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SUSTAINABLE COCOA INTENSIFICATION PRACTICES AND THEIR EFFECTS ON YIELD, INCOME AND HOUSEHOLD FOOD SECURITY IN GHANA

BY

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THIS THESIS IS SUBMITTED TO THE UNIVERSITY OF GHANA, LEGON IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF PHD IN APPLIED AGRICULTURAL ECONOMICS AND POLICY DEGREE

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DECLARATION

I, COLLINS EBENEZER APPIAH, the author of this dissertation titled "**ADOPTION OF SUSTAINABLE COCOA INTENSIFICATION PRACTICES AND THEIR EFFECTS ON YIELD, INCOME, AND HOUSEHOLD FOOD SECURITY IN GHANA**", do hereby declare that except for the duly acknowledged references, of which a plagiarism report is attached as Appendix 4, this dissertation is my original research. It has not been submitted, either wholly or in part, for any degree or diploma at this university or elsewhere.

..... 30/04/2026.....

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This dissertation has been submitted for examination with our approval as supervisors.

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Dr. Catherine Larochelle (Co-Supervisor). Date

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DEDICATION

I dedicate this work to all who persevere and never give up.

Dominus Illuminatio Mea



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My greatest appreciation goes to YHWH, my rescuing Knight, for His steadfast love and everlasting sustenance.

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ABSTRACT

Ghana's cocoa sector is constrained by low yields of 250–500 kg/ha, which are far below the potential of 1,891–3,500 kg/ha, leaving nearly 30% of farmers in extreme poverty. Although intensification through regimented farm management is widely promoted to enhance productivity, delayed and inadequate (subsidised) input distribution, along with high input costs, often hinders farmers' adherence to recommended agronomic practices. Moreover, excessive use of synthetic agrochemicals poses significant ecological risks. In the absence of affordable alternatives, many farmers often expand areas under cocoa cultivation, a strategy that drives deforestation and has drawn increasing international concern. Sustainable cocoa intensification, which enhances productivity while safeguarding ecological integrity, offers a promising solution, yet remains under-prioritised in Ghana's cocoa sector. This neglect is largely due to the dearth of empirical evidence on the potential synergies of integrated or bundled adoption to guide policies. Furthermore, little is known about the broader implications for household welfare, particularly in relation to food security. This study addressed these gaps by analysing the level and determinants of adoption of multiple sustainable cocoa intensification practices (SCIPs) in Ghana, and estimating their effects on yield, farm income and food security. It also identified incentives that could scale adoption of SCIPs. A four-stage sampling design was employed to survey 739 cocoa-farming households across 20 communities in six of Ghana's principal cocoa-producing regions. Using data for the 2022/2023 season, composite indices of intensification and sustainability were developed to classify cocoa plots into four typologies: (1) Neither Sustainable nor Intensified (NSNI), (2) Sustainable but not Intensified (SNI), (3) Intensified but not Sustainable (INS), and (4) Sustainably Intensified (SI). SCIPs adoption patterns and their determinants were analysed using a Multivariate Probit model, while a Multinomial Logit model was used to examine the predictors of the four typologies. The yield, farm income and food security effects of the adoption of SCIPs were estimated using a Multinomial Endogenous Switching Regression (MESR) model. The findings revealed low adoption of SCIPs, with 58.25% of the plots classified as NSNI and only 6.9% as SI. While some practices, including planting improved cocoa varieties, intercropping, and shade tree maintenance were relatively common, the adoption of organic fertilisers, pruning, hand pollination, mulching, organic pesticides, use of personal protective equipment (PPE), and cocoa tree renovation, were low. The adoption of SCIPs was positively influenced by plot ownership, topography, perceived soil fertility, training attendance, positive perception of extension services, credit access, input subsidies, and farm assets holdings. In contrast, walking distance, farming experience, drought risk, and location of plot within the transition zone of Ghana were significant barriers to adoption. The adoption of SCIPs significantly improved cocoa yield by 34.0% (223.86 kg/ha), farm income by 34.12% (GHS 1,325.49/ha), and household food security [with reductions in the Household Food Insecurity Access Scale (–63.46%) and Reduced Coping Strategies Index (–62.87%), alongside a 50.35% rise in the Household Food Consumption Score]. However, households faced a short-term decline in food security during the transition to SCIP adoption, highlighting the need for economic incentives. A fair and equitable producer price, payments for ecosystem services, secured tree tenure rights that will enable the legal sale of shade tree products, sustainability-based price premiums paid at the farmgate, and strengthened technical support through contextualised training emerged as critical incentives to foster inclusive and widespread adoption. Policies must prioritise the promotion of SCIPs as a proven strategy to enhance cocoa productivity, farm income, and household food security.

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LIST OF ACRONYMS

Afrint	Intensification of food crops agriculture in sub-Saharan Africa
AHP	Analytic Hierarchy Process
ATT	Average Treatment Effects on the Treated
ATU	Average Treatment Effects on the Untreated
CA	Conjoint Analysis
CHED	Cocoa Health and Extension Division
COCOBOD	Ghana Cocoa Board
CODAPEC	Cocoa Diseases and Pest Control Programme
CRIG	Cocoa Research Institute of Ghana
CSSVD	Cocoa Swollen Shoot Virus Disease
DEA	Data Envelopment Analysis
EPA	Environmental Protection Agency
EU	European Union
EW	Equal Weighting
FA	Factor Analysis
FAO	Food and Agriculture Organisation
HFCS	Household Food Consumption Score
HFIAS	Household Food Insecurity Access Scale
Hi-Tech	High Technology
HLPE	High Level Panel of Experts
IIA	Independence of Irrelevant Alternatives
INS	Intensified not sustainable

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IV	Instrumental Variables
JHS	Junior High School
JSS	Junior Secondary School
LBCs	Licensed Buying Companies
MESR	Multinomial Endogenous Switching Regression
MLE	Maximum Likelihood Estimation
MoFA	Ministry of Food and Agriculture
MVT	Multi-Valued Treatment Effects
NCRP	National Cocoa Rehabilitation Programme
NGO	Non-Governmental Organisation
NSNI	Neither sustainable nor intensified
OLS	Ordinary Least Squares
PCA	Principal Component Analysis
PEPs	Productivity Enhancement Programmes
PES	Payments for Ecosystem Services
PPE	Personal Protective Equipment
rCSI	reduced Coping Strategies Index
RISING	Research in Sustainable Intensification for the Next Generation
RUT	Random Utility Theory
SAFA	Sustainability Assessment of Food and Agriculture Systems
SCIPs	Sustainable Cocoa Intensification Practices
SES	Social-Ecological Systems
SI	Sustainable Intensification/ Sustainably intensified

