process. Due to its low nutritional value, rice husk is unsuitable for use as animal feed, and its siliceous content makes it resistant to natural degradation, leading to significant accumulation in tissues (Zerbino et al., 2011). Biochar derived from the pyrolysis of rice husk is acknowledged as one of several economically viable carbon materials suitable for use as adsorbents (Ogawa & Okimori, 2010). RH is a significant raw material noted for the biochar manufacturing process, which is used in trapping contaminants (Haefele et al., 2011). The conversion of agricultural waste into biochar through pyrolysis processes offers various advantages, including power generation, self-sustaining waste recycling, carbon capture and storage, enhanced soil properties, and improved plant growth (Dong et al., 2015; Huang et al., 2018). Typically, rice husk constitutes around 20% of the total weight of paddy rice (Pode, 2016). Rice husk is characterised by intrinsic traits including a sturdy outer layer, a high silicon content, limited nutritional value, and remarkable resistance to decomposition by microbial communities (Zou & Yang, 2019).

Rice husk, which often lacks significant economic value and poses notable disposal challenges, is employed in both treated and untreated states to eliminate a variety of pollutants (Scarlet et al., 2005). This versatile material is particularly advantageous in the removal of scarlet dye due to its chemical activatability, making rice husk the preferred raw material for producing biochar (Katheresan et al., 2018). Leveraging rice husk for soil remediation has the potential to be both a practical and eco-friendly solution. On a global scale, an estimated 750 million tons of rice are harvested annually. Unfortunately, around 20% of this production, roughly 160,000,000 tons, is converted into rice husk, which subsequently becomes an agricultural waste. This practice raises ecological concerns, including the need for landfill sites and contamination problems (Ramezanianpour, 2014; Soltani et al., 2015).

In summary, this review has covered a wide range of topics within the context of pesticide use among rice farmers. It has explored aspects such as the indicators of pesticide hazards, the potential for pesticide transport, and the effectiveness of adsorbents in pesticide removal. Additionally, this study has delved into the EIQ model and the utilisation of biochar as a pesticide adsorbent in soil, underscoring their significance in this study.

CHAPTER THREE

MATERIALS AND METHODS

This chapter describes a detailed description of the research design and methods adopted to achieve the objectives of the study.

Study Area

The study has conducted in four developed lowlands in three districts: Kassena Nankana Municipality, Builsa North and Builsa South of upper East region. Laboratory procedures and experimentation were performed in the Soil Science laboratory at the technology village of the University of Cape Coast.

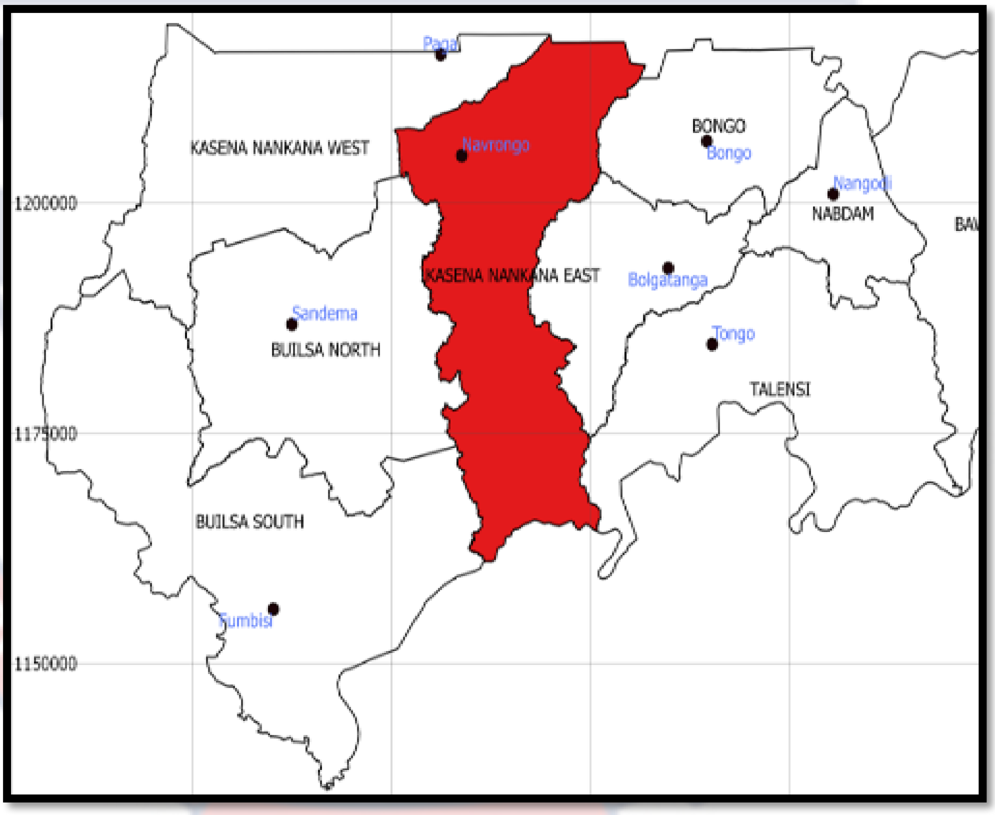

Figure 1: Map showing the Study Area.

Kassena Nankana East Municipality

Historically, the area currently recognised as the Kassena Nankana district was a part of Ghana's Upper East Region. In 1988, it was designated as a separate regular district assembly. On February 29, 2008, both the Kassena

Nankana East District and the Kassena Nankana West District were established. The Kassena Nankana East District was granted municipal assembly status on June 28, 2012. The capital of this municipal assembly is located in Navrongo, which is situated in the western part of the Upper East Region.

Builsa North Municipal District

The Upper East Region is composed of fifteen districts, one of which is the Builsa North Municipal Assembly. Over the years, this district underwent several name changes. On February 29, 2008, the southern part of the Builsa District was separated to form the Builsa South District. Consequently, the remaining northern part was renamed the Builsa North District. Finally, on December 19, 2018, it officially became known as the Builsa North Municipal District Assembly.

The district's administrative center is Sandema, located in the western part of the Upper East Region. The majority of the population consists of the Builsa people, who are the native inhabitants. Sandema is also home to a significant population of Kantosi, the dominant ethnic group in the region. Within the Builsa North Municipality, three Senior High Schools (SHS) are present - Sandema Senior High School, Sandema Senior High Technical School, and Wiaga Senior High School. Additionally, the district capital, Sandema, hosts the Youth Leadership Training Institute. Agriculture is a vital component of the local economy in the Builsa North District, with a primary focus on subsistence farming. The manufacturing sector does not play a major role in the area, and the district is in the early stages of developing its tourism sector.

Builsa South Municipal Assembly

Builsa South District is one of the 15 districts in the Upper East Region of Ghana. It was originally a part of the Builsa District but was divided on June 28, 2012. The southern portion became the Builsa South District, while the northern part became the Builsa North District. Later, on December 19, 2018, the district assembly was elevated to municipal status and renamed the Builsa North Municipal District. The capital of the Builsa South Municipal Assembly is Fumbisi, situated in the western part of the Upper East Region.

Sampling Procedure

A descriptive survey with a multi-stage sampling approach (Okoffo et al., 2016) was used to evaluate the risks associated with pesticide use. The sampling procedure consisted of four distinct stages. In the initial stage, the Upper East Region of Ghana was purposively chosen due to its significant rice production. For the second stage, Kassena Nankana East, Builsa North, and Builsa South districts—recognised for their substantial rice cultivation activities in the Upper East Region—were randomly selected from among the various rice-producing districts in the area. In the third stage, three pivotal rice-growing communities were randomly chosen from a list of communities engaged in rice cultivation in the selected districts. These communities included Bonia and Gaani in the Kassena Nankana East district, Wuru in Gaani, Chuchuliga, Naasa, and Siwaransa in the Builsa North district, and Gbedembilisi, Fumbisi, and Nadema in the Builsa South district. In the final stage, a total of 388 rice farmers were randomly sampled for the study.

Sample Size Determination

The 2017 Ghana Agricultural Productivity Survey disclosed a significant number of rice farmers in the Upper East Region, with a total count of 109,905. Notably, more than 9,000 of these rice farmers were concentrated within the Kassena-Nankana Municipality (MoFA, 2017). A sample of 388 farmers, representing 19.82% of the farming communities. Agyedu et al. (2011) have noted that a representative sample of 20% or more of the study population is adequate to ensure the reliability of the recorded data and the subsequent validity of the conclusions. In this study, Slovin's equation was employed to calculate the size of the sample from the given population size. Slovin's formula allows the researcher to select a population sample with the desired level of precision (Stephanie, 2013). The Slovin equation is expressed as follows:

$$n = \frac{N}{1 + N\,(e)^2} \quad \text{.............................. (Eqn. 1)}$$

Where: n: Sample size

N: Total population (109,905)

e: Error tolerance or error of margin (0.05)

Target population: rice farmers, Sample size: 388.

Sampling Techniques and Sample Selections

Data Collection Instruments

Questionnaire Design

A questionnaire was adapted from Paintsil (2017), and additional information can be located in the appendix A. However, a brief overview has been provided here. **Section A** focused on demographic and farm-related characteristics, including gender, age, occupation, education level, household size, the number of household members below the age of 18, the age of the farm, and the size of the farm. **Section B** contained questions related to knowledge of pesticides, including the names of known pesticides, prohibited pesticides, and understanding of how pesticides are exposed and transferred in the environment. **Section C** covered details about pesticide use patterns, including a table specifying pesticide names, active ingredients, application amounts per area, application intervals, and equipment used. This information was supplemented with details about pesticide properties and reference values from databases linked to models. The section also included information about the reasons for pesticide use, sources of the pesticides used, common crop pests and diseases, types of pesticides employed, sources of knowledge about pesticide application, and factors influencing the timing of pesticide applications. **Section D** focused on assessing the participants' attitudes toward pesticide use. It included questions related to their agreement or disagreement with certain statements. These statements encompassed topics such as the importance of having sufficient knowledge before handling chemicals, the perceived health risks associated with chemical use, the necessity of adhering to precautions during pesticide application, the belief that chemicals contribute to good crop yields, and the idea that chemical use should be restricted to protect the environment. **Section E** of the questionnaire focused on the protective measures taken by participants during pesticide application. It gathered information on the quantities and intervals of pesticide application, the reasons for using chemicals on their farms, and the factors influencing the timing of pesticide spraying. The questionnaire was distributed and collected over a period of 15 working days.

Various question types were employed to gauge elements in sections A, B, and D, encompassing questions that did not provide answers, questions with predefined responses, and questions with moderately limited choices. For segment C, data was assessed using a five-point Likert scale, typically ranging from 1 to 5, with 1 representing the lowest degree of agreement and 5 denoting the highest level of agreement.

Main Determinants

The main variables under examination include:

(I) Awareness of the effects of pesticides on human health and the environment.

(II) Safety measures taken during pesticide application.

(III) Health-related symptoms experienced after pesticide application, including headaches, eye irritation, skin rashes, itching, and chest pain.

To evaluate farmers' understanding of the consequences of pesticide use on human health and the environment, participants answered questions about the following aspects:

1. Whether pesticide usage or exposure has an impact on human health.
2. Whether pesticide use affects soil quality.
3. Whether pesticides have an impact on nearby rivers or water bodies.
4. Whether they are aware of the broader environmental effects of pesticides.
5. Whether they know that pesticides can persist in the soil for an extended period.

In terms of protection and safety, participants were queried about their use of Personal Protective Equipment (PPE) while applying pesticides, including:

1. Boots
2. Hat
3. Nose mask

4. Gloves
5. Overalls
6. Goggles

These responses provided insights into farmers' knowledge and safety practices related to pesticide use.

Questionnaire Administration

All 388 rice farmers who took part in the research study completed it on their own and in English. The researcher, however, used an interpreter to translate into the local languages of the areas (Builsa, Kassena, Mamprusi, Nakani, and Nankana) for the farmers who had difficulty understanding English. Farmers for the interview were chosen without regard to gender, religion, or political affiliation. Before any farmer was interviewed, the objective of the research project was explained to village chief farmers and other relevant opinion leaders in each selected community. This helped ensure that the farmers receive appropriate chain of command in each community, which helped improve data accuracy.

Selection of Farmers

The multi-stage technique of sample selection used in this research consisted of four (4) phases. In the initial phase, the Upper East Region was purposefully chosen because of its high rice production. In the subsequent steps, Kassena-Nankana, Builsa North and Builsa South districts were identified to be some of the main rice farming areas in the East Region were chosen at random from the Region's several rice growing districts. During third step, three (3) major rice growing communities were sampled at random from a list of rice-cultivating communities in the districts selected (Table 3). In the final stage, rice farmers were picked at random from every one of the three rice-growing communities. The survey included a total of 388 rice farming households, randomly selected from nine (9) communities. The number of respondents selected in each district is indicated in Table 3 below.

Table 1: Number of Respondents Segregated by District

Districts	Communities	Frequency	Percentage (%)
Kassena Nankana	Bonia	45	132 (34%)
	Gaani	45	
	Wuru	42	
Builsa North	Chuchuliga	45	135 (35%)
	Naasa	45	
	Siwaransa	45	
Builsa South	Fumbisi	42	121 (31%)
	Gbedembilisi	40	
	Nadema	39	
Total		388	100%

Calculation of Risk of Pesticides Application using EIQ Model.

In this study, the Environmental Impact Quotient (EIQ) method was employed to evaluate the environmental impact associated with the commonly used pesticides in rice production within the research areas (Kovach et al., 1992a).

Section C of the questionnaire was structured to gather information regarding pesticide usage. It featured a table where participants supplied data concerning the pesticide's name, active ingredient, the volume applied per application, how often it was used, and the equipment utilised. Subsequently, the Environmental Impact Quotient (EIQ) method was employed to assess the environmental impact of these pesticides. The EIQ model generated a score for all pesticides used during the season, offering an overall measure of their environmental impact (Kovach et al., 1992).

This EIQ model systematically computed a numerical score encompassing all the pesticides utilised throughout the season, thereby offering a comprehensive measure of their collective environmental impact. The pesticide-related data, including information about the active ingredients and quantities in grams (g), along with application rates denoted in grams of active ingredient per hectare (ha), which were acquired through the questionnaire survey, were integrated into the Environmental Impact Quotient (EIQ) model for analysis and evaluation.

In (Section C; Q.32), along with essential information gathered from pesticide data sheets, these details were employed for conducting the calculations. The EIQ value was ascertained by averaging the components linked to farm workers, consumers, and ecological impacts. The provided equations for these diverse components are accompanied by associated variables and their corresponding explanations, which are detailed in Table 2.

Table 2: Components and Mathematical Model of EIQ

Components	Category	EIQ
El Applicator: C x DT x 5 El Picker: C x DT x P	**El Farm worker =** El Sprayer + El picker	**EIQ** (El Farm worker + El Consumer + El Ecology)/3 ………….(Eqn. 2)
El Consumer: C x (S + P)/2 x SY El Ground Water: L	**El Consumer =** El Consumer + El Ground water	
El Fish: F x R El Bird: D x (S + P)/2 x 3) El Honey Bee: Z x P x 3 El Natural Enemies: B x P x 5	**El Ecology =** El Fish + El Bird + El Honey Bee + El Natural Enemies	

The EIQ formula

EIQ={C[(DT*5) + (DT*P)] + [(C*((S+P)/2) * SY) + (L)] + [(F*R) + (D*((S+P)/2) *3) + (Z*P*3) +B*P*5)]}/3

Source: Kovach et al., 1992

Table 3: Variables and Corresponding Symbols in Environmental Impact Quotient (EIQ) Calculation

Variables	Symbol
Long-term effects	C
Dermal toxicity	DT
Bird toxicity	D
Bee toxicity	Z
Beneficial Arthropod toxicity	B
Fish toxicity	F
Plant surface half-life	P
Soil residue half-life	S
Mode of action	SY
Leaching potential	L
Surface runoff potential	R

Source: Kovach et al., 1992

The EIQ calculations were exclusively conducted through the online EIQ calculator provided by Cornell University (NYSIPM, 2017). The inclusion of the EIQ Field Use Rating in this risk assessment was essential to secure a precise evaluation of pesticides and approaches to pest management. The EIQ Field Use (EIQ F.U.) is calculated using the equation as illustrated in Eqn. 3:

EIQ F.U. = EIQ * % active ingredient (AI) * application rate (R) kg/ha..(Eqn.3).

The total impacts resulting from the application of all pesticides throughout a growing season were calculated by adding the product of the individual EIQ Field Use Rating and the application frequency, using equations 3, 4, and 5.

Field Total EI = $\sum$ [EIQ F. U.$*$ $Application\ frequency$]………….. (Eqn. 4)

Field Total EI = $\sum$ [EIQ $*$ % Active Ingredient (AI) $*$ application rate (R)$*$$Application\ frequency$] …………………………………….. (Eqn. 5)

Laboratory Experiment

Leaching Sample Collection

Soil Sampling

A meeting was organized with a rice extension officer who had prior experience in selecting soil samples from rice cultivation areas. The extension division of the Ministry of Food and Agriculture (MoFA) provided the list of all the districts involved in rice cultivation in the region. Two rice-growing districts, Kassena-Nankana and Builsa North, were purposively selected. Within these two districts, three communities were randomly chosen for the collection of soil samples. Within each of the selected communities, a farm was randomly chosen, and soil samples were collected from these farms. A simple random sampling approach was used to select individual soil cores, with each core being chosen independently and randomly. The process involved clearing away surface vegetation and litter, followed by the collection of 1 kilogram of topsoil from a depth of 0 to 20 centimeters. In total, 60 soil samples were collected.

The geographical coordinates of each sampling site were documented using the Global Positioning System (GPS). Soil samples from three farms in Kassena-Nankana were merged and designated as S1, while three soil samples from three farms in Builsa North were combined and marked as S2. The collected samples were carefully packaged, labeled, and transported to the laboratory. In the research laboratory, any aggregate stones, leaves, and roots were meticulously removed. The gathered soil samples were allowed to air dry, ground into a fine powder, and then passed through a 120-mesh nylon sieve.

Biochar Sampling

The researchers used various forms of biochar sourced from the Center for Scientific and Industrial Research (CSIR) in Kumasi, Ashanti Region. This included biochar derived from corn cobs and biochar made from rice husks. Both rice husk biochar (RHB) and corn cob biochar (CCB) were employed as adsorbents for the purpose of remediating environmental contaminants. Biochar was selected due to its local availability, low cost, and prior research on its effectiveness as an adsorbent for pesticides in contaminated soils. Temperature plays a crucial role in influencing the chemical and physical properties of the processed biochar. Raising the pyrolysis temperature results in an increase in the total surface area and the carbonized portion of the biochar, enhancing its capacity for adsorption (Tang et al., 2013; Yuan et. al., 2019). To ensure consistency and facilitate comparisons, both types of biochar were produced using a uniform thermal decomposition temperature of 450 degrees Celsius.

Biochar and Soil sample Characterisation

A mortar was employed to crush the biochar materials, and samples were filtered through a 2mm sieve to obtain a standardized sample. The soil samples were air-dried in the laboratory by spreading them on a polythene sheet for two days. The large aggregates were broken down into smaller pieces. The sample was then ground through a 2-mm fine mesh to achieve a consistent particle size. The soil samples, which were filtered through a 2 mm sieve, were placed in loosely sealed black containers and maintained at a controlled temperature of 37 degrees Celsius for subsequent analysis. Both biochar and soil samples were characterised through a series of tests to assess their chemical and physical properties which included measurements of ionic strength (pH), organic carbon content, readily accessible nitrogen, phosphorus (P) levels, replaceable bases, calcium and magnesium content, replaceable acidity, moisture content, and textural class. These assessments were conducted following specific procedures.

Determination of Soil Particle Size

According to Rowell (1994), pipette analysis was conducted to determine soil particle size. This involved measuring and weighing 500 ml of soil (with a precision of 10 grams ± 0.01) in a beaker. The liquid was filtered after which 20 ml of hydrogen peroxide was added and left until the foaming subsided. The organic components were removed by heating the solution and then allowed to cool.

The soil treated with peroxide was placed in a 500 ml plastic container. Then, 10 ml of a dispersion agent was added, and the final volume was adjusted to 200 ml, after which it was vigorously shaken overnight. For precise volume measurement, the contents were funneled into a 500 ml graduated measuring cylinder, and any remaining space was filled with distilled water. A plunger was used to carefully mix the suspension.

After letting the suspension settle for 40 seconds, a 25 ml sample was collected from a depth of 10 cm below the surface and placed into a pre-weighed beaker. A significant quantity of clay and silt settled during this time. After 5 hours, the suspension had cleared, and a 25 ml sample was obtained from a depth of 10 cm. This accounted for the bulk of the clay.

The pipetted suspensions were dried at 105°C until their weights reached a constant level. The sediment was meticulously transferred into a beaker, and the supernatant liquid was decanted. Repetitive cycles of stirring, settling, and decanting were employed to rinse the sediment and obtain a clear supernatant. The sand was dried at 105°C until its weight stabilised, and then it was transferred to a weighed beaker.

$$\text{Sand proportion } \left(\frac{m}{m}\right) = \frac{\text{Quantity of sand (mass)}}{\text{Oven-dried soil mass}} \times 100 \quad \ldots\ldots\ldots\ldots \text{(Eqn. 6)}$$

$$\text{The overall silt content of the sampled soil} = 25 \text{ ml of mass} \times \frac{500}{2} \quad \ldots \text{(Eqn. 7)}$$

$$\text{Percentage silt} = \frac{\text{Quantity of sand (mass)}}{\text{Oven-dried soil mass}} \text{ X } 100 \quad \ldots\ldots\ldots\ldots \text{(Eqn. 8)}$$

$$\text{The overall clay content of the soil specimen} = 25\text{ml of mass} \times \frac{500}{25} \ldots \text{(Eqn. 9)}$$

$$\text{Proportion of clay (\%)} = \frac{\text{amount of clay}}{\text{oven-dried soil mass}} \times 100 \ldots\ldots\ldots\ldots \text{(Eqn. 10)}$$

Soil samples were classified into textural classes using the USDA textural triangle, a method described by Rowell (1994).

Determination of pH

The pH of soil indicates the presence and concentration of hydroxonium ions (H_3O^+ or H^+) in a solution when the soil is dissolved. The pH of the soil has a significant impact on various aspects of crop growth and soil interactions. This includes the availability of nutrients and potentially harmful substances, the nature of microorganisms, their population, and the effectiveness of specific pesticides (Ecker & Sims, 1995).

Soil samples, each weighing 10 grams and previously desiccated, were carefully placed into zip-lock plastic bags. A measuring cylinder was employed to measure 25 ml of distilled water, which was then transferred to the soil specimen within a polyvinyl chloride test tube. The mixture was mechanically stirred for a maximum of 15 minutes. The pH was determined by inserting an electrode into the suspended soil after calibrating a digital pH meter at pH values of 4.00, 7.00, and 10.00, resulting in an accurate reading (Clark, 1928). The pH of each soil sample was tested three times, and the pH values were averaged. The pH of the biochar samples was determined using the same methodology.

Determination of Moisture Content

Freshly collected soil samples, weighing five grams (5 g), were accurately measured and deposited into an evaporating basin that had been dried in an oven. These samples were subsequently subjected to drying in a well-ventilated oven at 105°C until a stable weight was attained. The samples were cooled in a desiccator, and then the weight of the soil was measured. The initial moisture percentage was calculated based on the weight loss. The moisture concentration percentage was determined twice, and the average values were calculated for each. The average percent of water content of samples of biochar was ascertained using the same methodology. The average water content percentage of the biochar samples was also determined using the same method.

Calculation: % Moisture Content =

$$\frac{\text{(Weight of fresh soil (Wt) - Wt of oven-dried soil)}}{\text{(Weight of oven-dried soil)}} \times 100 \quad \text{............... (Eqn.11)}$$

But, Weight of fresh soil sample = M2-M1

Weight of oven-dried sample = M3-M1

Determination of Organic Carbon

A 0.5g soil sample was collected in duplicate and placed in a 500 ml Erlenmeyer flask, with the weight of the sample recorded. A pipette was used to gradually add 10 ml of $K_2Cr_2O_7$ solution to the soil sample while gently swirling it. Afterward, 20 ml of concentrated H_2SO_4 was added, and the mixture was allowed to sit for approximately half an hour. The addition of concentrated H_2SO_4 generated heat, which was necessary to drive the reaction to a successful completion.

After half an hour, the contents of the flask were diluted with 200 ml of distilled water and swirled once again to ensure a homogeneous mixture. Approximately 10 ml of H_3PO_4, NAF and 1 ml of the sample were treated with a diphenylamine indicator. A back titration was carried out by adding 0.5 g of $FeSO_4.7H_2O$ in 10 ml of distilled water (ferrous solution) to neutralize the excess $Cr_2O_7^{2-}$. This resulted in a green endpoint. A blank experiment was also conducted using the same reagents, but without the soil and biochar.

Calculation:

$$\text{Organic carbon} = \frac{(B - S) \times \text{Molarity of Fe2+} \times 0.003}{\text{Weight of soil}} \times \frac{100}{77} \times 100 \ldots\ldots \text{(Eqn.12)}$$

Where:

B = Blank titre value

S = Sample size titre value

F = Molarity of $K_2Cr_2O_7$

0.003 = 12/4000 = milliequivalent weight of carbon

100/77 = the factor converting the carbon that was oxidised to the total carbon.

100 = the factor to convert from a decimal to a percentage

Determination of Total Nitrogen

A method for determining exchangeable acidity was conducted following a procedure similar to that described by Anderson and Ingram (1993). A 10-gram soil sample was mixed with 1.0 M KCl solution to reach a final volume of 25 milliliters and then filtered. The soil was leached by adding five 25 ml portions of 1.0 M KCl at regular intervals. Each portion was titrated with

0.1 M NaOH, and phenolphthalein was used as an indicator. The color of the aliquot changed from clear to pink, and the following equation was used to calculate the subsequent exchangeable acidity:

$$\% N = \frac{(S - B) \times \text{Volume of the solution}}{10^2 \times \text{aliquot} \times \text{Proportion of the sample (weight)}} \quad \text{……………..(Eqn.13)}$$

Where:

S = The tire of the sample

B= the tire used as blank

Determination of Available Phosphorus

The procedure for determining the quantity of readily available phosphorus in soil samples using the P-Bray 1 Method can be divided into the following paragraphs:

Sample Preparation

1. An air-dried soil sample weighing 1 g was combined with 10 ml of Bray 1 extraction solution in a 50 ml centrifuge tube.
2. The extraction solution consisted of 15 ml of 1.0 N ammonium fluoride (NH_4F) and 25 ml of 0.5 N hydrochloric acid (HCl).
3. The soil and extraction solution were shaken for 5 minutes to form a soil solution.

Filtration

4. The soil solution was poured carefully into a 50 ml conical flask lined with filter paper, specifically Whatman filter paper.

Chemical Reaction

5. A 4 ml aliquot of the color-forming reagent (Reagent B) was added to 2 ml of the filtrate in a 25 ml round-bottom test tube.

Reagents

1. Reagent B consists of a combination of potassium antimony tartrate and ammonium molybdate with ascorbic acid.
2. Allowing the mixture to stand for five minutes to facilitate the chemical reaction.

Dilution and Color Development

6. The solution was diluted to a final volume of 25 ml by adding distilled water.
7. The solution was left undisturbed to allow the color to develop.

Measurement

8. Measuring the absorbance of the solution at 882 nm using a spectrophotometer from the CE 1000 series.

Standard Solution Preparation

9. Standard solutions with concentrations of 0 g P/ml, 0.1 g P/ml, 0.2 g P/ml, 0.4 g P/ml, 0.6 g P/ml, 0.8 g P/ml, and 1.0 g P/ml were prepared from a 5 g P/ml stock solution.

Color Development of Standards

10. The standardized mixtures were allowed to stand for a maximum of 15 minutes to allow for a color change, and then their absorbance at 882 nm was measured.
11. The absorbance of the standardized solutions was measured at 882 nm.

Reference Curve

12. A reference graph was plotted by correlating the absorbance with the concentration of standard reaction mixtures.

Phosphorus Quantification

13. Determining the phosphorus content in a soil sub-sample (aliquot) using the calibration curve derived from the reference graph.

Cation Exchange Capacity (CEC) Analysis

Cation exchange capacity (CEC) quantifies a soil's capacity to retain and exchange cations (Saidi, 2012). The CEC of soil represents the quantity of negatively charged sites on the soil's surface that can retain positively charged ions (cations) like calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^{+}) through electrostatic interactions. Agriculturally productive soil may not necessarily have a high CEC because soil CEC can also be influenced by acidic cations such as H^{+} (hydrogen) and Al^{3+} (aluminum). Moreover, when used alongside other soil fertility indicators, CEC is a strong predictor of soil productivity and quality (Taghizadeh-Mehrjardi, 2016; Khaledian et al., 2017). Cations were determined using the following procedure:

Sample Preparation

A 5g air-dry soil sample was weighed and placed into a 50 mL thin-neck centrifuge tube. Then, 33 mL of a 1.0 M CH_3COONa (sodium acetate) solution was added, and the tube was sealed with a rubber cork. The solution was mechanically stirred for approximately 5 minutes at 2000 rpm, and the supernatant liquid was separated by centrifugation. This process was repeated three times. Subsequently, 33 mL of 95% isopropyl alcohol was added to the solution, sealed with a rubber cork, stirred for about 5 minutes, and then centrifuged until the supernatant became clear. The process was repeated until the electrical conductivity (EC) of the decanted substance read fewer than 40 mS/cm. Finally, 33 mL of $NH_4CH_3CO_2$ (ammonium acetate) solution was added, the tubes were sealed, mechanically shaken for about five minutes, and again subjected to centrifugation until the supernatant solution was transparent.

Preparation of Standard Solution

The mixed washing was purified with ammonium acetate solution (CH_3COONH_4) to the 100 mL threshold using flame photometry. A series of Na (sodium) standardized solutions ranging from 0 – 10 millimolar were prepared. After, a standard calibration curve graph was created by plotting Na intensity on the X-axis and the flame photometry reading on the Y-axis. Samples collected from the sodium reference standard were fully integrated into the readings of the flame photometry, representing the concentration of the Na taken from the standardized graph. In order to improve the outcomes, LiCl (Lithium Chloride) was added at a concentration of about 5 me/litre of Lithium Chloride.

Titration Process

The following procedures were used to calculate the CEC of the soil: Ions were chelated with ethylenediaminetetraacetic acid (EDTA). Calcium and magnesium levels were measured simultaneously and independently, with magnesium determined using the difference. The sample solution was diluted to 150 mL using distilled water after 25 mL was transferred to a 250 mL conical flask. A mixture of KCN (potassium cyanide), ClH_4NO (hydroxylamine hydrochloride), $K_4Fe(CN)_6$ (potassium ferrocyanide), and $C_6H_{15}NO_3$ or $(CH_2OHCH_2)_3N$ (triethanolamine) with 15 mL of buffer solution (TEA) was prepared. Eriochrome black T (EBT) was added at a concentration of 0.005M to titrate against the EDTA.

Analysis Using Flame Photometry

The K+ and Na+ concentration levels were calculated with a flame emission photometer.

Calculations

The exchangeable Na in me/100 soil

$$= \frac{\text{Na concentration of extract (meq/l)}}{\text{Weight of soil}} \times \frac{\text{100 x volume of extract (100meq)}}{1000} \quad \text{(Eqn.14)}$$

$$= \frac{y \times 10}{\text{Weight of soil}} \quad \ldots\ldots\text{(Eqn.15)}$$

Where; y = Concentration of sodium (Na), Wt. = The weight of the soil,

The displaced Na is, in fact, a measure of the CEC (Cation Exchange Capacity) of the soil. Therefore, the meq Na/100g soil represents the meq of exchangeable cations (such as Ca, Mg, Na, and K) per 100 grams of soil (Motsara & Roy, 2008).

Calculation of Exchangeable acidity

The method for determining exchangeable acidity closely resembled the one described by Anderson and Ingram in 1993. A 10-gram soil sample was mixed with 1.0 M KCl to reach a final volume of 25 milliliters, and the mixture was subsequently filtered. The decision was made to leach the soil by adding five 25 ml aliquots of 1.0 M KCl at regular intervals. The aliquot was measured by titrating it with 0.1 M NaOH, and phenolphthalein indicator was added. The aliquot displayed a range of colors, from clear to pink. To calculate the subsequent exchangeable acidity, the following equation was used:

$$\text{Exchangeable } (Al^{3+} + H^{+}) = \frac{(2 \times T)}{\text{Sample weight}} \quad \ldots\ldots\text{(Eqn.15)}$$

Where:

T= titre value (millilitres) of 0.1M NaOH solution

Total Exchangeable Bases (TEB) = Exc. $(Ca^{2+} + Mg^{2+} + K^{+} + Na^{+})$

ECEC = Basic cations + Acidic cations

$(Ca^{2+} + Mg^{2+} + K^{+} + Na^{+}) + (H^{+} + Al^{3+} + NH_4^{+})$

Base Saturation (%) = (*Base cations/CEC*) x 100

Experiment on Column Leaching and Experimental Design

The vertical cylindrical structure (column) was built with polyvinyl chloride pipe using an inside diameter of 5 cm and a 17 cm height. The column's bottom was fully equipped with 2 cm drains perforations as well as drilled end stoppers as well as screwed to receive 13mm x 120 mm male – to male adaptor as drains pipelines. To avoid soil sample leakage inside the column, the gaps were filled with silicon caulk and garden mulch screen fibers. The vertical cylindrical structure was then secured to a rack made of wood with two connection binds, for a total of 28 cable ties per column (Silveira, 2006).

The study employed a randomized complete block design (RCBD). In total, 30 vertical cylindrical structures were used. The vertical cylindrical structure was laid out in a randomized complete block pattern to be exposed to relatively similar experimental conditions (Kerman et al., 1999).

Column Leaching Experiment and Experimental Design

Soil 1: 2 amendments (Corn cobs and rice husks) at 2 rates (0.5% and 1%) + 3 controls with 3 replicates = [15 samples]

Soil 2: 2 amendments (Corn cobs and rice husks) at 2 rates (0.5% and 1%) + 3 controls with 3 replicates = [15 samples].

Thus, 2 soil types [2 amendments x 2 rates x 3 replicates] + 6 controls = 30 columns.

Figure 2: Soil Column Leaching Experimental Setup.

Chemical Analysis

According to the collected data of the farmers' qualitative investigative feedback regarding the kinds of pesticides used, Lambda Cyhalothrin was discovered to be the highest pesticide utilised by farmers in the research location. As a result, Lambda Cyhalothrin was used in the experimental investigation.

Table 4: Label of Samples as used in text

Soils/ Adsorbent/ Rates	Labels
Soil 1 (Kassena Nankana East)	S1
Soil 2 (Builsa North)	S2
Corn Cob Biochar	CCB
Rice Husk Biochar	RHB
0%	N/A
0.5%	N/A
1 %	N/A

Column Leaching Experiment

The experiment began with the application of 250 ml of Lambda Cyhalothrin, diluted with distilled water, to a uniform soil sample. The soil sample was allowed to air-dry for a day, simulating the conditions in which unintentional pesticide pollution could potentially occur on the soil surface. Each 200 g soil sample was subjected to a treatment involving three different levels of corn cob and rice husk biochar (0%, 0.5%, and 1% of the sample's weight). These treated samples were then stored in zip-lock containers. The samples within the sealable plastic containers were mixed thoroughly by hand using gloves to ensure even distribution. The samples, wrapped in plastic bags, were incubated at 37 ^{o}C for 7 days. During this incubation period, they were kneaded daily and exposed to air briefly (5-10 minutes) to prevent conditions favorable for anaerobic respiration (Miyittah et al., 2011).

The pre-prepared soil samples into columns in small increments using a spoon. A plunger was used to gently press down on the soil while simultaneously vibrating the columns. This process was continued until the surface of the soil no longer sank, ensuring consistent loading to achieve reproducible results, as recommended by OECD (1994). The columns were saturated with water before the loading process, following the procedure outlined by OECD (1994). Artificial rainfall was used to ensure that air was removed from the pore spaces within the columns. After the removal of excess water by gravitational pull, the columns were allowed to equilibrate, and the pore volume was observed to be 90 ml. It was assumed that each drainage activity corresponded to one pore volume. The leaching process involved adding 90 ml of artificial rainwater to each column once a week for a total of 4 weeks. Artificial raindrops were evenly distributed across the entire surface by placing glass fibers on the surfaces of all the columns, following the OECD guidelines (1994). The columns were watered with 90 ml of pH-balanced distilled water from the study site's rainfall using a funnel for distribution. Clear polythene sheets were employed to cover the wet columns after watering, minimizing moisture loss and maximizing field capacity.