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SIAF	Sustainable Intensification Assessment Framework
SIPs	Sustainable Intensification Practices
SNI	Sustainable not intensified
TAM	Technology Acceptance Model
TNA	Thematic Network Analysis
UCM	Unobserved Components Models
US	United States of America
VIF	Variance Inflation Factor



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CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

1.1.1 Cocoa productivity in Ghana

Cocoa productivity in Ghana remains low, with smallholder cocoa farms reporting some of the world's lowest yields – averaging between 250 and 500 kg/ha (Asante et al., 2022; Abdulai et al., 2020; Aneani & Ofori-Frimpong, 2013; Dormon et al., 2007). In contrast, findings from experimental trials suggest potential yields ranging from 1,891 to 3,500 kg/ha, indicating to a substantial yield gap (Asante et al., 2022; Abdulai et al., 2020; Ofori-Frimpong et al., 2006; Ahenkorah et al., 1987 & 1974). Compared with the global average cocoa yield of 800 kg/ha and those of key cocoa-producing countries such as Côte d'Ivoire (600 kg/ha), Indonesia (700 kg/ha), and Malaysia (1,800 kg/ha), Ghana's cocoa productivity lags behind (Suh & Molua, 2022; van Vliet et al., 2021; Fahmid et al., 2018; Daymond et al., 2017; Wessel & Quist-Wessel, 2015). Given that cocoa output is the primary source of income for cocoa-farming households, low productivity directly contributes to rural poverty and food insecurity in Ghana (Adams & Carodenuto, 2023; Dompreh et al., 2021). For example, studies indicate that approximately 30% of cocoa farmers live below the World Bank's extreme poverty threshold of US$1.90/day (van Vliet et al., 2021; Vigneri & Kolavalli, 2018), while nearly 90% of them do not earn a living income (Fountain & Hütz-Adams, 2022; van Vliet et al., 2021).

The causes of the low cocoa productivity in Ghana are multifaceted. Poor soil fertility, inadequate pest and disease management, and ineffective weed control are key contributors (Kongor et al., 2024; Amponsah-Doku et al., 2022; Asante et al., 2022; Abdulai et al., 2020). Pests such as capsids or mirids (*Distantiella theobromae* and *Sahlbergella singularis*) and diseases like black pod, caused by *Phytophthora megakarya* and

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Phytophthora palmivora, are known to result in annual pod losses of 25% and 45%, respectively (Miyittah et al., 2022a&b; Sarfo et al., 2018; Akrofi et al., 2015). In addition, the Cocoa Swollen Shoot Virus Disease (CSSVD), transmitted by mealybugs (*Planococcus spp.* and *Stictococcus spp.*), can reduce yields by up to 70% (Kongor et al., 2017; Ameyaw et al., 2014). Furthermore, 23% of cocoa farms in Ghana have trees older than the optimal productive age of 30 years, many of which are infested with mosses and mistletoes (*Tapinanthus bangwensis*) (Kongor et al., 2017). The increasing impacts of climate change have further intensified these constraints (Asante et al., 2021; Abdulai et al., 2018; Läderach et al., 2013).

To address these constraints, farmers are encouraged to follow recommended farm management protocols. These include the application of 375 kg of fertiliser per hectare, four insecticide sprays per season (August–December), and six to nine fungicide sprays per season (March/April onwards), to align treatments with peak pest and disease activity (Danso-Abbeam & Baiyegunhi, 2018; Kolavalli & Vigneri, 2017). However, high input costs remain a major barrier to adopting these practices (Danso-Abbeam & Baiyegunhi, 2017; Kongor et al., 2017). For instance, the average seasonal spending on agrochemicals per acre was found to be significantly higher in Ghana (US$45) compared to Côte d'Ivoire (US$14) (Danso-Abbeam et al., 2014; Nkamleu et al., 2007).

1.1.2 Intensification strategies by Government of Ghana to improve cocoa productivity

Intensification through compliance with recommended farm management protocols has been widely promoted to enhance the productivity of cocoa plots in Ghana. Conventional cocoa intensification is the process of increasing outputs through increased use of input like high-yielding varieties, chemical fertilisers, pesticides, irrigation, and advanced pollination

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techniques on existing farmland (Sadhu et al., 2020; Vanlauwe & Dobermann, 2020; Petersen & Snapp, 2015; Mueller et al., 2012; Matson et al., 1997). In Ghana, the government has promoted intensification through the Productivity Enhancement Programmes (PEPs) of the Ghana Cocoa Board (COCOBOD), including the Cocoa Diseases and Pest Control Programme (CODAPEC), the Cocoa High Technology Programme (Hi-Tech), and the National Cocoa Rehabilitation Programme (NCRP). These initiatives aim to boost yields by using subsidised agro-inputs, improved cocoa varieties, and labour services (Acheampong et al., 2023; Danso-Abbeam & Baiyegunhi, 2017; Baffoe-Asare et al., 2013).

However, the quantity and frequency of subsidised inputs distributed through these programmes remain inadequate to achieve optimal productivity (Boateng et al., 2023; Ali et al., 2018; Danso-Abbeam et al., 2014; Abankwah et al., 2010). Moreover, inefficiencies in input distribution often result in delayed access, compelling farmers to supplement with expensive market-based purchases (Acheampong et al., 2023; Boateng et al., 2023; Attipoe et al., 2021). For example, cocoa farmers in Ghana reported sharp increases in per-hectare input costs between 2013 and 2019, when fertilisers rose from US$556 to US$1,254, pesticides from US$267 to US$745, and herbicides from US$230 to US$481 (Sadhu et al., 2020).

Beyond the economic burden, the frequent application of pesticides and herbicides poses health risks to farmers and threatens biodiversity (Ansah et al., 2023; Miyittah et al., 2022a & b; Bhandari et al., 2018). These chemicals negatively affect beneficial organisms such as natural pollinators and pest predators, undermining ecological balance and long-term farm sustainability (Miyittah et al., 2022b; Tetteh et al., 2018; Tothmihaly et al., 2019; Dormon et al., 2007).

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1.1.3 Extensification as a solution at the community level results in deforestation

Faced with high input costs, many resource-poor cocoa farmers in Ghana increasingly adopt extensification, which is the expansion of land under cocoa cultivation, as a coping strategy to offset declining yields (Kalischek et al., 2023; Parra-Paitan & Verburg, 2022). However, this practice often comes at an environmental cost, particularly through the conversion of forest reserves to cocoa farms, thereby accelerating deforestation (Kalischek et al., 2023; Ashiagbor et al., 2022). In response to these environmental concerns, the European Union (EU) has proposed legislation mandating strict sustainability standards for cocoa imports, including a ban on cocoa products linked to deforestation (EU, 2021). Non-compliance with these requirements poses significant risks to Ghana's cocoa economy, which supports the livelihoods of approximately four million people (Bangmarigu & Qineti, 2018). In particular, the income and food security of an estimated 800,000 rural households, whose primary source of livelihood is cocoa farming, could be severely affected (Wongnaa et al., 2021; Dompreh et al., 2021; van Vliet et al., 2021).

1.1.4 Sustainable intensification of cocoa production as a long-term solution

Sustainable intensification is advocated as a long-term strategy to enhance cocoa yields whilst mitigating the adverse consequences of both extensification and the excessive reliance on agrochemicals (Ajibade et al., 2023; Jain et al., 2023; Smith et al., 2017; Pretty & Bharucha, 2014). It has been defined as the application of management, planning, and technological strategies that enhance agricultural productivity whilst minimising adverse environmental effects (Helfenstein et al., 2020; Rockström et al., 2017; Struik et al., 2017; Pretty, 2008). Sustainable cocoa intensification has also been defined as the integration of a suite of management practices and techniques designed to increase the quantity and quality of cocoa beans produced per unit area in a cost-effective manner, to enhance

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profitability and improve farmers' livelihoods, and to safeguard the environment, conserve biodiversity and vital agroecological services, and ensure the long-term viability of cocoa cultivation for future generations (Kongor et al., 2024; Ajibade et al., 2023; Garnett et al., 2013). Sustainable cocoa intensification practices (SCIPs) comprise a combination of agricultural intensification measures, including improved cocoa varieties, hand pollination, inorganic fertilisers, and pesticides, alongside sustainability strategies organised across three main dimensions of sustainability: economic, environmental and social dimensions (Sadhu et al., 2020; Helfenstein et al., 2020; Vanlauwe & Dobermann, 2020; Matson et al., 1997). Within the economic dimension, practices include maintaining optimal tree age, rehabilitating and renovating ageing and moribund farms, enhancing post-harvest handling (through pulp pre-conditioning, fermentation, and drying), and improving input-use efficiency (Kongor et al., 2024; Struik et al., 2014). The environmental dimension encompasses integrated pest, disease and soil fertility management strategies that are locally available and affordable, including the planting of multipurpose shade trees, and water management strategies such as mulching and water harvesting ecologically (Kongor et al., 2024; Abdulai et al., 2020; Vanlauwe & Dobermann, 2020). Meanwhile, the social dimension focuses on strengthening farmer associations and cooperatives, promoting alternative livelihoods like intercropping and livestock rearing, ensuring compliance with child labour regulations, and promoting the safe handling of agrochemicals (Kongor et al., 2024; Ajibade et al., 2023; Mockshell and Kamanda, 2018).

1.2 Conceptual Framework for the Adoption of Sustainable Cocoa Intensification Practices (SCIPs)

Cocoa productivity in Ghana is severely impeded by soil degradation, particularly declining fertility resulting from suboptimal soil management practices (Amponsah-Doku et al.,

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2022; Amfo et al., 2021; Abdulai et al., 2020; Lahive et al., 2019). Additionally, ineffective management of pests, diseases, and weeds, which is largely driven by high labour costs and limited access to subsidised inputs, further constrains yields (Asante et al., 2022; Dormon et al., 2007, 2004). These challenges are compounded by inefficiencies in extension service delivery (Lawson et al., 2020) and ageing cocoa tree stocks in cocoa orchards, exacerbated by inadequate rehabilitation and renovation efforts (Abdulai et al., 2020; Asare et al., 2018; Streck et al., 2017) (see Figure 1.1). Also, unfavourable land tenure arrangements, together with the encroachment of unregulated mining activities, continue to diminish the availability of arable land. Consequently, many farmers are driven towards extensification, characterised by expanding cocoa cultivation into protected forest zones, thereby accelerating deforestation (Figure 1.1). Furthermore, climate projections suggest that without effective interventions, major cocoa-growing regions in West Africa could become unsuitable for cocoa cultivation by 2050 (Parra-Paitan et al., 2024; Asante et al., 2021; Bunn et al., 2019). Persistently low cocoa yields translate into diminished farm incomes, with deleterious implications for household food security (Figure 1.1).

Nevertheless, emerging evidence indicates that the successful adoption of SCIPs holds significant potential addressing these constraints and improving productivity (Kongor et al., 2024; Bandanaa et al., 2021; Helfenstein et al., 2020). A range of plot and household-level characteristics, such as the nature of plot ownership, plot topography, distance between residence and plot, farming experience, and access to extension services, subsidised inputs, and credit, may significantly influence the likelihood of adopting SCIPs (Figure 1.1). Furthermore, both intrinsic incentives, such as a positive perception of SCIPs, and extrinsic incentives, including an equitable cocoa producer price and price premiums, can encourage farmers to adopt these practices (Piñeiro et al., 2020; Jambo et al., 2019) (Figure 1.1).