The leachate, which was collected on a weekly basis, underwent analysis using Gas Chromatography – Mass Spectrometry (GC – MS). This comprehensive experimental procedure was employed to investigate pesticide leaching in the soil.

Extraction of Lambda Cyhalothrin in Solid Phase

A 500 mg C-18 bonded silica cartridge was used to extract the analyte from the pesticide leachate matrices. The cartridges were conditioned before packing by treating them with 10 mL of methanol. Following the conditioning, 6 mL of demineralised water was added to keep the cartridges hydrated throughout the process. The sample, amounting to 200 ml, was loaded onto the pre-conditioned cartridge and thoroughly rinsed using 6 ml of demineralized water to remove any remaining matrices. Subsequently, the sample was eluted three times with 3 ml of methanol.

Quality Assurance (QA) / Quality Control (QC)

The comprehensive analysis also incorporated quality assurance and a validation procedure (US EPA method 8260D, 2017; Gao, Guo, Zhang, and Hu, 2014). The glassware underwent an extensive cleaning process. It commenced with a washing step, using detergent and tap water from the laboratory's taps. Subsequently, it was rinsed with distilled water and then cleaned further with analytical-grade acetone. Ultimately, the glassware was dried before being used in the analysis.

The leachates from the sample sites in Kassena Nankana and Builsa North were subjected to analysis. In addition, blank samples were prepared and subsequently analysed using gas chromatography. Each sample was spiked with 5 µL of a 0.2 ppm Lambda standard before the recovery process to evaluate the extracts recovered. The recovery was quantified as a percentage of the extracted amount. The internal standards demonstrated a recovery rate ranging from 70% to 98% for Lambda. This indicates that the method employed is consistent and reproducible.

Statistical Analysis

The questionnaire data underwent examination using Microsoft Excel, Statistical Package for the Social Sciences (SPSS) Version 26 (IBM, Chicago, IL, USA), and SAS software. The analysis incorporated Descriptive Statistics (frequency and percentage) and inferential statistics, specifically Oneway analysis of variance.

Cross Tabulations and Analysis of Demographic Characteristics

Cross tabulations were utilised to investigate the connections between farmers' demographic characteristics and their agricultural practices. This statistical method allowed exploration of the relationship between two categorical variables, revealing significant associations between various demographic factors and agricultural behaviors. The approach was valuable in unveiling patterns and trends, becoming a crucial tool for understanding the relationships within this research scope.

Negative Log-Log Regression Analysis

A negative log-log regression analysis was conducted, apt for managing skewed or non-normally distributed data, which could pose challenges for other modeling methods. This analysis involved the use of Cramer's values, odds ratio, and P-values. Odds ratios were derived through the negative log-log regression to determine independent risk factors associated with experiencing a burning sensation after pesticide application. Variables included in this analysis were Cleaning the sprayer after pesticide application (i.e., no cleaning, cleaning on the farm, cleaning in the bush), Crops treated with pesticides (as a continuous variable), use of headgear (as a continuous variable), and gender (with female as the reference point).

Odds Ratios

In interpreting the negative log-log regression analysis, odds ratios were the focal point. An odds ratio of 1 signifies that the factor has no influence on the odds of experiencing a burning sensation after pesticide application. An odds ratio greater than 1 suggests that the predictor is linked to increased odds of experiencing a burning sensation. Conversely, an odds ratio less than 1 indicates a decreased likelihood of experiencing a burning sensation after pesticide application.

Repeated Measures Analysis

Significant variations in leachate samples, considering effects within and between treatments and weeks, were evaluated through repeated measures analysis using PRO GLM in the SAS software, with a set significance level (α) of 0.05.

Chapter Summary

A descriptive survey approach was employed to assess farmers' understanding of pesticide application on rice farms and to quantify the associated risks, ultimately addressing the first and second objectives of the study. The data was collected from smallholder rice farmers through the use of questionnaire. The selection of farmers for the survey was done through a combination of random and purposive sampling methods, with a specific focus on those who applied pesticides to their farms.

The study involved a sample size of 388 smallholder farmers. The information gathered from these farmers was utilised as input for risk assessment using a tool known as the Environmental Impact Quotient (EIQ). This tool helps assess the potential environmental impact of pesticide use.

A soil column leaching experiment was carried out to study the transport and removal of Lambda Cyhalothrin, one of the frequently used pesticides in the study area. The analysis of pesticide content in the leachates obtained from this experiment was performed using Gas Chromatography-Mass Spectrometry (GC-MS).

CHAPTER FOUR

RESULTS AND DISCUSSIONS

To assess the usage and impacts of pesticides in the Upper East Region

Introduction

This chapter includes the examination, presentation, and interpretation of the study's findings. The data was analysed and interpreted based on the study's research hypotheses. Moreover, it delves into a comprehensive examination of the most crucial findings, conducting a thorough exploration of the data in comparison to relevant prior research. This approach aims to uncover significant patterns, address key issues, and gain a comprehensive understanding of the phenomena under study.

To Assess Smallholder Rice Farmers' Knowledge on Pesticide Application

Statistical Analysis of Demographic Background of Respondents (n=388)

Table 5: Socio-demographic characteristics of study population

Variable	Category	Fre.	%
Sex (Gender)	Male	283	73
	Female	105	27
Age (Years)	20 below	51	13
	21 - 30	160	41
	31 - 40	104	27
	41 - 50	45	12
	51 - 60	23	6
	61 above	5	1
Level of education	No education	104	27
	Primary Education	127	33
	Secondary Education	79	20
	Certificate/Diploma	53	14
	Degree	25	6
Religion	Christian	274	71
	Muslim	42	11
	Traditionalist	72	18
Occupation (s)	Farming only	302	78
	Farming + Government Employees	23	6
	Farming + Artisans + Traders	13	3
	Farming + Student	50	13
Farm size (acres)	1-5 acres	315	81
	6-10 acres	45	12
	11-15 acres	11	3
	16-20 acres	9	2
	20 acres above	8	2
Years of Experience	1-3 years	76	20
	4-6 years	142	37
	7-10 years	86	22
	More than 10 years	84	21
Household size	1-5 persons	10	2
	6-10 persons	199	51
	11-15 persons	69	18
	16-20 persons	45	12
	21 and above	65	17

The demographic data collected during the survey were subjected to statistical analysis. This analysis was conducted to provide an overview of the variables studied, presenting them in terms of frequency and percentage. Table 5 displays the demographic characteristics of the respondents in the study area.

The majority of the respondents, constituting 73%, were male, while 27% were female. This distribution suggests that rice farming in the Upper East region, similar to other parts of Ghana, is predominantly undertaken by males (Tetteh Anang, 2015; Addison et al., 2016; Acheampong et al., 2017; Mabe et al., 2018; Asante et al., 2023). This pattern can be attributed to the physically demanding nature of rice farming, which tends to be less appealing to many women. Ayoola et al. (2011) proposed that women usually focus on taking care of children and running the household. These responsibilities might restrict their time and ability to be highly involved in rice farming, but they could be more engaged in tasks related to processing and selling farm products. Women play a fundamental part in agricultural pursuits and improving the standard of living in rural regions, especially within the context of Africa (Uzonna & Qijie, 2013).

The age distribution of the farmers in the study was as follows: 41% of them fell in the 21-30 age group, 27% were in the 31-40 age range, 12% were between 41 and 50 years old, 13% were 20 years or younger, 12% were in the 41-50 age category, and 6% were in the 51-60 age range. Only 1% of the farmers were over 60 years old, as indicated in Table 5. It is evident that the majority of rice farmers are under the age of 50. This suggests that the majority of the farming population consists of youth aged between 21 and 30 years. This finding aligns with the results of a study conducted by other researchers (Taiwo & Bart-Plange, 2016). This finding suggests that the majority of the respondents were in their productive years and still possessed the physical energy required for labor-intensive agricultural practices in Ghana. This discovery has the potential to enhance agriculture in the study area, particularly given that farming in the region heavily relies on manual labor due to the limited availability of mechanized equipment. It is worth noting that in a country like Ghana, there is a shortage of all factors of production except labor.

Among the 388 respondents, 33% (127), 20% (79), 14% (53), and 6% (25) had attained formal education at the primary, secondary, and tertiary levels, respectively (Table 5). While there were farmers without any formal education, those who had received formal education had completed their schooling at the primary level at most. This was evident from the fact that 27% (104) of the respondents did not read the pesticide labels before applying them. This finding is consistent with the results of prior studies conducted by Anang and Amikuzuno (2015), Imoro et al. (2019), all of which were carried out in Northern Ghana, as well as the study by Mustapha et al. (2012) conducted in Borno State and Matanmi et al. (2011) in Patigi LGA, Nigeria. Consequently, many of these farmers obtained information about pesticides from retailers.

The majority (78%) of the respondents were primarily engaged in farming, while the remaining 22% combined farming with various non-farming activities, including roles in civil service, trading, and other occupations (Table 5). This aligns with the conclusions drawn by Osei Danquah (2019) in the Upper East Region of Ghana, Ayoola et al. (2011) and Olumba, (2014) conducted in Anambra State. It suggests that rural residents are primarily engaged in farming activities. The results indicate that the majority of farmers (78%) rely on farming activities as their primary source of income and livelihood, with a small number combining farming with other businesses or government work for additional income.

Majority of the farmers constituting 81%, tilled rice farms spanning from 1 to 5 acres, signifying that the majority of the respondents are engaged in small-scale rice farming (Table 5). This suggests that the majority of the respondents engage in small-scale rice farming primarily for their subsistence rather than commercial purposes, and only trade the harvested output for cash. These results are consistent with the findings of Kyei and Matsui, (2018) in the Upper East Region of Ghana and Mustapha et al. (2012) in Borno State, Nigeria, where the majority of respondents also had rice farms ranging from 1 to 5 hectares. 12% of the respondents cultivated between 6-10 acres, 3% farmed within 11-15 acres, and 2% managed between 16-20 acres, and more than 20 acres of rice farmland.

The experience levels in rice farming were grouped and the distributions were displayed in Table 5. This distribution of experience among respondents in rice farming suggests a varied level of expertise within the surveyed population. A significant proportion, constituting 37%, falls within the 4 to 6 years' experience range, indicating a considerable number of farmers with a moderate level of familiarity in this agricultural domain. The subsequent 22% with experience ranging between 7 and 10 years represents a considerable portion with a higher level of expertise. Additionally, 21% having over 10 years of experience signifies a group of seasoned farmers, while the 20% of respondents with 1 to 3 years of experience reflects a segment of newer participants in the rice farming sector. These figures collectively portray a diverse pool of experience levels among the farmers involved in the study, supporting the conclusions drawn by Asante et al. (2023) in the Upper East region, Ghana.

Among the 388 respondents, the majority, specifically 71% (274), identified as Christians, while 11% (42) identified as Muslims. Additionally, 51% of the respondents had a household size of 6-10 members, which, while relatively large, is advantageous for farm labor provided by the family. In addition, 18% had households with 11-15 members, 17% had households with 21 or more members, 12% had households with 16-20 members, and only 2% had households with 1-5 members. These statistics provide an understanding of the various household sizes among the participants in this study. These results align with findings of Sedem-Ehiakpor et al. (2017) in Upper East region, Ghana and Mustapha et al. (2012) in Borno State, Nigeria, both of which noted that the most common household size ranged from 6 to 10 members. The substantial size of households may stem from the polygamous nature of rural farmers. This association may be attributed to the rural farmers' perception that larger household sizes are an advantageous and cost-effective approach to maximize farm output by leveraging family labour.

Table 6: ANOVA Table for the Age of Respondents

Source of Variation	***SS***	***df***	***MS***	***F***	***P*-value**
Between Groups	58.258	3	19.419	14.884	.000
Within Groups	501.021	384	1.305		
Total	559.278	388			

Source: Author's computation from field survey, 2022.

Table 6 illustrates the ANOVA results for the Age of Respondents. It delineates the variation attributed to age groups concerning agricultural productivity. The "Between Groups" demonstrates a significant variance (SS = 58.258) across the different age groups. The degrees of freedom (df = 3) point to the number of groups under comparison. The calculated F-ratio (F = 14.884) indicates a notable difference in the mean agricultural productivity between these age categories. The associated p-value of .000 reveals a highly significant result, implying that the observed differences are not likely due to random chance.

Conversely, "Within Groups" represented by SS = 501.021 and df = 384, portrays the variance within each age group. The F-ratio is not calculated in this instance, as it doesn't assess differences between groups. The "Total" row summarizes the overall variation across all respondents, indicating a total sum of squares (SS = 559.278) and total degrees of freedom (df = 388).

The statistically significant result in the "Between Groups" suggests that age is a meaningful factor influencing agricultural productivity among the respondents. The notable difference in agricultural productivity between age groups as indicated by the F-value implies that the varying age brackets may have a significant impact on the study's variables or outcomes. Younger age groups might display different levels of productivity compared to older age groups, indicating a potential need for tailored approaches concerning agriculture, including training, resource allocation, or policy formulations.

Pesticide Safety and Risk Awareness

Th findings regarding farmers' awareness of pesticide safety and the related risks, are provided in Table 6. This table presents the results of an investigation into the farmers' knowledge concerning the health effects of pesticides and the various pathways through which these substances enter the human body, organisms, and the environment. The statistical data indicates a significant level of awareness among farmers regarding the risks and pathways of pesticide poisoning, underscoring a comprehensive understanding of the health risks and modes of poisoning linked with pesticide usage. The findings of the study revealed that 87.9% of the respondents were conscious of the impact of pesticides on human health. Similarly, the results indicated that 87.9% of the farmers recognised the hazardous nature of agrochemicals. Moreover, in a similar study conducted in Nigeria, Yusha'u et al. (2023) identified that 87.1% of the participating farmers acknowledged the potential impact of pesticides on human health. The findings regarding the respondents' perceptions of the impact of pesticides on the environment indicate that 68.0% recognised groundwater pollution, while 77.8% were aware of the contamination of food due to pesticide use. The principal ways farmers recognised for pesticide poisoning are through skin contact (81.4%), and inhalation (83.0%), among other possible methods.

Table 7: Knowledge of Pesticide Toxicology

Questions Asked	Responses % (N)		
	Yes	No	I Don't Know
Do pesticides have the potential to induce adverse health effects?	87.9 (341)	7.5 (29)	18 (4.6)
Do different pesticides share identical health impacts? effect?	33 (128)	58.2 (226)	8.8 (34)
Is the use of pesticides hazardous?	87.9 (341)	7.5 (29)	4.6 (18)
Is it possible for pesticides to be absorbed into the body through breathing?	83.0 (322)	9.8 (38)	7.2 (28)
Is it possible for pesticides to penetrate the body through the skin?	81.4 (316)	10.8(42)	7.8 (30)
Can pesticides enter the body through oral exposure?	82.7 (321)	12.1 (47)	5.2 (20)
Is it possible for residues of pesticides to remain in the air?	72.4 (281)	15.0 (58)	12.6 (49)
Is it possible for residues of pesticides to persist in the soil?	74.5 (289)	14.4 (56)	11.1 (43)
Is it possible for residues of pesticides to be present in underground water?	68.0 (264)	21.4 (82)	10.6 (41)
Is it possible to detect pesticide residues in fruits?	77.8 (302)	14.2 (55)	8.0 (31)

Pesticides Identified in the Study Area

Farmers demonstrated a lack of detailed knowledge about the pesticides they used. This included unawareness of specific brand names, the chemical classification, and the active ingredients in these pesticides. Due to the farmers' limited familiarity, only a small selection of pesticides was mentioned (Table 6). This suggests a restricted scope of understanding among farmers regarding the various pesticides available or being used. The use of broad terms, like referring to multiple pesticides under the name "DDT," suggests a tendency among farmers to use general, overarching names rather than specific, individual pesticide names. This indicates a potential lack of distinction or detailed knowledge regarding different pesticide types and their specific identities.

Table 8: Identified Forbidden Pesticides Familiar to Farmers

Brand names	Frequency	Percentage (%)
Aldrin	3	0.8
Atrazine	53	13.7
DDT	200	51.5
Dieldrin	2	0.5
Furadan	79	20.4
Unknown	51	13.1

The statistics presented in table 8 illustrate the forbidden pesticides that farmers are aware of and can identify. These figures provide an insight into the frequency and distribution of different forbidden pesticides that farmers are familiar with or recognise. It reveals which pesticides are more commonly known among this group, with some like DDT and Furadan being more prominently identified compared to others.

Use of Pesticides: Exploring Application Insights, Purpose, Application Practices, and Application Proficiency

Farmers face notable challenges with animal pests, particularly grasshoppers, which account for 42.3% of the issues illustrated in figure 3. This substantial percentage underscores the potential impact of grasshoppers on agricultural practices, indicating possible crop damage that could reduce yields and affect farmers' incomes. The prominence of grasshoppers as a significant challenge suggests a potential reliance on pesticides or other pest control methods to manage these issues effectively. Consequently, the presence of such a substantial challenge might lead to increased expenses on pest management or potential economic losses due to reduced crop productivity. This emphasises the critical need for efficient pest management strategies to address grasshopper infestations. It also underscores the importance of promoting sustainable and integrated pest control methods to reduce dependency on pesticides, ensuring a balanced approach to maintaining crop health and securing agricultural productivity.

In response, a substantial majority (74.48%) of farmers rely on pesticides, as highlighted in figure 4, to address these pressing issues. This prevalent use of pesticides (78.09%) reflects a heavy dependence on these chemicals as the primary method to combat agricultural pests (figure 5). This aligns with previous studies that emphasise the predominant reliance on pesticides as a primary method for pest control in agriculture (Miyittah et al., 2020; Miyittah et al., 2022).

Although pesticides offer a common remedy for pest and weed management, this dependency raises concerns about potential overuse. Overreliance on pesticides can lead to various environmental, health, and sustainability issues (pest resistance). Consequently, it underscores the importance of exploring alternative and integrated pest management strategies to lessen the reliance on pesticides (Miyittah et al., 2022). Approaches like crop rotation, biological pest control, and the adoption of less harmful or non-chemical methods are crucial for maintaining crop health and effectively managing agricultural challenges in a more sustainable manner. Farmers' knowledge could be expanded through relatively moderate discussion in focus groups (LePrevost et al., 2013).

The statistics from figure 6 indicate the distribution of respondents based on the time frame within which they applied pesticides. These findings reveal a diverse pattern in the duration of pesticide application among the respondents. The higher percentage of respondents (36.86%) reported recent pesticide use (4-6 years) suggests a change or initiation in pesticide application practices among the surveyed individuals. This could be due to changing farming methods, increased awareness, or evolving pest management strategies. The declining percentage (21.59%) with longer pesticide application durations (over a decade) may indicate a turnover in agricultural practices, with new entrants (19.59%) or a shift in the agricultural demographic using fewer pesticides over extended periods (1-3 years).

Figure 7 illustrates the diverse array of information sources contributing to farmers' understanding of pesticides. Extension officers account for the largest proportion at 34.5%, followed by agrochemical shops at 29.4%, and fellow farmers at 24.7%. Pesticide labels contribute a smaller percentage at 6.4%, while personal experiences constitute 5% of the overall sources of knowledge for farmers. This supports study by Yakubu et al. (2023), indicating that farmers that farmers acquire knowledge about pesticide application through their own practical experiences. These statistics highlight the varied channels through which farmers acquire information. Agrochemical stores and agricultural extension agents (AEAs) operating within the Departments of Agriculture under the Ministry of Food and Agriculture (MoFA) in the study districts offer commendable services an these findings are consistent with prior research conducted by Asante et al. in the same study region in 2023.

The substantial percentage attributed to extension officers underlines the impact of professional advice on farming practices, reflecting the reliance on expert agricultural guidance. The significant reliance on agrochemical shops indicates the substantial role played by commercial entities in disseminating information, influencing farmers' decision-making processes in pesticide usage. The considerable percentage assigned to fellow farmers highlights the significance of informal knowledge-sharing networks among farmers, indicating the value of peer-based learning in agricultural communities. The contrast between the relatively smaller percentages for pesticide labels and personal experiences suggests a balance between official guidance from product labels and the importance of learning derived from practical, on-field experiences.

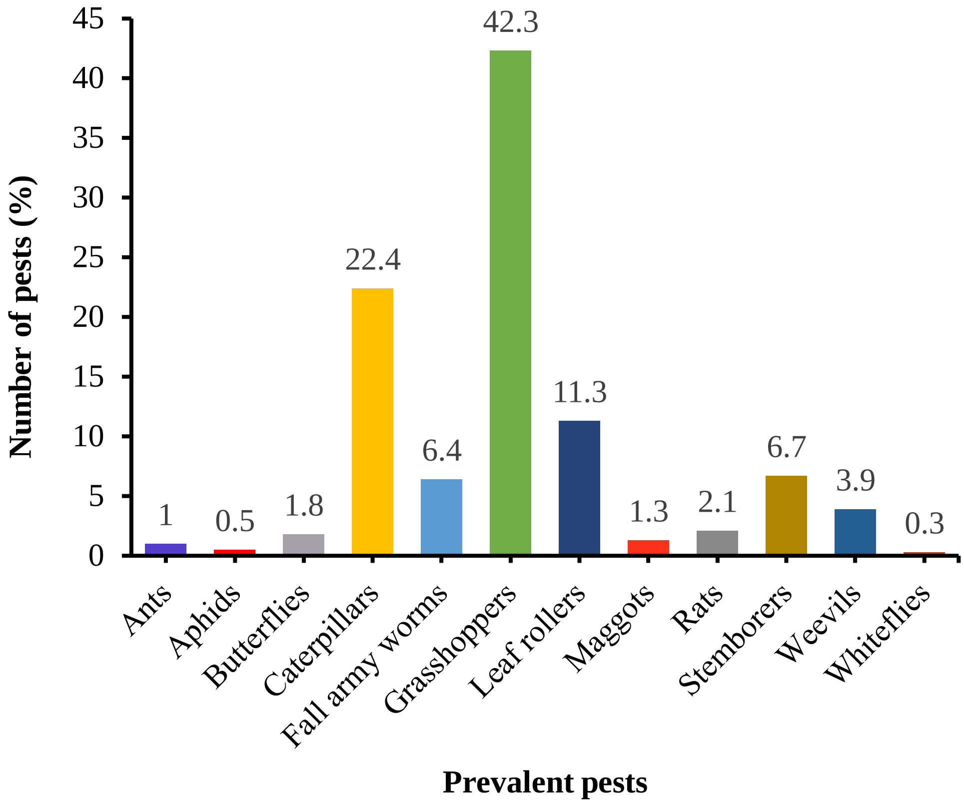

Figure 3: Major insect pests experienced by the farmers.

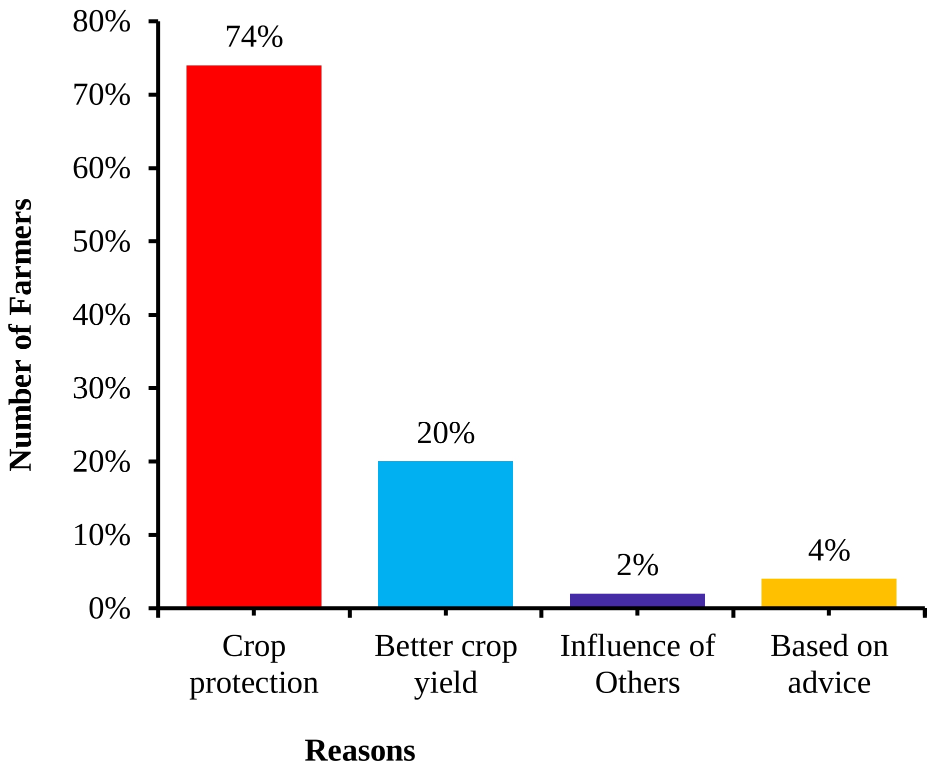

Figure 4: Reasons Why Farmers Apply Pesticides.

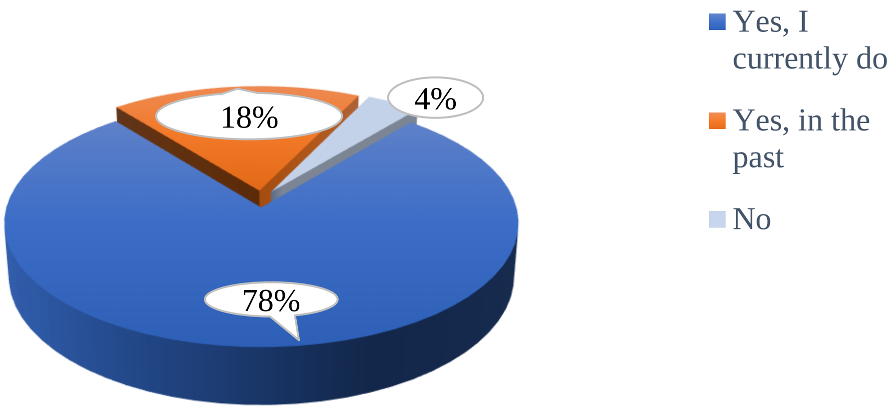

Figure 5: Frequency of Pesticides Applications

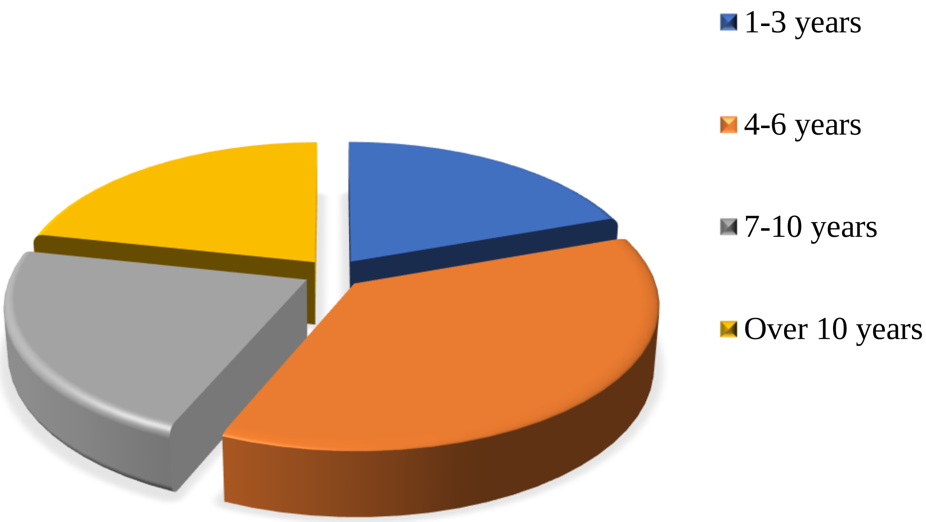

Figure 6: Farmers' Years of Experience in Pesticides use

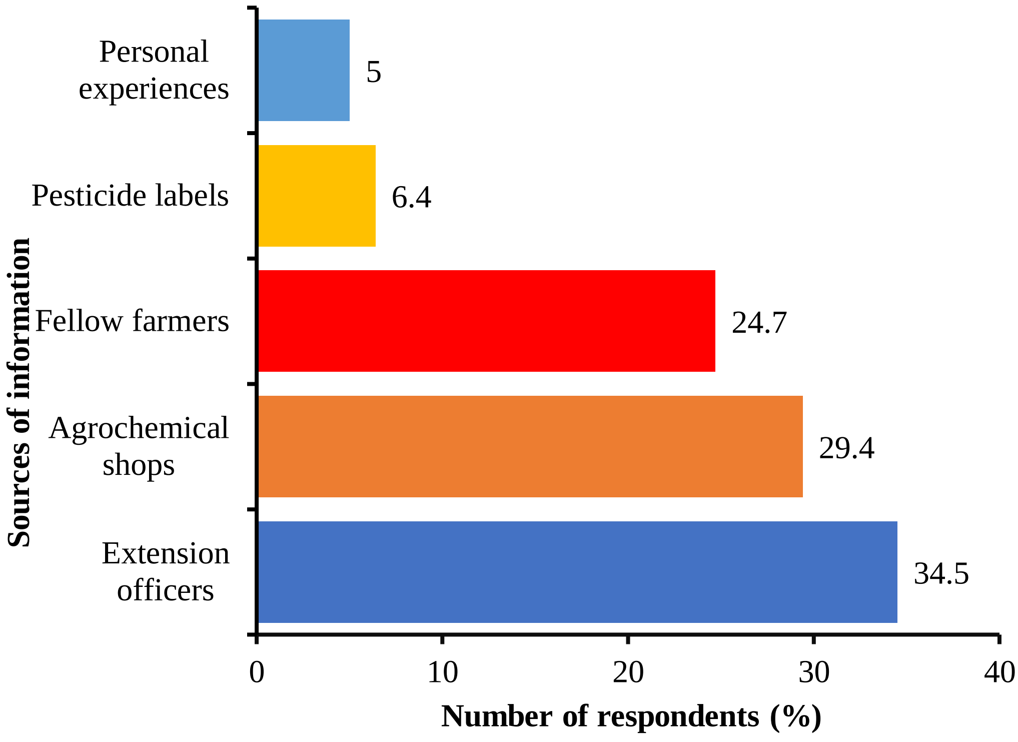

Figure 7: Farmers' Sources of Knowledge regarding Pesticide Application.

Attitudes towards Pesticide Use

The statistics in table 9 provide insights into the usage of Personal Protective Equipment (PPE) among respondents. The varying rates of utilisation for different safety gear items indicate a mixed adoption of protective equipment among the surveyed individuals, the usage of nose masks was notably high at 70%, indicating a consciousness and commitment toward respiratory protection. This is consistent with an earlier study conducted in the study region, which suggested that farmers are adequately safeguarded while applying pesticides (Asante et al., 2023). Conversely, the use of protective coveralls was lower, with only 45% employing them. This aligns with previous research by Asamani (2022), which indicates that farmers often prioritise increasing profitability over prioritising their health to achieve greater economic value. Failure to use appropriate safety gear may yield unexpected consequences. For example, using shoe socks to secure trousers in a paddy field has caused foot rots, as highlighted among the rice farmers (Asamani, 2022). This raises concerns about the safety practices among the surveyed population.

In general, the statistics provided illustrate a mixed pattern in farmers' usage of Personal Protective Equipment (PPE). While some safety gear like nose masks (70%), gloves (65%), and pesticide application boots (67%) had relatively higher usage rates, other items such as goggles (49%), head protection gear (50%), and protective coveralls (45%) showed more varied or lower adoption rates.

Table 9: Use of Personal Protective Equipment

Variables	Responses (%)	
	Yes	**No**
Goggles	191 (49)	197 (51)
Head Protection Gear	195 (50)	193 (50)
Nose mask	271 (70)	117 (30)
Pesticide Application Boots	259 (67)	129 (33)
Protective Coverall	176 (45)	212 (55)
Protective gear	260 (67)	128 (33)
Gloves	253 (65)	135 (35)

Storage of Pesticides

Figure 8 illustrates the various preferences and approaches farmers employ when storing pesticides. Some farmers opted to keep pesticide bottles in their homes, the majority recognised the importance of secure storage locations, aiming to prevent accessibility by children. Approximately one-fourth of the respondents highlighted different locations for storing their purchased pesticides. The most frequently cited storage sources included store rooms (43.3%), farms (24%), and local agrochemical stores (11.6%). Interestingly, a considerable portion, about 7% of respondents, chose to store pesticides in their residences, albeit in secure locations. This finding validates the study carried out in the Nanumba-North Municipality of Ghana as detailed by Yakubu et al. (2023).

The post-purchase decision-making regarding the space for storing chemical pesticides is revealed that 4.1% of respondents resorted to storing chemicals within their bushes, while slightly over 1.3% opted to keep them in their toilet facilities. These choices indicate a diverse range of storage locations, perhaps influenced by factors such as convenience or perceived safety.

The data underscores a significant consideration among farmers regarding the proper storage of pesticides. While the majority prioritise secure storage to prevent access by children, the range of locations chosen for storage highlights a need for further education or awareness on appropriate and safe storage practices. These statistics shed light on the current trends in pesticide storage among farmers, indicating both responsible practices and the need for continued guidance on best storage practices to ensure safety and efficacy.

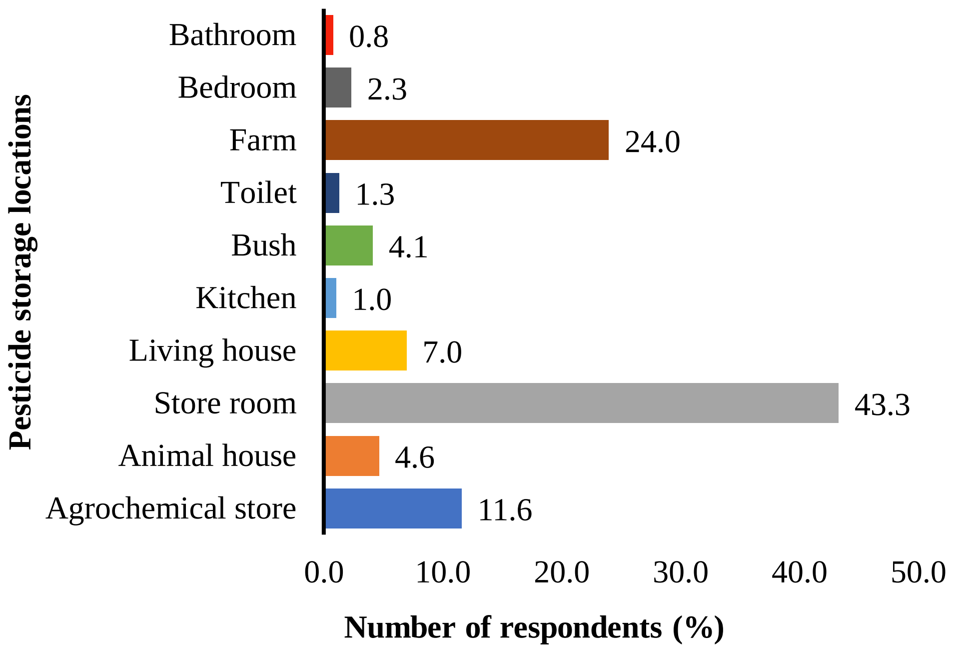

Figure 8: Farmers' Pesticide Storage Locations

Source of Pesticides

Figure 9 shows that farmers primarily obtain pesticides from various sources. The predominant share of pesticides used by the farmers, comprising 66.8%, was sourced from town agrochemical shops. Agrochemical stores located in villages supplied 17.0% of the pesticides. A smaller yet notable proportion, accounting for 9.5%, was acquired from agricultural supply stores. Additionally, extension officers contributed 5.2% of the pesticides provided to farmers. Lastly, cooperative societies represented the smallest share at 1.5%. Collectively, these diverse channels exemplify the range of sources from which farmers procured the necessary pesticides for their agricultural activities.