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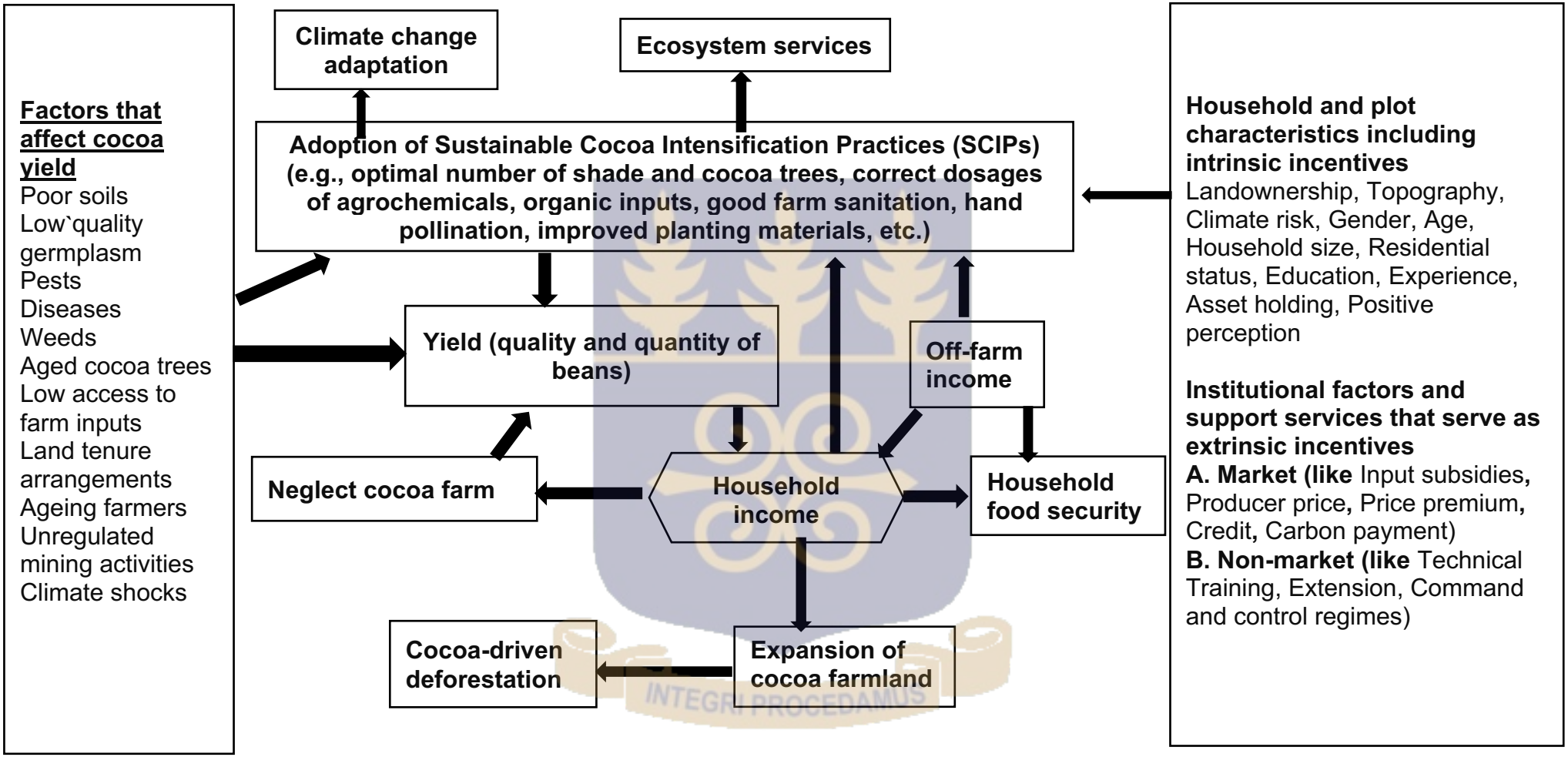


Figure 1.1: Conceptual framework depicting the adoption of SCIPs and its effects on yield, income and household food security

Source: Author's conceptualisation (2024)

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Consequently, farmers who successfully adopt SCIPs are likely to experience higher yields, which, in turn, would lead to increased household income and enhanced food security, particularly when coupled with an acceptable cocoa producer price (see Figure 1.1). Moreover, higher incomes enable farmers to reinvest in their farms, fostering long-term productivity, generating ecosystem services, and contributing to climate change mitigation (Figure 1.1).

1.3 Problem Statement

Although sustainable intensification has been extensively studied in the context of staple crops such as rice and maize, primarily because of their direct implications for food security (Nyarindo et al., 2024; Adams et al., 2024a; Kotu et al., 2022; Kotu et al., 2017; Ortega et al., 2016; Kassie et al., 2015), its application within the cocoa sector remains significantly underexplored (Parra-Paitan et al., 2024). Limited empirical attention has been paid to the adoption dynamics of SCIPs, creating a critical knowledge gap. In the absence of robust, context-specific data on the adoption level of SCIPs and their outcomes, policymakers and stakeholders are left without the empirical foundations necessary to craft targeted and effective sustainability interventions.

First, existing research has largely adopted a fragmented approach, focusing predominantly on individual practices such as shade tree planting or organic fertiliser use, and their isolated effects on yield (Gockowski et al., 2013; Ruf et al., 2006), farm income (Bandanaa et al., 2021; Boeckx et al., 2020), and ecosystem services (Heidenreich et al., 2022; Bennett et al., 2021; Boeckx et al., 2020). This piecemeal focus overlooks the compounded benefits of a bundled, systems-based adoption of SCIPs. Also, the narrow scope of the conceptualisations of Sustainable Cocoa Intensification by existing studies has been highlighted by Helfenstein et al. (2020). For instance, Helfenstein et al. (2020) suggested

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that future studies should expand the scope of the concept to encompass the multiple dimensions of both agricultural intensification and sustainability. Moreover, the three interdependent pillars of sustainability (i.e., the economic, environmental, and social dimensions) are often insufficiently captured, thereby limiting a holistic understanding of sustainable intensification in the cocoa value chain. A significant limitation of the current literature is the tendency to overlook the social dimension of sustainability (Helfenstein et al., 2020; Mahon et al., 2018; Smith et al., 2017; Mouratiadou et al., 2021; Robling et al., 2023). This suggests that potential impacts on farmers' well-being and livelihoods are frequently overlooked. Parra-Paitan et al. (2024) and Toledo-Hernández et al. (2023) recommended that future research should explore a broader range of innovative strategies to support sustainable cocoa production on a global scale.