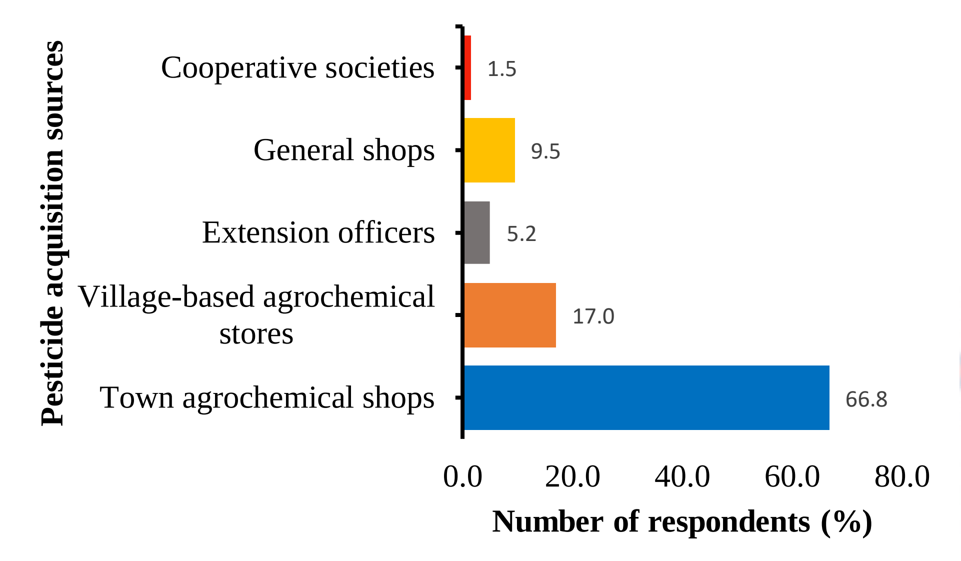

Figure 9: Source of Pesticides

Disposal of Empty Pesticide Containers

Figure 10 visually represents the varied approaches adopted by farmers in the disposal of empty pesticide containers. The statistical data depicted in the figure highlights the multifaceted strategies utilised by farmers for managing these containers post-use. The predominant approach appears to be burning on farms, representing 44.3% of the disposal methods used. Additionally, disposing of containers on farms holds a substantial share at 27.3%, while burying on farms accounts for 18.3%. This finding validates the study carried out in the region of Nanumba-North in Ghana (Yakubu et al., 2023). In contrast, a smaller proportion is attributed to reusing or donating containers (2.8%), selling them (2.3%), and storing in store rooms (1.5%). The action of gathering them registers at 3.4%, indicating another method utilised by farmers for disposal. The statistics highlight a notable reliance on on-farm disposal methods, notably burning and direct disposal, potentially signaling a need for promoting more environmentally friendly and safer strategies for pesticide container disposal within farming communities.

The most common disposal method observed was discarding the empty pesticide cans and residue from the spraying equipment directly onto the field. This connection illustrates the correlation between the observed behavior of farmers indiscriminately discarding empty bottles and the findings from Mergia et al. (2021) research, emphasizing the commonality in careless disposal practices among farmers.

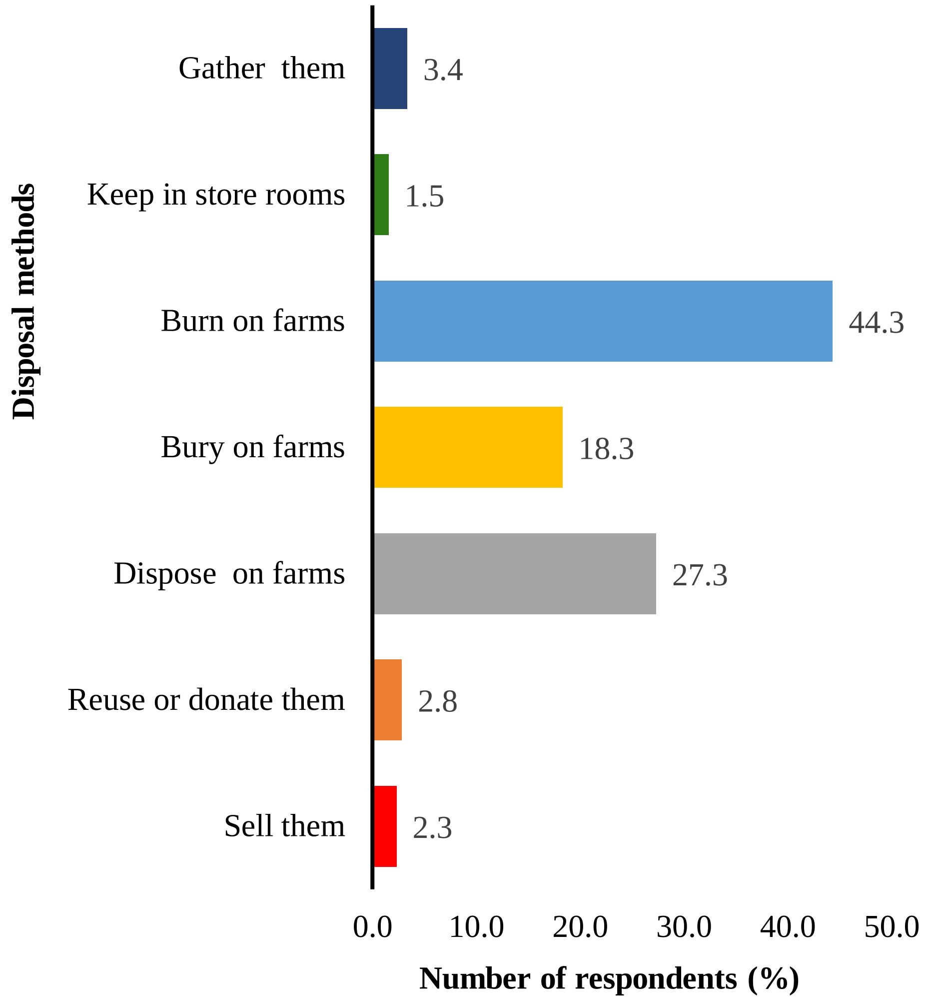

Figure 10: Disposal Methods of Empty Pesticide Containers.

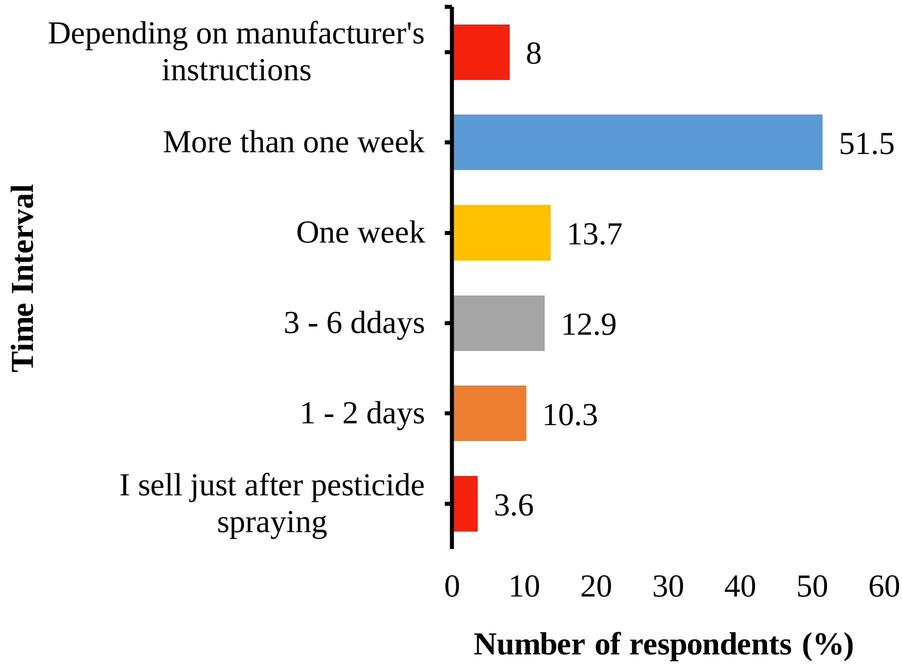

Figure 11: Time Interval Between Final Pesticide Application and Commencement of Crop Sale and Consumption.

Figure 11 displays the distribution of the time gap between the final pesticide application and the start of crop sale and consumption. The majority of farmers (51.5%) wait more than a week to sell or consume their crops after pesticide application. This finding is coherent with the data provided by (2019, 2019). This demonstrates a cautious approach, allowing time for any residual pesticide to diminish before offering produce for sale or consumption. The diversity in waiting times reflects the various practices among farmers. Some sell immediately after spraying (3.6%), while others wait for different durations such as 'One week' (13.7%), '3-6 days' (12.9%), and '1-2 days' (10.3%), suggesting individual preferences in terms of waiting durations.

The waiting durations of one week or more can be seen as a risk mitigation measure, aiming to ensure the safety of the produced crops for consumers. This delay allows for the dissipation or breakdown of potentially harmful residues on the crops. A smaller proportion of farmers (8%) follow specific instructions provided by manufacturers before selling or consuming crops, indicating a reliance on guidelines from pesticide manufacturers for safe handling and sale. These findings could have implications for regulatory practices, as the diversity in waiting times may impact compliance with safety and sale regulations established by agricultural authorities or food safety standards.

Overall, the results suggest a range of practices among farmers concerning the duration between pesticide application and the sale or consumption of crops, which can affect consumer safety, sales strategies, and compliance with regulations.

Symptoms commonly associated with pesticide poisoning

The symptoms associated with pesticide poisoning, as indicated in the provided table (Table 10), include a range of health issues experienced by individuals exposed to pesticides. Each symptom carries its own significance and potential implications. The data reveals that a significant proportion of individuals reported various symptoms, with a majority experiencing a burning sensation (60%) and itching/irritation of the skin (65%). These symptoms can indicate direct contact with irritant chemicals and highlights potential skin or eye irritation. Other prevalent symptoms include weakness (58%), skin rash (52%), and chest pain (56%). These symptoms often signify overall physical fatigue or muscular weakness (Yakubu et al., 2023), potentially due to exposure to toxic substances.

Additionally, symptoms such as watering eyes (41%), dizziness (38%), and fever (33%) were reported by a considerable percentage of individuals. This might indicate a more severe reaction to the chemicals, potentially suggesting a systemic response to toxic exposure. Less frequently reported symptoms encompassed forgetfulness (25%), vomiting (20%), and diarrhea (17%). Forgetfulness is a cognitive symptom might imply the effects of toxic exposure on mental functions. Vomiting and Diarrhea could indicate gastrointestinal irritation or systemic toxicity, leading to dehydration and requiring careful management to prevent further complications. The findings of Neghab et al. (2014), which involved 268 married male farmers in Iran, align with the occurrence observed in many developing nations where farmers periodically experience health issues, requiring occasional hospitalization after pesticide use (Atreya et al., 2012). Prolonged exposure to pesticides can result in various health consequences, contingent upon the pesticide's toxicity and the amount absorbed by the body.

Table 10: Common Symptoms associated with Frequent Pesticide Poisoning

Symptoms	Frequency	%
Burning sensation	232	60
Weakness	224	58
Fever	129	33
Teary eyes	157	41
Skin rash	201	52
Itching and skin irritation	253	65
Dizziness	146	38
Pain in the chest	217	56
Forgetfulness (amnesia)	95	25
Vomiting	76	20
Watery stools (Diarrhoea)	67	17

Factors Predicting the Occurrence of Burning Sensation after Pesticide Application: A Negative Log-Log Model

Table 11 presents the results of a Negative Log-Log Model investigating the factors that predict the occurrence of a burning sensation following pesticide application. The table illustrates the significant factors identified through the model, shedding light on the variables influencing the likelihood of experiencing this specific sensation after pesticide use. The variables include the odds ratios, standard errors, p-values, and confidence intervals (CI) associated with burning sensation, as well as biosocial and contextual factors.

Model 1 demonstrates that gender was statistically significant, suggesting that female farmers had a lower likelihood of experiencing a burning sensation (OR = 0.049, $p < 0.002$) as a symptom following pesticide application compared to their male counterparts. This could stem from various factors. It might be due to differences in exposure levels, personal protective measures, or varying physiological responses between genders. Female farmers might use protective equipment more consistently, have fewer instances of direct contact with pesticides, or have different susceptibility or physiological reactions to the chemicals compared to their male counterparts, contributing to the observed difference in the likelihood of experiencing a burning sensation. In some cases, female farmers might delegate the task of pesticide spraying to male farmers or other individuals. This could result in reduced direct exposure to pesticides due to occasional leaks from knapsack spray cans (Peprah, 2011), subsequently affecting the likelihood of experiencing symptoms like a burning sensation after pesticide application. This practice might lead to difference in the experience of symptoms between male and female farmers.

In Model 2, after controlling for biosocial factors, the results indicated that female farmers who relied on male farmers (OR = 0.042, $p < 0.01$) as applicators during pesticide application were more likely to avoid experiencing a burning sensation compared to their male counterparts. female farmers were approximately 95.8% less likely to experience a burning sensation during pesticide application compared to their male counterparts. They might assign the task of spraying to their male counterparts, who could be using personal protective equipment during pesticide application. Likewise, farmers who wash their sprayer on the farm (OR = 0.046, $p < 0.014$) after pesticide application were approximately 95.4% less likely to experience a burning sensation compared to their counterparts.

In model 3, contextual factors influencing famers' choice to use PPE were considered by controlling sprayer. Findings related to the cleaning of sprayers by farmers did not display statistical significance in models 2 and 3. However, the variable associated with the use of sprayed crops was statistically significant in model 3. Farmers who wash the sprayer on farms (OR = 0.042, $p < 0.03$) after pesticide application were significantly less likely to experience a burning sensation compared to their male counterparts.

Table 11: Factors Predicting the Occurrence of Burning Sensation after Pesticide Application: A Negative Log-Log Model

	Key predictor					**Biosocial factors**					**Contextual factors**				
Variables	**OR**	SE	P value	Cont.	Int.	**OR**	SE	P value	Cont.	Int.	**OR**	SE	P value	Cont.	Int.
Gender (Ref: Male)															
Female	0.049	0.016	**0.002**	0.019	0.08	0.042	0.017	**0.01**	0.01	0.075	0.046	0.017	**0.005**	0.014	0.079
Cleaning the sprayer after pesticide application (**Ref**: clean under tap at home)															
I do not clean the sprayer						0.053	0.031	0.082	-0.007	0.113	0.05	0.031	0.109	-0.01	0.111
Clean on the farm						0.046	0.019	**0.014**	0.0095	0.083	0.042	0.019	**0.03**	0.004	0.08
Clean in the bush						-0.06	0.086	0.483	-0.229	0.108	-0.07	0.086	0.432	-0.23	0.1
Crops treated with pesticides (Ref: No)															
Yes						0.038	0.02	0.058	-0.001	0.078	0.039	0.02	**0.053**	-0	0.079
Use of headgear (No)															
Yes											-0.02	0.015	0.164	-0.05	0.009

OR = Odd ratio, SE = Standard error. Bold fonts indicate a statistically significant relationship.

Relationship between the Gender of Farmers and Disposal of Empty Pesticide Containers

Table 12 displays how farmers' gender relates to their choices of disposing of empty pesticide containers, presenting counts and respective percentages based on the disposal methods and gender of the farmers. The obtained Pearson chi-square statistic ($\chi2$ = 12.859), with a corresponding p-value (Pr = 0.045), demonstrating a significant relationship between the disposal methods of empty pesticide containers and farmers' gender. The Cramer's V statistic is 0.1374, which is close to 1, suggesting a modest degree of association. This value indicates a relatively weak association between gender and the disposal methods of pesticide containers.

During the field survey, empty pesticide containers were observed on cocoa farms, supporting the claims made by the farmers. This observation aligns with the findings reported by Paintsil (2017) and Ansah (2019). The observed disposal practices were notably different between male and female farmers. Male farmers largely leaned towards discarding the containers (78%) and burying them on the farm (76.1%), while female farmers tended to dispose of the containers (23.5%) and bury them on the farm (23.9%) more evenly. This tendency of male farmers aligns with a similar pattern uncovered in a study conducted by Okoffo et al. (2016), emphasizing their inclination to carelessly discard pesticide containers in comparison to their female counterparts. Moreover, the discovery of pesticide containers in close proximity to water bodies further highlights the issue, as noted by (Afari-Sefa et al., 2015). The imprudent disposal of these containers, pesticides, or residual spray solutions presents the risk of soil and environmental contamination through processes such as runoff, leaching, and aerial dispersion to nearby areas.

In summary, the data suggests a moderate level of correlation, indicating a discernible relationship between gender and the disposal methods of empty pesticide containers. Both male and female farmers demonstrate distinct tendencies in their approaches to disposal practices.

Table 12: Relationship between the Gender of Farmers and Disposal of Empty Pesticide Containers

Gender	Disposal Methods of Empty Pesticide Containers							
	Sell them	Reuse	Discard	Burry farm	Burn farm	Keep them	Gather them	Inferential statistics
Male	6 (66.7)	6 (54.5)	78 (76.5)	54 (76.1)	126 (73.3)	1 (16.7)	10 (76.9)	$\chi2$= 12.859 Pr = 0.045
Female	3 (33.3)	5 (45.5)	24 (23.5)	17 (23.9)	46 (26.7)	5 (83.3)	3 (23.1)	Cramer's V = 0.1374

$\chi2$ = Pearson's chi square; Pr = P – value; Cramer's V value, ranging from 0 to 1, signifies the strength of the association, with a value closer to 1 indicating a stronger association. Values in parentheses represent the percentage of farmers.

Association between the Gender of Farmers and the Disposal Sites of Empty Pesticide Containers

Table 13 illustrates the relationship between farmers' gender and their chosen sprayer-cleaning locations after applying pesticides. It presents the percentage distribution of cleaning areas among male and female farmers. The Pearson chi-square ($\chi 2$) value of 10.069 with a p-value of 0.039 suggests a statistically significant association between the gender of the farmers and their chosen sprayer cleaning locations.

Additionally, the Cramer's V statistic of 0.1623 is indicative of a moderate association, implying a fair relationship between the gender of the farmers and their preferences for cleaning sites. It shows that male and female farmers tend to differ in their choices for sprayer-cleaning locations. Specifically, male farmers predominantly clean sprayers near water bodies (74.2%) and on farms (78.5%), whereas female farmers are inclined to do so near water bodies (25.8%) and in the bush (75%). The statistical analysis reveals a connection between the gender of farmers and their chosen locations for cleaning sprayers post-pesticide application.

Table 13: Association between Gender of Farmers and Disposal Sites of Empty Pesticide Containers

Gender	**Disposal Sites**					
	Water bodies	At home	Unwashed	Farm	Bush	Inferential statistics
Male	89 (74.2)	63 (68.5)	13 (59.1)	113 (78.5)	1 (25)	$\chi2$=10.069, Pr = 0.039
Female	31 (25.8)	29 (31.5)	9 (40.9)	31 (21.5)	3 (75)	Cramer's V = 0.1623

$\chi2$ = Pearson's chi square; Pr = P – value; Cramer's V value, ranging from 0 to 1, signifies the strength of the association, with a value closer to 1 indicating a stronger association. Values in parentheses represent the percentage of farmers.

Association between the Age of Farmers and the Location for Cleaning Sprayers Post Pesticide Application

Table 14 illustrates the connection between farmers' age and their chosen locations for cleaning sprayers after using pesticides. The figures in parentheses display the proportion of farmers in each category. The statistical analysis presents the Pearson chi-square ($\chi 2$) value at 35.737 with a p-value (Pr) of 0.017, signifying a statistically significant relationship between the age of farmers and their chosen locations for cleaning sprayers after pesticide application. The Cramer's V value is 0.153, suggesting a moderately strong association between the age of the farmers and their sprayer-cleaning locations.

Examining the data reveals that the cleaning practices differ across various age groups. For farmers aged 20 years and below, the majority tend to wash the sprayers at home (17.4%), followed by discarding them (14.2%). In contrast, farmers aged 21-30 years predominantly discard the sprayers (50.0%), and those aged 31-40 years frequently clean them on the farm (34.0%).

The statistical inferences demonstrate a variance in sprayer-cleaning practices concerning the age of the farmers. Younger farmers (aged 21-30 years) seem inclined to discard the sprayers, while those in other age groups exhibit diverse preferences in their sprayer-cleaning locations.

Table 14: Association between the Age of Farmers and the Location for Cleaning Sprayers Post Pesticide Application

Age	**Cleaning Site of Sprayers**					
	Discard	At home	Unwashed	Farm	Bush	Inferential statistics
20 years below	17 (14.2)	16 (17.4)	2 (9.1)	14 (9.7)	1 (25.0)	$\chi2$= 35.737
21-30 years	60 (50.0)	36 (39.1)	9 (40.9)	51 (35.4)	2 (50.0)	Pr = 0.017
31-40 years	25 (20.8)	21 (22.8)	6 (27.3)	49 (34.0)	1 (25.0)	Cramer's V = 0.153
41-50 years	10 (8.3)	17 (18.5)	3 (13.6)	14 (9.7)	0 (0.0)	
51-60 years	4 (3.3)	1 (1.1)	2 (9.1)	16 (11.1)	0 (0.0)	
61 and above	4 (3.3)	1 (1.1)	0 (0.0)	0 (0.0)	0 (0.0)	

$\chi2$ = Pearson's chi square; Pr = P – value; Cramer's V value, ranging from 0 to 1, signifies the strength of the association, with a value closer to 1 indicating a stronger association. Values in parentheses represent the percentage of farmers.

Relationship between the Formal Education of Farmers and the Cleaning Sites of Sprayers after Pesticide Application

Table 15 depicts the association between the formal education of farmers and their choice of locations for cleaning sprayers following pesticide application. The table showcases the frequencies (and percentages) of different educational levels and the sites chosen by the farmers for sprayer cleaning. The Pearson chi-square ($\chi 2$) value is 33.821, with a corresponding p-value (Pr) of 0.006. This implies a statistically significant relationship between the formal education levels of farmers and their chosen locations for cleaning sprayers.

The Cramer's V statistic stands at 0.149, indicating a moderate degree of association between the farmers' educational levels and their preferences for cleaning sprayers in specific locations. Specifically, those with no formal education or primary education tend to clean sprayers near water bodies and at home, while individuals with higher education levels demonstrate a lower tendency to do so in these places.

The findings suggest that formal education might influence the choices made by farmers regarding the location for cleaning sprayers after pesticide application. There is a distinct trend where lower levels of education are associated with higher percentages of cleaning near water bodies and at home compared to higher educational levels.

Table 15: Relationship between the Formal Education of Farmers and the Cleaning sites of Sprayers after Pesticide Application

Formal education	**Cleaning Site of Sprayers**					
	Water bodies	At home	Unwashed	Farm	Bush	Inferential statistics
No formal education	17 (14.2)	33 (35.9)	9 (40.9)	44(30.6)	1 (25.0)	$\chi2$= 33.821
Primary education	39 (32.5)	28 (30.4)	5 (22.7)	49(34.0)	2 (50.0)	Pr = 0.006
Secondary education	32 (26.7)	12 (13.0)	3 (13.6)	30(20.8)	1 (25.0)	Cramer's V = 0.149
Certificate/ Diploma	19 (15.8)	15 (16.3)	1 (4.5)	17(11.8)	0 (0.0)	
Degree	13 (10.8)	4 (4.3)	4 (18.2)	4 (2.8)	0 (0.0)	

$\chi2$ = Pearson's chi square; Pr = P – value; Cramer's V value, ranging from 0 to 1, signifies the strength of the association, with a value closer to 1 indicating a stronger association. Values in parentheses represent the percentage of farmers.

Association between Age of Farmers and Pesticide Storage Locations

Table 16 demonstrates the relationship between the age of farmers and the places where they store pesticides. The table outlines the distribution (in percentages) of different age groups and their tendencies in selecting storage sites for pesticides. The Pearson chi-square ($\chi 2$) value is calculated at 71.497, with a significant p-value (Pr) of 0.007. This statistical outcome indicates a strong relationship between the age of farmers and their preferred sites for storing pesticides.

Cramer's V statistic, measuring at 0.193, shows a moderate association between the age groups of farmers and their storage choices for pesticides. The younger age groups, particularly farmers aged 21-30 years, demonstrate higher frequencies of storing pesticides in the agrochemical store, suggesting a preference for more centralized storage locations. Conversely, the older age groups display more diverse preferences, with limited storage choices in specific locations like the living house, store room, or farm. Overall, the data suggests a noticeable relationship between the age of farmers and their decisions regarding where to store pesticides.

Table 16: Association between Age of Farmers and Pesticide Storage Locations

Age	Pesticide Storage Locations									
	Agrochemical store	Animal house	Store room	Living house	Kitchen	Bush	Toilet	Farm	Bedroom	Bathroom	Inferential statistics
20 years below	12 (26.7)	3 (16.7)	19(11.6)	7 (26.9)	0 (0.0)	1 (6.3)	2 (40.0)	5 (5.4)	0 (0.0)	2 (66.7)	χ2= 71.497 Pr = 0.007
21-30 years	20 (44.4)	9 (50.0)	58(35.4)	13(50.0)	3 (75.0)	7 (43.8)	1 (20.0)	41 (44.1)	7 (77.8)	0 (0.0)	Cramer's V
31-40 years	5 (11.1)	4 (22.2)	49 (29.9)	4 (15.4)	1 (25.0)	4 (25.0)	1 (20.0)	33 (35.5)	1 (11.1)	0 (0.0)	= 0.193
41-50 years	5 (11.1)	2 (11.1)	26 (15.9)	0 (0.0)	0 (0.0)	1 (6.3)	1 (20.0)	7(7.5)	0 (0.0)	1 (33.3)	
51-60 years	3 (6.7)	0 (0.0)	10 (6.1)	1 (3.8)	0 (0.0)	3 (18.8)	0 (0.0)	6 (6.5)	0 (0.0)	0 (0.0)	
61 above	0 (0.0)	0 (0.0)	2 (1.2)	1 (3.8)	0 (0.0)	0 (0.0)	0 (0.0)	1 (1.1)	1 (11.1)	0 (0.0)	

χ2 = Pearson's chi square; Pr = P – value; Cramer's V value, ranging from 0 to 1, signifies the strength of the association, with a value closer to 1 indicating a stronger association. Values in parentheses represent the percentage of farmers.

Association between Farmers' Formal Education and Reading Manufacturer Notifications.

Table 17 presents the relationship between the formal education level of farmers and their habits of reading manufacturer notifications. The values within the table represent the counts (and corresponding percentages) of farmers based on their education levels and whether they read the manufacturer notifications provided with the products. The Pearson chi-square statistic ($\chi 2$) is 39.487, and the associated p-value (Pr) is 0.000. These statistics indicate a statistically significant association between farmers' formal education and their reading habits of manufacturer notifications. Cramer's V value, which is 0.226, suggests a moderate association between formal education and reading the manufacturer notifications among farmers. Higher education levels show a tendency towards reading these notifications more frequently compared to lower education levels.

Table 17: Association between Farmers' Formal Education and Reading Manufacturer Notifications

Formal education	**Reading of Manufacturer Notification**			
	Yes	No	I don't know	Inferential statistics
No formal education	53 (20.9)	46(40.7)	4 (23.5)	$\chi2$ = 39.487
Primary education	74 (29.1)	45(39.8)	5 (29.4)	Pr = 0.000
Secondary education	62 (24.4)	12(10.6)	5 (29.4)	Cramer's V = 0.226
Certificate/ Diploma	47 (18.5)	6 (5.3)	0 (0.0)	
Degree	18 (7.1)	4 (3.5)	3 (17.6)	

$\chi2$ = Pearson's chi square; Pr = P – value; Cramer's V value, ranging from 0 to 1, signifies the strength of the association, with a value closer to 1 indicating a stronger association. Values in parentheses represent the percentage of farmers.

Association between Farmers' Districts and the Locations they choose for Cleaning Sprayers After Applying Pesticides

Table 18 demonstrates the association between farmers' districts and the locations they choose for cleaning sprayers after applying pesticides. The values are represented as percentages. In Builsa North, approximately 34.2% of farmers wash sprayers in water bodies, 65.2% at home, 72.7% do not wash them, 7.6% on the farm, and 75.0% in the bush.

The Pearson chi-square ($\chi 2$) value of 133.254 with a p-value (Pr) of 0.000 indicates a significant association between the district and the cleaning locations for sprayers. Moreover, Cramer's V at 0.418 denotes a substantial association. In Builsa South, 20.8% wash at water bodies, 8.7% at home, 9.1% unwashed, 59.0% on the farm, and 25.0% in the bush. In Kassena Nankana East, 45.0% wash at water bodies, 26.1% at home, 18.2% unwashed, 33.3% on the farm, and 0.0% in the bush.

The influence of district on the locations where farmers choose to clean sprayers after pesticide application suggests a regional pattern or inclination among farmers. The differences in cleaning locations across districts might be influenced by various factors such as cultural norms, environmental considerations, access to water bodies, or individual preferences within each specific district.

These regional variations can be beneficial for implementing targeted educational programs or interventions. This insight could aid in promoting safer and more responsible pesticide handling practices, potentially mitigating environmental contamination risks.

Additionally, it can assist in the design of region-specific initiatives to raise awareness about the importance of appropriate sprayer cleaning practices and their impact on environmental and human health.

Table 18: Association between Farmers' Districts and the Locations they choose for Cleaning Sprayers After Applying Pesticides

Districts	**Cleaning Site of Sprayers**					
	Water bodies	At home	Unwashed	Farm	Bush	Inferential statistics
Builsa North	41 (34.2)	60 (65.2)	16 (72.7)	11 (7.6)	3 (75.0)	$\chi2$=133.254
Builsa South	25 (20.8)	8 (8.7)	2 (9.1)	85 (59.0)	1 (25.0)	Pr= 0.000
Kassena Nankana East	54 (45.0)	24 (26.1)	4 (18.2)	48 (33.3)	0 (0.0)	Cramer's V= 0.418

$\chi2$ = Pearson's chi square; Pr = P – value; Cramer's V value, ranging from 0 to 1, signifies the strength of the association, with a value closer to 1 indicating a stronger association. Values in parentheses represent the percentage of farmers.

Association between Farmers' Districts and Disposal of Pesticide Residues Post Application

Table (19) demonstrates the distribution of disposal practices for pesticide remnants among different districts, and the influence of the district on farmers' disposal of pesticide residues after application is reflected in the variation in disposal practices across different regions. The table also highlights the variations in practices across different regions, as indicated by the percentages of farmers using different methods of disposal. In Builsa North, there is a substantial percentage (73.7%) of farmers disposing of pesticide residues by throwing them into water bodies, while a significant portion (60.9%) buries the residues on the farm. In contrast, Builsa South shows a higher percentage of farmers (50.4%) reporting no leftovers, and a relatively low percentage (1.4%) burying residues on the farm. Kassena Nankana East presents different trends, with a considerable number of farmers (60.9%) opting to store residues for future use. The Pearson Chi-Square ($\chi 2$) value at 104.968, indicates a statistically significant association between farmers' districts and their methods of pesticide residue disposal. The Cramer's V value, reaching 0.371, also indicates a moderate to strong association, signifying that the districts strongly influence the choices of pesticide residue disposal methods among farmers.

These disparities suggest that the local district might play a role in shaping the disposal practices of pesticide residues among farmers. This influence might be due to various factors such as local regulations, awareness campaigns, environmental considerations, or traditional practices that differ from one district to another. Understanding these district-specific disposal behaviors is critical for implementing targeted interventions and educational programs tailored to the specific needs and practices of each region. It could lead to the development of more effective and context-sensitive strategies for responsible pesticide residue management, thereby minimizing environmental impact and enhancing agricultural sustainability.

Table 19: Association between Farmers' Districts and Disposal of Pesticide Residues Post Application

Districts	**Dispose remnants of pesticides after end of application (%)**					
	On farm	Throw in water bodies	Bury on farm	No leftover	Store for future use	Inferential Statistics
Builsa North	21.3	73.7	60.9	32.6	14.1	$\chi2$=104.968 Pr= 0.000 Cramer's V= 0.371
Builsa South	33.7	10.5	1.4	50.4	25	
Kassena Nankana East	44.9	15.8	37.7	17.0	60.9	

$\chi2$ = Pearson's chi-square; Pr = P – value; Cramer's V value, ranging from 0 to 1, signifies the strength of the association, with a value closer to 1 indicating a stronger association. Values in parentheses represent the percentage of farmers.

Association between Farmers' Districts and Disposal of Empty Pesticide Containers

Table 20 displays the relationship between different districts and the methods used by farmers to dispose of empty pesticide containers. In Builsa North, selling containers to others (66.7%) and storing them in a room (83.3%) are the primary practices. Moreover, discarding (34.3%) and burying containers on the farm (52.1%) represent relatively common approaches. In Builsa South, respondents mostly favor discarding (43.1%) and burning containers on the farm (38.4%) instead of selling or reusing them. On the other hand, in Kassena Nankana East, the disposal practices are more varied. Burying containers on the farm (35.2%), burning them on the farm (44.2%), and storing them in a room (16.7%) are the most prevalent methods employed.

The Chi-square test ($\chi2$ = 83.368, Pr = 0.000) indicates a statistically significant relationship between the districts and the disposal methods of empty pesticide containers, demonstrating that the districts play a role in influencing the disposal practices. The Cramer's V value (0.329) suggests a moderate association between the districts and the methods of container disposal, highlighting diversity across the regions.

Table 20: Association between Farmers' Districts and Disposal of Empty Pesticide Containers

Districts	**Disposal of Empty Pesticide Containers**							
	Sell to others	Reuse/ Donate them	Discard	Bury on farm	Burn on farm	Keep in store room	Gather them	Inferential Statistics
Builsa North	6 (66.7)	11 (100)	35 (34.3)	37 (52.1)	30 (17.4)	5 (83.3)	8 (61.5)	$\chi2$=83.368
Builsa South	0 (0.0)	0 (0.0)	44 (43.1)	9 (12.7)	66 (38.4)	0 (0.0)	1 (7.7)	Pr= 0.000
Kassena Nankana East	3 (33.3)	0 (0.0)	23 (22.5)	25 (35.2)	76 (44.2)	1 (16.7)	4 (30.8)	Cramer's V= 0.329

$\chi2$ = Pearson's chi-square; Pr = P – value; Cramer's V value, ranging from 0 to 1, signifies the strength of the association, with a value closer to 1 indicating a stronger association. Values in parentheses represent the percentage of farmers.

Relationship between Districts and the various Storage Locations preferred by Farmers for Pesticide Storage

Table 21 demonstrates the correlation between various districts and the favoured storage locations chosen by farmers for pesticide storage. It presents the percentages of farmers using specific storage areas within different districts, displaying a variety of storage practices among these regions. In the distinct districts, storage practices vary significantly. In Builsa North, the prevalent storage locations include the kitchen (100%), the living room (57.7%), and bush areas (81.3%). This district displays diverse utilisation, encompassing domestic spaces like the living room and more unconventional spaces like the bush. The versatile use of storage locations, spanning from domestic settings to unconventional areas, could suggest a potential risk for pesticide exposure in inhabited spaces (like living rooms) and outdoor locations (like the bush). This might raise concerns about potential health hazards due to pesticide exposure.

Builsa South predominantly utilises the store room (58.5%) for pesticide storage, although certain areas such as the bedroom (44.4%) show comparatively higher storage preferences. Traditionally, this district leans toward employing conventional storage areas like the store room. This traditional approach and preference for storing pesticides in a conventional area such as the store room, might imply a lower likelihood of exposure in living spaces but may still raise concerns about adequate safety measures in specific storage locations.

Kassena Nankana East displays a range of storage locations, with a stronger emphasis on the farm (64.5%) and the animal house (35.6%). The farm-related storage could imply better segregation of pesticides from living areas.

The statistical analysis, as indicated by the Chi-square test ($\chi2$ = 155.821, Pr = 0.000), confirms a statistically significant relationship between the districts and the chosen pesticide storage locations. The Cramer's V value of 0.451 suggests a strong association between the districts and pesticide storage areas, indicating the varying practices and preferences across different regions.

Overall, the varied storage practices across the districts highlight the necessity of comprehensive guidelines and training for farmers regarding safe pesticide storage to minimize health and environmental risks. It underscores the need for tailored education on safe storage practices according to the specific conditions and preferences observed in each district.

Table 21: Relationship between Districts and the Various Storage Locations preferred by Farmers for Pesticide Storage

District	Storage Locations										
	Agrochemical store	Animal house	Store room	Living house	Kitchen	Bush	Toilet	Farm	Bed room	Bath room	Inferential Statistics
Builsa North	22 (48.9)	9(50.0)	30 (18.3)	15(57.7)	4 (100)	13(81.3)	4 (80.0)	28 (30.1)	3 (33.3)	3 (100)	$\chi 2$=155.821 Pr=0.000
Builsa South	7 (15.6)	6(33.3)	96 (58.5)	2 (7.7)	0 (0.0)	0 (0.0)	0 (0.0)	5 (5.4)	4 (44.4)	0 (0.0)	Cramer's
Kassena-Nankana East	16 (35.6)	3(16.7)	38 (23.2)	9 (34.6)	0 (0.0)	3 (18.8)	1 (20.0)	60 (64.5)	2 (22.2)	0 (0.0)	V=0.451

$\chi 2$= Pearson's chi square; Pr = P – value; Cramer's V value, ranging from 0 to 1, signifies the strength of the association, with a value closer to 1 indicating a stronger association. Values in parentheses represent the percentage of farmers.

Objective 2: To assess the risk of pesticide application using the EIQ (Environmental Impact Quotient) model.