Second, there is a dearth of empirical evidence on the actual levels of sustainable intensification adoption at the cocoa plot level in Ghana. This data vacuum restricts the formulation of informed strategies to address pressing concerns such as land degradation, declining yields, and the adverse effects of climate change. Moreover, the socio-economic, institutional, and agroecological factors shaping farmers' decisions to adopt SCIPs are poorly understood. Without such insight, the development of inclusive and context-sensitive policies to promote widespread adoption remains elusive. Thus, although some cocoa farmers adopt sustainable practices out of necessity or intuition, these efforts are often uncoordinated and lack strategic coherence. Understanding the spectrum of adoption scenarios, as well as the determinants underpinning them, is imperative for optimising policy design and maximising the welfare impacts of SCIPs. Third, although SCIPs offer long-term agronomic, ecological, and livelihood benefits, their adoption is frequently hindered by short-term trade-offs. For instance, conventional open-sun monocropping systems may yield higher immediate returns compared to agroforestry-based sustainable

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systems (Wainaina et al., 2021; Bandanaa et al., 2021; Tsiboe et al., 2018; Mahrizal et al., 2012). This phenomenon has been observed even under hand pollination (Toledo-Hernández et al., 2023). However, these gains are often short-lived because open-sun monocropping significantly shortens the productive lifespan of cocoa trees. In contrast, agroforestry-based sustainable systems, despite delivering lower short-term yields, are associated with extended tree productivity, as evidenced by studies showing that hybrid cocoa varieties can remain productive for up to 29 years under shade compared to only 18 years without it (Mahrizal et al., 2014; Obiri et al., 2007). Nevertheless, the immediate economic constraints faced by smallholder farmers, coupled with limited awareness of these long-term benefits, often lead to a preference for short-term gains. Consequently, unless SCIPs provide clear and tangible short-term benefits, or are accompanied by adequate incentive mechanisms to offset initial losses, adoption amongst resource-constrained farmers is unlikely to scale (Vanlauwe & Dobermann, 2020; Tsiboe et al., 2018; Mahrizal et al., 2012; Ruf et al., 2006). Despite this, very little research has focused on identifying effective incentives to promote widespread adoption of SCIPs. This remains a vital component of any strategy aimed at facilitating a transition from unsustainable to sustainable practices. In response to recent calls in the literature (e.g., Parra-Paitan et al., 2024; Piñeiro et al., 2020; Jambo et al., 2019), which emphasises the need to explore how intrinsic and extrinsic incentives interact with socio-economic and biophysical conditions to influence adoption, this study seeks to generate empirical evidence to guide the formulation of data-driven and context-specific interventions.

Finally, although the productivity benefits of SCIPs have received some attention, a conspicuous gap remains in the literature regarding their broader welfare implications. In particular, limited research has examined the impact of joint or portfolio adoption of SCIPs on cocoa yield, farm income, and key household welfare indicators such as food security

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(Kim et al., 2019; Nkomoki et al., 2018). This gap hampers our understanding of the transformative potential of SCIPs in closing the cocoa yield gap while simultaneously enhancing household resilience and food security. Thus, there is a compelling need for research examining how the integrated adoption of SCIPs influences agronomic, economic, and food security outcomes among cocoa-farming households in Ghana.

From the foregoing, pertinent questions arise that this study proposes to answer. These questions are as follows:

1. Which sustainable cocoa intensification practices are being adopted by farmers in Ghana and what is the level of adoption of sustainable cocoa intensification practices on cocoa plots in Ghana?
2. Which factors influence farmers' choice of sustainable cocoa intensification practices in Ghana?
3. What is the effect of adopting sustainable cocoa intensification practices on the yield, farm income and food security of cocoa farming households in Ghana?
4. What incentives could promote the adoption of sustainable cocoa intensification practices among cocoa farmers in Ghana?

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1.4 Objectives of the Study

This study aims to assess farmers' adoption of sustainable cocoa intensification practices (SCIPs) and evaluate their effects on the yield, farm income, and food security of farming households in Ghana. The specific objectives of this study are to:

1. Identify the sustainable cocoa intensification practices adopted by farmers in Ghana and evaluate the level of adoption of these practices on cocoa plots.
2. Examine the factors that influence the adoption of the multiple sustainable cocoa intensification practices by farmers in Ghana.

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3. Estimate the effects of adopting multiple sustainable cocoa intensification practices on yield, farm income, and food security among cocoa farming households in Ghana.
4. Identify incentives that could encourage cocoa farmers to transition to adopting sustainable cocoa intensification practices in Ghana.

1.5 Hypotheses of the Study

Hypothesis 1

H_0: Household, farm-level and institutional characteristics have no effect on the adoption of multiple sustainable intensification practices in Ghana.

Hypothesis 2

H_0: The adoption of multiple sustainable intensification practices has no effect on the yield, farm income, or household food security of cocoa farmers.

1.6 Significance of the Study

This study makes important empirical, methodological, and policy contributions. First, by analysing SCIPs and their adoption levels, it provides critical insights into how farmers respond to sustainability challenges in cocoa systems. Unlike studies that examine practices in isolation, this research adopts a multidimensional, systems-based approach, offering a more realistic understanding of how practice combinations are implemented and interact to achieve productivity gains without adverse environmental trade-offs. The findings are directly relevant for policymakers, extension services, and development organisations promoting scalable, context-specific interventions. Second, the study advances understanding of the socioeconomic, institutional, and agroecological drivers of adopting multiple SCIPs. By examining these determinants alongside complementarities and trade-

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offs among practices, it generates nuanced evidence to inform targeted policies, extension strategies, and incentive design, particularly for COCOBOD, NGOs, and private sector actors involved in cocoa sustainability initiatives. Third, the study addresses a key gap by evaluating the joint effects of multiple SCIPs on cocoa yield, farm income, and household food security. Moving beyond single-practice impact assessments, it employs a multidimensional farm-level indicator framework and models alternative sustainable intensification pathways as a multinomial treatment regime. These findings are particularly important for farmers, development practitioners, and policymakers, as they demonstrate whether and how sustainable practices translate into tangible livelihood benefits. Particularly, farmers will benefit from insights into effective practice combinations and their potential livelihood outcomes.

Fourth, adoption of sustainable practices often entails short-term costs and risks, which can discourage farmers despite potential long-term benefits. By highlighting effective incentive structures, such as access to credit, extension services, input support, and market-based rewards, the study offers actionable recommendations for designing enabling environments that facilitate sustainable transitions. This is especially relevant for policymakers, certification bodies, and private sector actors engaged in sustainable sourcing and supply chain management to support farmer compliance. Methodologically, the study contributes by developing and applying a multidimensional farm-level indicator framework grounded in the Sustainable Intensification Assessment Framework (SIAF) and the Sustainability Assessment of Food and Agriculture Systems (SAFA). This represents one of the first empirical applications of such an integrated approach in a perennial crop system. The construction of farm typologies to identify distinct sustainable intensification pathways further provides a novel lens for capturing heterogeneity and informing targeted interventions. Thus, the study contributes to academic discourse by advancing

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methodological approaches and empirical understanding of sustainable intensification in perennial crop systems.