The survey findings identified the usage of 39 distinct pesticides on rice by respondents. Some of these pesticides shared identical active ingredients but were marketed under various trade names. The information provided primarily centers around the most frequently used active ingredients and their corresponding trade names for these pesticides. These pesticides exhibited Environmental Impact Quotient (EIQ) figures ranging from 0.1 to 127.4, detailed in Table 21. Farmers commonly utilised multiple insecticides during a crop season, with most indicating the use of three to four types of pesticides either in the current or previous cropping season. The proportions of these recorded pesticides were as follows: lambda-super at 35.1%, sulphur 80 at 34%, kocide at 33.8%, kondemn at 27.1%, and sarosate at 22.4%. Additionally, confidor was noted at 19.8%, dursban at 19.3%, round-up at 18.8%, and karate at 17.8%. Among these, the pesticide with the highest usage rate was lambda-super, containing Lambda-cyhalothrin, which possesses properties enabling it to function both as systemic and contact poisons.

Table 22 shows the Environmental Impact Quotient (EIQ) values of various pesticides, categorized as insecticides, fungicides, and herbicides. The EIQ value reflects the overall environmental impact of each pesticide. The EIQ Consumer, EIQ Worker, and EIQ Ecology values measure the impact on consumers, workers involved in pesticide application, and the broader ecological impact, respectively. While EIQ values provide a useful reference for comparing pesticides, they do not cover all aspects of pesticide safety and should be considered alongside other factors, such as specific toxicity, application practices, and local regulations, when making decisions about pesticide use. The EIQ values was calculated based on various factors, including toxicity, exposure, and risk. Lower EIQ values indicate lower potential impacts, while higher values suggest higher potential impacts.

The listed pesticides exhibit varying Environmental Impact Quotient (EIQ) values across different domains. Within the insecticides, Lambda demonstrates a relatively low EIQ value of 9.6, suggesting a lower potential overall impact on both the environment and health. Although the impact on consumers is relatively low at 0.6, the impact on workers stands at a moderate level of 4.7. It is noteworthy that this aligns with the research conducted by (Arora et al., 2019) in India on rice farm indicating that Lambda-cyhalothrin had a low Environmental Impact (EI) value of 0.023, positioning it as one of the safest pesticides. However, the EIQ Ecology value of 23.5 indicates a higher potential risk to the ecosystem. This observation coincides with a separate study conducted by (Awusi et al., 2018) in Ghana among cocoa farmers, where Lambda recorded an EIQ of 44.17, indicating a moderate to high level of potential impact. These contrasting findings emphasised the need for caution and careful consideration when using this pesticide.

In contrast, Dursban displays a higher EIQ value of 36.1, signifying a higher overall potential impact on the environment and health. The impact on consumers is moderate at 2.7, and workers experience a similar moderate impact of 8.1. Notably, the EIQ Ecology value of 97.6 indicates a substantial potential risk to the ecosystem.

In relation to Lambda which had an EIQ value of 9.6, Confidor's EIQ value of 50.4 indicates a notably higher potential impact on the environment. The difference in EIQ values between Confidor and Lambda suggests that Confidor may have a more considerable environmental impact compared to Lambda, emphasizing the need for a more cautious approach when using Confidor due to its higher EIQ value. This observation coincides with a separate study conducted by (Awusi et al., 2018). Its impact on consumers is high at 14.2, signifying potential health risks linked to its consumption. In terms of workers handling the pesticide, the EIQ Worker value of 9.5 suggests a moderate impact. However, the EIQ Ecology value of 127.4 portrays a very high impact, indicating a substantial risk to the environment. Karate, characterised by an EIQ value of 2.1, reflects a comparatively low potential impact on both the environment and human health. While its impact on consumers is moderate at 2.1, workers experience a very low impact at 0.1. Moreover, the EIQ Ecology value of 1 highlights a low impact, indicating a reduced potential risk to the ecosystem.

Comparing the EIQ values of different fungicides, Sulphur 80 demonstrates moderate impacts on consumers, workers, and the environment, signifying a moderate level of potential risk across these domains. Conversely, Kocide exhibits relatively low EIQ values, indicating lower potential impacts on consumers, workers, and the environment, suggesting a reduced level of risk in these areas when compared to Sulphur 80.

Among the listed herbicides, both Kondemn and Round-up exhibit moderate EIQ values, indicating a similar moderate potential impact on consumers, workers, and the environment. In contrast, Serosate stands out with relatively low EIQ values, suggesting a reduced potential impact on consumers, workers, and the environment in comparison to Kondemn and Round-up, signifying a lower level of potential risk across these domains. This observation coincides with a separate study conducted by (Awusi et al., 2018).

Table 22: EIQ Values and WHO Toxicity Class of Common Pesticides Used by Farmers

Pesticides	WHO hazard class	Active ingredient	Frequency	Rate of application (a.i. ml/g/acre)	EIQ Value	EI per acre		
Insecticides						Consumer	Worker	Ecology
Lambda	II	lambda Cyhalothrin (9.7%)	40	1150	9.6	0.6	4.7	23.5
Dursban	II	chlorpyrifos (58.5%)	39	361	36.1	2.7	8.1	97.6
Confidor	II	imidacloprid (200 g/L)	21	343	50.4	14.2	9.5	127.4
Karate	II	lambda Cyhalothrin (5 %)	23	420	2.1	2.1	0.1	1.0
Fungicides								
Sulphur 80	III	sulfur (80%)	19	112	5.9	1.5	3.9	12.2
Kocide	II	glyphosate (450 (g/l)	12	15	0.5	0.1	0.4	1.1
Herbicides								
Kondemn	III	glyphosate (450 (g/l)	8	102	14.1	2.8	7.8	32.1
Round-up	III	glyphosate (41%)	11	1002	12.6	2.5	6.6	28.8
Serosate	III	glyphosate (15%)	9	135	0.6	0.1	0.3	1.4

II =Moderately hazardous; III = Slightly hazardous; *Frequency = the number of times the pesticide is used for all harvest time per year. a.i. – Active Ingredient, WHO (2019) - World Health Organization, EIQ Environmental Impact Quotient and EI – Environmental Impact. *Environmental Impact Rating Levels -: < 25- (very low risk): < 50 - (low risk): 50- 99-(Moderate): 100 – 199 (high risk): and 200+ (very high risk).

Characterisation of Corn Cob and Rice Husk Biochar and Soil Samples.

The process of pesticide transformation within the soil profile is most accurately characterised by microbial breakdown, oxidation, hydrolysis, and photolysis. Research has also shown that the soil's pH level influences the absorption of pesticides (Katagi, 2012). Pesticide residues show a negative relationship with soil pH, influenced by factors such as total nitrogen, organic matter, and electrical conductivity, affecting the fate of pesticides (Z. Wang et al., 2021).

The variations in pH levels between Corn cob Biochar (CCB=8.03) and Rice Husk Biochar (RHB =6.77) reflect their distinct acidic and alkaline natures (Table 23). The pH difference suggests that CCB tends toward alkalinity, while RHB leans toward acidity. This pH contrast can significantly impact their capacity to interact with pesticides, affecting their adsorption potential based on their acidic or basic properties.

Moreover, the high pH levels of biochar are known to influence the hydrolysis of chemical pesticide residues in the soil, as indicated by studies (Zhang et al., 2012; Liu et al., 2018). Additionally, the nutritional composition of organic biochar raw material varies, ranging from woody (mineral-poor) resources to crop residues (mineral-rich). The surface functionalities of biochar directly relate to its pH, as supported by research (Zhou et al., 2019). These combined factors underline the importance of pH in influencing biochar's interactions with pesticides and its subsequent effects on soil and residue management.

The pH variations in biochar are notably impacted by its mineral ash content, with higher values generally indicating increased pH levels. As the temperature of the feedstock rises, there is a concurrent increase in the resulting pH of the biochar. These pH differences are heavily influenced by various factors, such as feedback mechanisms and soil properties. The influence of pH on pesticide immobilization demonstrates a slight increase from 75 to 85 percentage points within the pH range of 3-5. This value then declines to 75-65 percentage points between pH 6-8 and further markedly declines to 55 percentage points at pH 9.1 (Cederlund et al., 2016).

The CEC values measured for the soil samples (S1 & S2) and the absorbents (CCB & RHB) were 3.42, 8.42, 14.45, and 17.80 mmol/kg, respectively. Notably, S2 displayed a significantly higher CEC compared to S1. Moreover, the CEC for RHB was notably high, potentially suggesting the extended durability or longevity of the biochar. This is consistent with previous findings that indicate the CEC of fresh RHB is relatively low initially but increases over time (Ogawa & Okimori, 2010). Moreover, the rise in CEC of biochar may directly result from the abundance of functional groups, such as oxygen-containing groups like -CO [O] and -OH (Jeffrey & Saenger, 2012). According to similar research studies, the formation of carboxylic acid functional groups as a result of organic biochar combustion is what causes the sufficiently high CEC of biochar (Glaser et al., 2002). This implies that RHB, with a CEC of 17.80 cmolc/kg, contains more oxygen-containing functional groups than CCB, which has a CEC of 14.45 cmolc/kg.

S1, comprising 71.46% sand, 18.94% silt, and 9.61% clay, falls into the category of sandy loam. S2, consisting of 42.08% sand, 33.18% silt, and 24.8% clay, is classified as sandy clay based on its textural composition.

Table 23. Analysis and Chemical Properties of the Soil Samples and Amendments

Sample	pH	MC (%)	OC (%)	%OM	% N	P(µg/g)	CEC (cmol/kg)	Clay (%)	Sand (%)	Silt (%)	Textural Class
S1	5.0	0.87	0.89	1.53	0.07	25.73	3.42	9.61	71.45	18.94	Sandy loamy
S2	5.86	3.24	1.46	2.52	0.1	2.15	8.42	24.8	42.08	33.13	Loam
CCB	8.03	9.84	10.33	17.82	0.75	456.63	14.45	N/A	N/A	N/A	N/A
RHB	6.77	7.48	6.19	10.68	0.56	545.55	17.80	N/A	N/A	N/A	N/A

S1 = Soil sample from Kassena Nankana, S2 = Soil sample from Builsa North, % MC = Percentage of Moisture Content, % OC = Percentage of organic carbon, %OM = Percentage of organic matter, %N = percentage of nitrogen, P= Available phosphorus, CCB = Corn cob biochar, RHB = Rice husk biochar, CEC = Cation Exchange Capacity, N/A = Not applicable.

Mean Concentration Levels of Lambda Cyhalothrin in Untreated and Amendment-Treated Soil Samples

Table 24 presents the results showing the average concentration levels of Lambda in leachate collected over a four-week period. The findings revealed a notable statistical difference in the altered soil samples from Kassena-Nankana (SKN) for both treatments (F = 3.74; P = 0.0165) and treatment durations across weeks (F = 3.81; P = 0.0083). This indicates that while the addition of biochar made from corn cob and rice husk did not entirely eliminate the pesticide lambda, it did result in a reduction in its accumulation within the soil.

Soil 1 with 1% rice husk biochar (S1RHB) exhibited lambda adsorption during weeks 2 and 3, with levels ranging from 0.0133 mg/L to 0.0145 mg/L. In contrast, soil 1 with 0.5% corn cob biochar (S1CCB) demonstrated specific sorption in week 2, measuring 0.0154 mg/L. Soil sample 1 without any amendments, on the other hand, showed a decrease in lambda quantity over time (0.0153 & 0.0156 mg/L). The least buildup of lambda occurred during weeks 1 and 4. Particularly, 1% rice husk biochar (S1RHB) in soil 1 had the lowest lambda concentration at 0.0133 mg/L compared to 0.5% corn cob biochar (S1CCB).

However, in Builsa South, treatments (F =2.93; P = 0.0420) were significant whilst weeks were statistically insignificant (F= 1.59; P = 0.2028) (Table 23). As a result, there is insufficient proof that the null hypothesis is incorrect and indicates that there is no substantial difference in removing pesticides from soil using corn cob or rice husk organic carbon. This suggests that the presence of CCB and RHB lowered the amount of Lambda pesticide residues in the soil rather than removing them entirely.

Table 24: Mean Concentration Levels of Lambda Cyhalothrin in Untreated and Amendment-Treated Soil Sample 1

District	Treatments	Week 1	Week 2	Week 3	Week 4
Kassena-Nankana	Control soil (0%)	0.0158	0.0156	0.0157	0.0153
	Soil +CCB (0.5%)	0.0154	0.0152	0.0155	0.0155
	Soil +CCB (1%)	0.0168	0.0156	0.0157	0.0158
	Soil + RHB (0.5%)	0.0155	0.0154	0.0154	0.0148
	Soil + RHB (1%)	0.0163	0.0145	0.0133	0.0158
Repeated Measures Analysis		*P*			
Treatments		< 0.0165			
Weeks		0.1518			
Treatments * Weeks		< 0.0083			

The weekly scores are the averages of 3 replications. Analyses of repeated measures were executed with PROC GLM, significance at $p < 0.05$. All concentrations are in milligrams per liter (mg/L).

Table 25: Mean Concentration Levels of Lambda Cyhalothrin in Untreated and Amendment-Treated Soil Sample 2

District	Treatments	Week 1	Week 2	Week 3	Week 4
Builsa North	Control soil (0%)	0.0156	0.0154	0.0152	0.0152
	Soil +CCB (0.5%)	0.0154	0.0154	0.0142	0.0142
	Soil +CCB (1%)	0.0169	0.0157	0.0155	0.013
	Soil + RHB (0.5%)	0.0156	0.0154	0.0155	0.0142
	Soil + RHB (1%)	0.0195	0.0158	0.0148	0.0152
Repeated Measures Analysis		*P*			
Treatments		< 0.0420			
Weeks		2.93			
Treatments * Weeks		0.1896			

The weekly scores are the averages of 3 replications. Analyses of repeated measures were executed with PROC GLM, significance at $p < 0.05$. All concentrations are in milligrams per liter (mg/L).

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Introduction

A summary is provided in the concluding chapter of the study, bringing to the fore the study's outcomes as well as the conclusions, recommendations, and future research suggestions. As a result, the chapter concentrates on the policy implications of the study's findings. Recommendations based upon the research study's main conclusions and basic summary.

Summary of Findings

The study involved 388 smallholder rice farmers, examining their pesticide application knowledge and collecting insightful demographic statistics. The research revealed that 73% of respondents were male, indicating a dominant male presence in the Upper East region's agriculture. In terms of age distribution, 41% were within the 21-30 age bracket, indicating a significant proportion of young individuals in rice farming.

Furthermore, 78% of participants relied mainly on farming for income, with most (81%) cultivating rice farms between 1 to 5 acres, signifying predominantly smallholder subsistence farming within the surveyed population. Moreover, there were diverse educational levels among the farmers: 33% had primary education, and 27% admitted to not reading pesticide labels before use. Most households had 6-10 members, aligning with previous studies indicating larger families are advantageous for farm labor.

The study also unveiled farmers' awareness of the potential health risks associated with pesticides. About 87.9% understood the dangers to health, 68.0% recognised the potential to contaminate water, and 77.8% acknowledged the risk to food safety. Additionally, the research revealed that farmers had limited knowledge about the specifics of the pesticides they used. They often referred generally to pesticides with terms like "DDT" instead of using specific names. However, they demonstrated better recognition and identification of forbidden pesticides, such as DDT and Furadan, compared to other types.

Furthermore, the study brought to light the challenge of animal pests, with grasshoppers accounting for 42.3% of the problems. Farmers heavily relied on pesticides (74.48%) to combat these pests, raising concerns about potential overuse and its associated environmental and health risks. The data showed that farmers acquired pesticide knowledge from various sources: extension officers (34.5%), agrochemical shops (29.4%), fellow farmers (24.7%), pesticide labels (6.4%), and personal experiences (5%). This underlined the multifaceted nature of acquiring knowledge about pesticide application, combining expert guidance with practical experiences.

The statistics depicted a mixed adoption of safety gear items among participants: nose masks were frequently used at 70%, while protective coveralls were less utilised at 45%. It also highlighted the diverse practices of storing pesticides among farmers. Moreover, the research indicated varied methods of pesticide container disposal among farmers. The predominant approach was burning on farms (44.3%), followed by disposing of containers on farms (27.3%) and burying on farms (18.3%). In terms of waiting times between the final pesticide application and the sale or consumption of crops, 51.5% opted for a cautious approach, waiting over a week before selling or consuming their crops. The remaining participants had varied waiting periods.

Additionally, the study found that a significant proportion of individuals reported experiencing symptoms after pesticide application, such as skin irritation (52%), weakness (58%), chest pain (56%), and other symptoms related to potential pesticide exposure. Furthermore, the research conducted statistical analyses to identify factors influencing these symptoms. For example, gender-based differences and practices related to cleaning equipment post-pesticide application were found to significantly impact the likelihood of experiencing these symptoms.

The study explored further various connections between farmers' demographic attributes and their agricultural practices, revealing insightful patterns. Gender played a crucial role in pesticide container disposal, with distinct variations observed between males, who tended to discard or bury containers, and females, who exhibited more balanced disposal habits. Additionally, differences in post-pesticide application cleaning practices were highlighted, with males favoring water bodies and farms, while females tended to opt for bush areas or water bodies.

Furthermore, age emerged as a significant factor influencing cleaning approaches, with younger farmers displaying a propensity for discarding, while older groups demonstrated more diverse preferences. Formal education levels were closely tied to cleaning site preferences, showing that lower education levels were associated with a greater inclination towards water bodies and home-based cleaning practices.

Also, pesticide storage locations were influenced by the age of farmers, as younger farmers showed a preference for centralized storage, while older farmers displayed a more varied range of storage choices. Moreover, the level of education directly affected the likelihood of farmers reading manufacturer notifications, with higher education levels correlating with more frequent reading.

The study also underscored the profound influence of districts on farmers' decisions regarding cleaning sites, methods of pesticide residue disposal, disposal of empty containers, and choices for pesticide storage locations. These diverse findings stress the necessity of targeted education and region-specific interventions to foster safer agricultural practices tailored to the distinct needs and practices of each region.

The second objective of the research involved evaluating the Environmental Impact Quotient (EIQ) values of various pesticides, exposing their potential environmental and health impacts across different domains. The study revealed a range of EIQ values for the analyzed pesticides. Lambda demonstrated a lower overall impact (EIQ 9.6) on the environment and health but posed a higher risk to the ecosystem. Conversely, Dursban exhibited a higher potential impact (EIQ 36.1) across all domains, particularly on the ecosystem. Confidor's EIQ value of 50.4 indicated notably higher potential environmental impact compared to Lambda, emphasizing the need for cautious usage. Karate, with an EIQ of 2.1, showed a comparatively low potential impact on the environment and health.

Among fungicides, Sulphur 80 presented moderate impacts, while Kocide indicated lower potential impacts across consumers, workers, and the environment. In the listed herbicides, both Kondemn and Round-up exhibited moderate EIQ values, while Serosate showed lower potential impacts in comparison, signifying a reduced level of risk across all domains. These findings underscored the diverse potential impacts of various pesticides and emphasised the necessity of careful consideration in their application.

Finally, the investigation focused on the transport and removal of pesticides in soil within the study area. The findings indicated that there were reduced concentrations when corn cob and rice husk biochar were added as adsorbents. This underscored the role of biochar in reducing pesticide concentrations. The adsorption was highly influenced by factors such as soil pH, type, moisture, ambient temperature, and organic matter content. The extent to which the pesticide was adsorbed relied on its concentration, and the initial concentration gradually decreased throughout the four-week period. Of all the biochar types used, the 1% rice husk demonstrated the highest absorption of lambda in the soils. The reason for the low concentration in both unaltered soil types at the conclusion of the experiment might be attributed to the biodegradation of pesticides within the soil.

Conclusion

The research highlighted a significant awareness among farmers regarding the potential health risks associated with pesticides. However, this awareness was accompanied by a limited specific knowledge of various pesticide types, with a better recognition of forbidden pesticides compared to others. This general lack of specific knowledge among farmers regarding the pesticides they use, often referring generally to pesticides using terms like "DDT," potentially indicates gaps in understanding the products applied, which could affect safe and effective usage. The statistics further revealed a higher utilisation of nose masks compared to protective coveralls, suggesting potential inadequacies in protective measures during pesticide application. Additionally, diverse practices in storing and disposing of pesticides among farmers raised concerns about potential environmental contamination and health hazards, especially with improper disposal methods such as burning pesticide containers on farms. The heavy reliance on pesticides to combat animal pests, notably grasshoppers, raised concerns about potential overuse and associated environmental and health risks.

Farmers acquired pesticide-related knowledge from various sources, showcasing the diverse nature of learning methods. However, there was varied adoption of safety gear, with a lower utilisation of protective coveralls compared to nose masks. Furthermore, the waiting period between pesticide application and crop sale or consumption varied, indicating diverse approaches among farmers.

A significant proportion of individuals reported experiencing various symptoms post-pesticide application. Gender-based differences and post-application equipment cleaning practices significantly influenced the likelihood of experiencing these symptoms.

The study extensively probed into the correlations between farmers' demographic attributes and their agricultural practices, revealing insightful gender-based disparities in pesticide container disposal and post-application cleaning preferences. Gender discrepancies were pronounced, with males more inclined to discard or bury containers, while females exhibited more varied disposal approaches. Cleaning site preferences after pesticide application showed gender-specific tendencies, with males favoring water bodies and farms, while females leaned towards the bush or water bodies. Furthermore, age influenced cleaning practices, where younger farmers were prone to discarding, while older groups displayed diversified preferences. Lower education levels correlated with a tendency towards water bodies and home cleaning, whereas higher education levels demonstrated a likelihood of reading manufacturer notifications. Districts significantly impacted various farming choices, emphasizing the necessity for tailored educational interventions for each region, ensuring safer agricultural practices catering to regional needs and practices.

Different pesticides demonstrated varying potential impacts across different domains. While some pesticides showed lower overall impact but posed risks to specific ecosystems, others exhibited higher potential environmental impacts, emphasising the necessity for cautious usage.

The study revealed the role of biochar, particularly rice husk, in reducing pesticide concentrations in soils. The adsorption of pesticides was influenced by various factors, including soil conditions and biochar type. The declining pesticide concentration in unaltered soil types might be attributed to the biodegradation of pesticides within the soil over the research period.

Considering the observed efficacy of biochar, particularly rice husk biochar, in reducing pesticide concentrations and aiding degradation within the soil, it is recommended to explore and encourage the wider adoption of biochar as an eco-friendly and effective soil amendment. Initiating educational campaigns and extension services to raise awareness about the benefits and proper utilisation of biochar among smallholder farmers could significantly contribute to improving soil health, reducing environmental impact, and promoting sustainable agricultural practices. Additionally, exploring the economic feasibility of large-scale biochar implementation within smallholder farming communities could provide valuable insights into its long-term viability and practicality. Further research and experimentation on the optimal application methods and types of biochar for different soil conditions could provide additional insights, encouraging its more widespread and effective implementation in agricultural settings.

Recommendations

Based on the findings of the research conducted among smallholder rice farmers, several recommendations have been proposed to enhance practices and minimise the potential risks associated with pesticide usage:

1. **Education and Training Programs:** It is recommended that the Ministry of Food and Agriculture (MoFA) initiates and supports comprehensive educational programs for smallholder farmers. These programs should focus on:

   a) Enhancing farmers' understanding of safe pesticide application practices, with a significant emphasis on the importance of reading and comprehending pesticide labels before use.

   b) Additionally, educating farmers on proper storage and environmentally friendly disposal practices for pesticides and their containers is crucial. This includes emphasizing safe disposal methods while discouraging burning or improper disposal of pesticide containers on farms.

2. **Diversification of Knowledge Sources:** Farmers should be encouraged to seek knowledge from diverse sources, such as agricultural extension officers, agrochemical shops, fellow farmers, and credible online resources. This diversified approach will offer a more comprehensive understanding of pesticide usage and its associated risks.

3. **Promotion of Safety Measures:** There should be advocacy for the consistent use of personal protective equipment (PPE) during pesticide application. While nose masks are frequently used, there should be greater promotion and adoption of other PPE, such as protective coveralls, to ensure comprehensive protection against potential health hazards.
4. **Regular Monitoring and Symptom Awareness:** There should be established systems for regular monitoring of farmers' health post-pesticide application and increase awareness regarding potential symptoms of pesticide exposure. Immediate reporting and seeking medical assistance upon experiencing symptoms should be encouraged.
5. **Reducing Overreliance on Pesticides:** Integrated pest management strategies should be promoted to reduce excessive reliance on pesticides. Alternative pest control methods, encouraging a more balanced and sustainable approach to pest management should be encouraged.
6. **Enhancing Biochar Application:** The potential benefits of biochar should be highlighted in reducing pesticide concentrations in the soil. Farmers should be encouraged to explore and utilise biochar, such as rice husk and corn cob biochar, as effective adsorbents to reduce the environmental impact of pesticides.
7. **Community-Based Initiatives:** There should be support for the formation of farmer cooperatives or community groups where experiences, best practices, and challenges in pesticide application can be shared. This collective knowledge-sharing approach could enhance overall pesticide application practices.

8. **Regulation and Enforcement:** Rules and regulations governing pesticide use, storage, and disposal should be strengthened by implementing stricter guidelines. This would help ensure adherence to safety protocols and environmentally responsible practices.
9. **Continuous Research and Extension Services:** Further research on the impacts of pesticides, alternative pest control methods, and the effectiveness of biochar in reducing pesticide concentrations should be encouraged and supported. Extending these findings and providing guidance through continuous extension services would benefit a larger number of farmers.

By implementing these recommendations, it is possible to enhance the knowledge base, safety practices, and environmental consciousness among smallholder rice farmers, thus fostering more sustainable and safer agricultural practices.

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APPENDICES

APPENDIX A

SOIL COLUMN LEACHING EXPERIMENTAL SETUP

APPENDIX B

ASSESSMENT OF AGROCHEMICAL USAGE IN THE UPPER EAST REGION, GHANA

Personal information of the respondent

Village: ………. District: …………... Date: ………Questionnaire no: ……

a) BACKGROUND

1) What is your gender?

☐ Male (1)

☐ Female (2)

2) What is your age?

…………………

3) What is your ethnic affiliation?

……...............................

4) What is your job or profession?

……………………………

5) What is your religious belief?

☐ follower of Christianity (1)

☐ Follower of Islam (2)

☐ Traditionalist (3)

☐ Other (specify) ……………...

6) What is your level of formal education?

☐ No formal education

☐ Primary education

☐ Secondary Education

☐ Academic Degree

☐ Other (Specify)……….

7) Within the family, what is your position?

☐ Father (1)

☐ Mother (2)

☐ Daughter (3)

☐ Son (4)

☐ Other (Specify) ……………

8) What constitutes the primary economic activity in your household?

☐ Farming (1)

☐ Day worker (2)

☐ Small business (3)

☐ Other (Specify) ……………

9) In your household, how many people are there? ………………………

10) Below 18 years old, how many individuals are there in the household?.................

11) Specify the approximate size of your farm …………………………….

12) Which crops from the following list do you cultivate for personal consumption as well as for selling?

Tick (√)		Crops	Tick (√)		Crops
For personal use	On sale		For personal use	On sale	
		Beans			Cowpea
		Cabbage			Cucumber
		Carrot			Maize
		Cassava			Mangoes
		Green pepper			Millets
		Carrot			Oranges
		Cocoyam			Palm wine
		Garden eggs			Plantain
		Green pepper			Rice
		Melon			Sugarcane
		Okra			Sweet potatoes
		Onion			Others:
		Tomatoes			……………………
		Yam			……………………

b) **PESTICIDE KNOWLEDGE**

13) Can you list the names of the pesticides you are familiar with

……………………….............................?

………………………………………….

14) List the forbidden pesticides you are acquainted with

………………………….................

…………………………………..

15) Do pesticides have the potential to induce adverse health effects?

- [ ] Yes (2)
- [ ] No (1)
- [ ] I have no knowledge (1)

16) Is the health impact the same for all pesticides?

- [ ] Yes (2)
- [ ] No (1)
- [ ] I have no knowledge (1)

17) Is the use of pesticides hazardous?

- [ ] Yes (2)
- [ ] No (1)
- [ ] I have no knowledge (1)

18) Is it possible for pesticides to enter the body through inhaling?

- [ ] Yes (2)
- [ ] No (1)
- [ ] I have no knowledge (1)

19) Is it possible for pesticides to get into the body through through the skin?

- [ ] Yes (2)
- [ ] No (1)
- [ ] I have no knowledge (1)

20) Is it possible for pesticides to get into the body through the mouth?

- [ ] Yes (2)
- [ ] No (1)
- [ ] I have no knowledge (1)

21) Is it possible for pesticide residues to remain in the air?

- [ ] Yes (2)
- [ ] No (1)
- [ ] I have no knowledge (1)

22) Is it possible for soil to retain residues of pesticides?

- [ ] Yes (2)
- [ ] No (1)
- [ ] I have no knowledge (1)

23) Is it possible to detect pesticide residues in groundwater?

- [ ] Yes (2)
- [ ] No (1)
- [ ] I have no knowledge (1)

24) Is it possible to identify pesticide residues in fruits?

- [ ] Yes (2)
- [ ] No (1)
- [ ] I have no knowledge (1)

25) Is it possible to detect pesticide residues on vegetables?

- [ ] Yes (2)
- [ ] No (1)
- [ ] I have no knowledge (1)

26) Are manufacturer notifications something you read?

- [ ] Yes (2)
- [ ] No (1)
- [ ] I have no knowledge (1)

27) Do you respect manufacturer notifications?

- [ ] Yes (2)
- [ ] No (1)
- [ ] I have no knowledge (1)

(C) PESTICIDE USE

28) Have you had any experience with using pesticides?

☐ Yes, I am presently using them (go to no. 29)
☐ Yes, previously (go to no. 30)
☐ No (go to no. 33)

29) How many years of experience did you have with pesticide use?

☐ 1 – 2 years
☐ 4 – 6 years
☐ 7 – 10 years
☐ Over a decade

30) What is the reason for your use of pesticides?

☐ To safeguard crops from insects
☐ To enhance the growth of crops
☐ Due to the usage of pesticides by others
☐ I used pesticides based on the advice I received
☐ Other……………………….

31) Why did you stop using pesticides?

☐ Did not show good response (1)
☐ Scarcity availability of pesticides (2)
☐ High buying costs (3)
☐ Other (specify) ....

32) How do you obtain or purchase the pesticides you use?

☐ In town, there are shops that sell agrochemicals (1)
☐ Agrochemical shops in the village (2)
☐ Officers involved in extension services (3)
☐ General shops (4)
☐ Cooperative societies (5)
☐ Other (specify) …………

33) Specify the insecticides, fungicides, and herbicides you use if you currently employ pesticides (answered "Yes" on question 28)

Category of pesticides	**Crops treated with pesticides**	**Season of the year**	**Quantity for each application per unit area.**	**Timing of application (Final spraying before harvest or post-harvest)**	**Methods of application, i.e. knapsack sprayers**
Fungicides:					
Herbicides:					
Insecticides:					

34) On your farm, what are the common crop pests that you encounter?
   i. ……………………………………………
   ii. …………………………………………..
   iii. …………………………………………..
   iv. ………………………………………….
   v. ………………………………………….

35) On your farm, what are the prevalent crop diseases that you encounter?
   i. ………………………………..
   ii. ………………………………..
   iii. ………………………………..
   iv. ……………………………….

36) How do you determine the timing for the application of pesticides on your farm?

☐ Existence of pests (1)

☐ Level of pest infestation (2)

☐ Timing of planting (3)

☐ Following scheduled spraying on the calendar (4)

☐ On economic thresholds (5)

☐ Others (specify) ………………………….

37) How did you come by the knowledge regarding the methods and rates of applying pesticides?

☐ Agrochemical shops (1)

☐ Extension officers (2)

☐ The labels found on pesticide packaging (3)

☐ Colleague farmers (4)

☐ Personal experience (5)

38) What is your method for diluting or blending the pesticide prior to applying it?

☐ Mix more than one types of pesticides with water in one container (1)

☐ Mix one type of pesticide with water in a container (2)

☐ Depending with instructions on the label (3)

☐ I have no knowledge (4)

D) ATTITUDES TOWARDS PESTICIDE USE

What is your level of agreement or disagreement with the following statements?

39) Adequate understanding is essential when employing pesticides.

☐ Completely agree (5)

☐ Agree (4)

☐ Hold a neutral position (3)

☐ Disagree (2)

☐ Completely disagree (1)

40) Minimal health risks are associated with the use of pesticides.

☐ Completely agree (5)

☐ Agree (4)

☐ Hold a neutral position (3)

☐ Disagree (2)

☐ Completely disagree (1)

41) Pesticides should be used with precautions.

☐ Completely agree (5)

☐ Agree (4)

- [ ] Hold a neutral position (3)
- [ ] Disagree (2)
- [ ] Completely disagree (1)

42) Securing a good crop is reliant on the importance of using pesticides.

- [ ] Completely agree (5)
- [ ] Agree (4)
- [ ] Hold a neutral position (3)
- [ ] Disagree (2)
- [ ] Completely disagree (1)

43) Restrictions should be imposed on the use of pesticides.

- [ ] Completely agree (5)
- [ ] Agree (4)
- [ ] Hold a neutral position (3)
- [ ] Disagree (2)
- [ ] Completely disagree (1)

E) PROTECTIVE MEASURES

44) In the past three months, did you engage in pesticide application?...

a) During the application, did you use gloves?

☐ Yes ☐ No

b) Did you use protective goggles during the application?

☐ Yes ☐ No

c) During the application, did you have anything covering your head?

☐ Yes ☐ No

d) During the application, did you use an oral/nose mask??

☐ Yes ☐ No

e) During the application, did you use specialized boots?

☐ Yes ☐ No

f) During the application, did you wear an overall?

☐ Yes ☐ No

45) Have you employed protective gear while handling pesticides, such as during mixing or spraying?

- [ ] Yes (go to no.40)
- [ ] No (go to no.41)

46) If you responded yes, please specify the protective gear you have utilised

…………………………………………………………

47) Do you believe that the utilisation of pesticides is on the rise, remains steady, or is decreasing, in your opinion?

☐ On the rise (3)

☐ Constant (2)

☐ Declining (1)

48) What, in your view, are the factors contributing to the rise, constancy, or decline?

a) On the rise

………………………………………………

………………………………………………

……………………………………………....

b) Declining

..……………………………………………

……………………………………………..

……………………………………………..

……………………………………………..

c) Constant

……………………………………………..

……………………………………………..

……………………………………………..

49) In what location do you keep the pesticides?

☐ Agrochemical store (1)

☐ Housing for animals (2)

☐ Storage space (3)

☐ Living residence (4)

☐ Kitchen (5)

☐ Bush (6)

☐ Lavatory (7)

☐ Farm (8)

☐ Sleeping room (9)

☐ Bathroom

50) What is the location where you discard empty pesticide containers?

☐ Sell to others (1)

- ☐ Repurpose or offer to others (2)
- ☐ Dispose of on the farm (3)
- ☐ Bury in the soil on the farm (4)
- ☐ Burn on the farm (5)
- ☐ Store it in the storage room (6)
- ☐ Gather them together in a single location (7)

51) Where do you discard leftover pesticides after completing the application?

- ☐ At the farm (1)
- ☐ Dispose in rivers, lakes, or irrigation channels (2)
- ☐ Bury in the soil on the farm (3)
- ☐ No leftover remains (4)
- ☐ Keep for later use (5)

52) Where do you clean the sprayers post-pesticide application?

- ☐ In rivers, lakes or irrigation canal (1)
- ☐ At home, using taps or water from a bucket (2)
- ☐ I refrain from washing (3)
- ☐ Clean using a piece of cloth or paper and discard it (4)
- ☐ Farm (5)
- ☐ Bush (6)

53) How much time elapses between the last pesticide application and the sale of crops?

- ☐ I sell immediately after applying pesticides (1)
- ☐ 1-2days (2)
- ☐ 3 - 6 days (3)
- ☐ A period of seven days (4)
- ☐ Beyond a week (5)
- ☐ In accordance with the guidelines provided by the manufacturer (6)

Others (specify) ....

54) Do you consume the crops treated with pesticides as part of your family's food?

- ☐ Yes (2)
- ☐ No (1)

55) Following the application of pesticides to crops, have you ever encountered

a. headache?

☐ Yes ☐ No

b. Feelings of burning in the eyes or face?

☐ Yes ☐ No

c. weakness?

☐ Yes ☐ No

d. fever?

☐ Yes ☐ No

e. Excessive tearing of the eyes?

☐ Yes ☐ No

f. skin rash?

☐ Yes ☐ No

g. skin irritation?

☐ Yes ☐ No

h. dizziness?

☐ Yes ☐ No

i. Discomfort in the chest?

☐ Yes ☐ No

j. forgetfulness?

☐ Yes ☐ No

k. vomiting?

☐ Yes ☐ No

l. diarrhoea?

☐ Yes ☐ No

☐ Other (specify) …………...

Thank you for your Cooperation