1.7 Organisation of the Study

This thesis is structured into six chapters. Chapter One serves as the introduction, providing the study's background, conceptual framework, problem statement, objectives, hypotheses, and significance. Chapter Two offers a comprehensive overview of cocoa production in Ghana. Chapter Three critically reviews the literature, including definitions of key concepts relevant to the research objectives, a review of methodological approaches, empirical findings on the adoption of SCIPs, and identification of gaps in the literature that inform the study's objectives. Chapter Four outlines the theoretical framework that underpins the study together with the data collection and sampling procedures, as well as the model specifications for data analysis, aligned with the objectives of the study. The results and discussion are presented in Chapter Five. The final chapter provides a summary, conclusions, and recommendations derived from this study. This is followed by the references cited in the text and the appendices.

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CHAPTER TWO

AN OVERVIEW OF COCOA PRODUCTION IN GHANA

2.1 Introduction

This chapter, divided into three sections, presents an overview of cocoa production in Ghana. Section 2.2 describes the agroecological characteristics that support cocoa cultivation in Ghana. A brief review of the level of cocoa productivity and an overview of the factors that influence the productivity of cocoa farms in Ghana are presented in Section 2.3. Section 2.4 outlines the role of COCOBOD in the cocoa sector and provides an overview of the current Productivity Enhancement Programmes (PEPs) implemented by COCOBOD.

2.2 Agroecological Characteristics of Ghana that Promote Cocoa Production

Cocoa (*Theobroma cacao*) is an economically significant crop grown by approximately six million smallholder farmers across the tropics and subtropics of Africa and South America (Wilson et al., 2019; Kongor, 2018). Cocoa trees thrive in humid and warm climates (Wilson et al., 2019; Läderach et al., 2013). The plant requires annual rainfall between 1500 and 2000 mm, as well as optimal temperatures ranging from a mean minimum of 18–21°C to a mean maximum of 30–32°C (Asante et al., 2022; Wilson et al., 2019; Läderach et al., 2013). This is because cocoa plants require average daytime temperatures of 30 to 32.1°C for optimum photosynthesis, while pod development increases linearly from 20°C to 28°C (Balasimha et al., 1991).

In Ghana, these ideal conditions are found within three agroecological zones: evergreen rainforest, semi-deciduous forest, and forest/savanna transitional zones (COCOBOD, 2022). These zones cover nine regions: Ahafo, Bono, Bono East, and Oti in the

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forest/savanna transitional zone; parts of the Western North and Central, Ashanti, Eastern, and Volta regions in the semi-deciduous forest zone; and Western and parts of Western North regions in the evergreen rainforest zone (COCOBOD, 2022). The rainfall distribution in these regions is bimodal, with two wet and two dry seasons occurring annually. The main wet season is from April to June/July, while a minor wet season from September to November (Asante et al., 2022). The main dry season runs from December to February/March, and a shorter dry period lasts from July to August (Asante et al., 2022). This rainfall pattern, combined with the temperature ranges, is ideal for pod setting and development (Kosoe & Ahmed, 2022; Anim-Kwapong & Frimpong, 2008). The peaks in leaf flushing, flower production, and pod setting coincide with the main wet season (April to June/July) (Asante et al., 2022; Dzandu et al., 2021). Additionally, the minor dry season (July to August) aligns with the early or mid-stage of pod development. Pods take approximately five to six months to mature after pollination, with harvesting starting in October. Ghana has two harvesting seasons: *the major harvesting season*, which spans the minor wet season to the early part of the main dry season (i.e. October to January, peaking in November), and *the minor harvesting season*, which is characterised by a lower output and occurs from April/May to mid-September, peaking in April/ May.

Understanding these agroecological characteristics of Ghana is important for grasping the challenges and opportunities in enhancing cocoa productivity, which is discussed in section 2.3.

2.3 Cocoa Productivity in Ghana

2.3.1 Definition of cocoa productivity

Cocoa yield refers to the quantity of dried cocoa beans harvested and sold per unit area within a specific period and is typically expressed in metric tons per hectare. It serves as a

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direct measure of farm output, shaped by various factors, including tree age and health, agronomic practices, soil fertility, climatic conditions, and the adoption of advanced cultivation techniques. Despite the variations in bean quality in Ghana, farmgate pricing does not directly reflect these differences. Cocoa productivity, on the other hand, extends beyond mere output, focusing on the efficiency with which resources such as land, labour, and capital are utilised to achieve yield. While yield quantifies production volume, productivity assesses the balance between inputs and outputs. A farm that achieves a high yield may still demonstrate low productivity if excessive inputs such as labour, fertilisers, or pesticides are required. Conversely, a farm with a relatively lower yield can exhibit superior productivity if resources are efficiently allocated, maximising returns while minimising costs and the environmental impact.

2.3.2 Level of cocoa productivity in Ghana

Ghana is the second largest producer of cocoa beans in the world, after Côte d'Ivoire. Together, Ghana and Côte d'Ivoire supply over 50% of the cocoa beans on the global market (COCOBOD, 2022; Daymond et al., 2020 & 2017). This significant supply is mainly attributed to the area of cultivation and the expansion of cocoa farms rather than improvements in yield (Kalischek et al., 2023; Suh & Molua, 2022; Parra-Paitan & Verburg, 2022). For instance, the average reported yield per hectare of smallholder cocoa farms in Ghana, ranging from 250 to 500 kg/ha, is amongst the lowest in the world (Asante et al., 2021; Wessel & Quist-Wessel, 2015). Several studies have documented this low farm-level cocoa productivity in Ghana. For example, Kongor et al. (2018) reported a productivity of 250 kg/ha, whereas Dormon et al. (2007) found a productivity of 380 kg/ha. Abdulai et al. (2020), Aneani and Ofori-Frimpong (2013), and Ofori-Frimpong et al. (2006)

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reported values of approximately 400 kg/ha, whereas Fontaine and Huetz-Adams (2020) recorded 500 kg/ha.

Moreover, experimental-based yield estimates indicate that Ghana produces cocoa well below its potential. Studies by Abdulai et al. (2020) and Ofori-Frimpong et al. (2006) reported potential yields of 2125 kg/ha and 1891.3 kg/ha, respectively, while Appiah et al. (2000) estimated 3245.97 kg/ha. Furthermore, Ahenkorah et al. (1987) and (1974) reported potential yields of 2000 kg/ha and 3500 kg/ha, respectively. This yield gap highlights the underperformance of cocoa production in Ghana, particularly in smallholder farms. Asante et al. (2022) further reinforced this by estimating a mean absolute yield gap of 4577 kg/ha, corresponding to a relative yield gap of 86% for smallholder cocoa farms in Ghana.

2.3.3 Factors that influence cocoa productivity in Ghana

Use of improved planting materials (Hybrid cocoa cultivars)

Four main traditional cocoa varieties are cultivated in Ghana: *Amelonado* (also called *Forastero* or Tetteh Quarshie), *Amazonia, Criollo*, and *Trinitario* (Kongor et al., 2024; Afoakwa et al., 2011; Ofori-Frimpong et al., 2006; Adomako & Adu-Ampomah, 2003). While the *Criollo* variety is prized for its superior chocolate flavour, it is not widely grown in Ghana due to its vulnerability to pests and diseases (Ofori-Frimpong et al., 2006; Adomako & Adu-Ampomah, 2003). In contrast, the *Amazonia* and *Amelonado* (Tetteh Quarshie) varieties, which have a milder chocolate flavour, thrive under Ghana's agroecological conditions (Dzandu et al., 2021; Adomako & Adu-Ampomah, 2003). The *Trinitario* variety, a natural hybrid of *Amelonado* and *Criollo*, produces beans with a moderate flavour and is moderately resistant to pests and diseases (Ofori-Frimpong et al., 2006; Kongor, 2018).

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In addition to these traditional varieties, several hybrid cocoa varieties have been identified in Ghana, including Series II, Modified Series II, Inter Amazon, and clones of Criollo and Nacional (a variety native to Ecuador) (Obeng-Bio et al., 2022; Dzandu et al., 2021; Cilas et al., 2018; Ofori et al., 2015). These hybrid cocoa cultivars, developed through intensive breeding programmes by Cocoa Research Institute of Ghana (CRIG) under COCOBOD, offer higher yields in less time and have been bred for improved disease resistance under proper agronomic practices (Obeng-Bio et al., 2022; Dzandu et al., 2021; Ofori et al., 2015; Asare et al., 2010; Dormon et al., 2004). Research by Asante et al. (2022) and Abdulai et al. (2020) indicates that increasing the proportion of hybrid cocoa trees per hectare can lead to significant yield improvements on smallholder farms. Also, the adoption of hybrid cocoa materials has been associated with yield increases of up to 50% (Asare et al., 2010), making it a promising practice for enhancing productivity.

Age of cocoa trees

The yield of cocoa varies with tree age, conditional on factors such as site quality, germplasm, and farm management (Somarriba et al., 2021; Obiri et al. 2007). Although a cocoa tree can live over 100 years, its economic lifespan typically ranges from 30 to 40 years if not renovated/rehabilitated (Somarriba et al., 2021). A productive cocoa tree is defined as a healthy tree with green leaves, a stem, and branches that bear more than 20 cocoa pods annually (Bangmarigu and Qineti, 2018; Dormon et al., 2004), maintaining these characteristics for at least three years (Dormon et al., 2004). In Ghana, traditional cocoa farms can remain productive for 50–80 years, whereas the productive lifespan of hybrid varieties is 29 years with shade and 18 years without shade (Mahrizal et al. 2014; Obiri et al. 2007).

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Several studies have highlighted the decline of cocoa productivity as trees age. Gotsch and Burger (2001) found that age 15 was the peak productive stage for cocoa in Malaysia, with yields remaining stable until approximately 30 years before declining sharply, rendering farms nearly unproductive by year 40. Similar observations were reported by Aneani et al. (2017) and Ofori-Bah and Asafu-Adjaye (2011) in Ghana. Also, Assiri et al. (2003) and Ahenkorah et al. (1987) reported that yields stabilise around year 10 and begin deteriorating at 30. Abdulai et al. (2020) found that cocoa trees with an average age of 16 years produced higher yields compared to those with an average age of 22 years. Laryea (1969) documented a 20% reduction in yield in farms that exceeded 30 years of age. Notably, Kongor et al. (2017) reported that approximately 23% of cocoa trees in Ghana have surpassed their productive lifespan of 30 years.

To put the relationship between cocoa productivity and tree age in proper perspective, Atkins and Eastin (2012) classified cocoa trees into different productivity classes based on their age. Class A (5–7 years old) represented young, highly productive trees. Class B (7–15 years old) was the peak productive period. Class C (15–25 years old) saw a decline in yield, while Class D (25–35 years old) showed a further drop in productivity. Trees over 35 years of age were considered Class E and Class F, which were highly unproductive.

Incidence of pests and diseases

Poor management of pests and diseases has been identified as a major factor contributing to low cocoa productivity in Ghana (Boateng et al., 2023; Acheampong et al., 2023; Attipoe et al., 2021; Akrofi et al., 2015). The main pests affecting cocoa production in Ghana include cocoa capsids or mirids (*Distanthiella theobromae* and *Salbegella singularis*), cocoa shield bugs (*Bathycoelia thalassina*), and mistletoes (*Tapinanthus bangwensis*).

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Cocoa capsids, in particular, are responsible for mean annual pod losses of about 25% (Miyittah et al., 2022b; Sarfo et al., 2018; Akrofi et al., 2015).

The primary diseases affecting cocoa production in Ghana are the Black Pod Disease and the Cocoa Swollen Shoot Disease (CSSVD) (Boateng et al., 2023; Kongor et al., 2017; Opoku et al., 2000). Black Pod Disease, caused by *Phytophthora palmivora* and *Phytophthora megakarya*, is a fungal infection that results in the browning, blackening, and rotting of cocoa pods and beans (Akrofi et al., 2015; Dormon et al., 2007). It thrives under damp (wet and humid) conditions, particularly during the minor dry season (Wessel & Quist-Wessel, 2015). It has been reported to cause mean annual pod losses of approximately 45% (Miyittah et al., 2022b; Danso-Abbeam & Baiyegunhi, 2017; Akrofi et al., 2015; Opoku et al., 2000). CSSVD, caused by a virus transmitted by mealybugs (*Planococcus sp.* and *Stictococcus sp.*), can severely reduce yield by up to 70% at the peak of its incidence (Boateng et al., 2023; Kongor et al., 2017; Ameyaw et al., 2014).

Depletion of soil fertility

Soil fertility depletion has also been identified as a significant factor contributing to low cocoa productivity in Ghana (Amponsah-Doku et al., 2022; Abdulai et al., 2020; Ali et al., 2018; Appiah et al., 2000). Cocoa plants require well-drained, aerated soils that can hold adequate water to make nutrients available for optimal growth (van Vliet & Giller, 2017; Snoeck et al., 2010). However, approximately 83.3% of the soils used for cocoa cultivation in Ghana are reported to be suboptimal for cocoa farming (Quaye et al., 2021). These soils are characterised by low cation exchange capacity (<24 cmol/kg) and low organic carbon content (0.39 ± 0.009 g/100 g), with nitrogen and phosphorus being the most limiting nutrients (Amponsah-Doku et al., 2022; Quaye et al., 2021; Snoeck et al., 2010).

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Furthermore, these soils often have low pH (<5.5), making them susceptible to aluminium toxicity, which hampers nutrient uptake by cocoa plants (Quaye et al., 2021). According to Amponsah-Doku et al. (2022), low pH is primarily a result of the continuous application of nitrogenous fertilisers without the concurrent use of liming agents to counteract the pH decrease that occurs when plants take up ammonium.

Planting density

Unstandardised planting densities have been identified as a significant yield-limiting factor in the literature (Asante et al., 2022, 2021; Abdulai et al., 2020; Sonwa et al., 2018; Daymond et al., 2017; Souza et al., 2009). While experimental evidence confirms that cocoa yield per hectare increases with planting density (Smith, 2015; Souza et al., 2009; Dias et al., 2000), exceeding the optimal threshold intensifies competition, suppressing tree growth and reducing fruit production in residual trees (Wood, 1964). Additionally, high-density planting increases the incidence of disease (Souza et al., 2009; Dias et al., 2000). Studies have found a positive correlation between planting density and the incidence of diseases on cocoa farms, largely due to the microclimate effects and the increased ease of disease transmission in densely planted areas (Asante et al., 2022; Abdulai et al., 2020; Souza et al., 2009). Additionally, higher planting densities lead to greater competition for essential growth resources among cocoa trees, which can further hinder productivity (Sonwa et al., 2018; Souza et al., 2009).

Jagoret et al. (2017), Smith (2015), and Alvim (1964) identified 1568 trees per hectare as the optimal density, beyond which yields decline. According to Kongor (2017), CRIG recommended a planting distance of 3m × 3m for cocoa trees in the cocoa-growing regions, a spacing regimen that accommodates 1,111 trees per hectare. Also, a standardised planting density of 1246 trees per hectare has been widely acknowledged as optimal for cocoa

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farming in Ghana (Asante et al., 2022; Abdulai et al., 2020). Planting densities below 800 plants per hectare are considered low and may limit yield potential, as wider spacing reduces canopy coverage and resource use efficiency (Somarriba et al., 2021). When density falls below a critical threshold, gaps in the cocoa canopy create entry points for weeds, pests, and diseases, fostering unfavourable microclimatic conditions that hinder tree growth and yield.

Land tenure arrangements

Land tenure arrangements have been recognised as a key socio-cultural and economic factor affecting cocoa productivity in Ghana (Asamoah and Owusu-Ansah, 2017). Ertiro (2006) noted that land tenure security significantly influences farmers' investment decisions and attitudes toward cocoa production. Kongor (2017) identified three primary land tenure systems in Ghana's cocoa-growing regions: ownership, family land, and sharecropping. Sharecropping, prevalent across the sector, exists in two forms – '*Abunu'* and '*Abusa'* (Asamoah and Owusu-Ansah, 2017). Under '*Abunu'*, the sharecropper cultivates the farm until maturity, after which the land is divided equally between the sharecropper and the owner. Traditionally, sharecroppers gain full ownership of their portions, including trees, with the right to bequeath them. In some cases, however, the farm remains undivided, and only the proceeds are shared, leaving the sharecropper without inheritance rights and vulnerable to disputes upon the owner's death. In contrast, under '*Abusa'*, the landowner establishes the farm, while the sharecropper manages and maintains it. Crop proceeds are split into three categories: one-third for the sharecropper, one-third for the landowner, and the remaining third for input costs. The sharecropper holds no ownership rights over the land or farm.

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Customary land tenure systems in Ghana, such as the '*Abunu*', and '*Abusa*' sharecropping arrangements, have been identified as factors that disincentivize migrant farmers from making long-term investments in cocoa farming (Acheampong et al., 2023; Asaaga et al., 2020). Shared ownership and the division of farm outputs can reduce the incentive for farmers to invest in improving soil fertility, adopting new farming practices, and increasing productivity, as farmers do not own land in the long term. Another major challenge with sharecropping is the frequent disputes between landowners and sharecroppers, as agreements often lack legal documentation, allowing contracts to be terminated at short notice. Asamoah and Owusu-Ansah (2017) linked the relatively low adoption of farm management practices amongst sharecroppers to the insecurity of these tenure arrangements.

Participation in training programmes and access to extension services

Access to technical information through extension services plays a crucial role in the diffusion of innovation among farmers. According to Binam et al. (2008), contact with extension agents and participation in training programmes help farmers adopt better agricultural practices and improve cocoa productivity. Extension services that provide guidance on pest and disease management, fertilisation, and crop management have been found to significantly enhance cocoa yields by increasing farmers' knowledge and skills.

Ageing cocoa farmers

The ageing of cocoa farmers has also been identified as a significant factor influencing cocoa productivity in Ghana (Abdulai et al., 2020; Kroeger et al., 2017; Asare et al., 2014). According to Abdulai et al. (2020), older cocoa farmers often face challenges in effectively performing essential farm management tasks such as timely weeding, pruning, and

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spraying. These tasks are critical for maintaining high productivity, and their inability to manage them effectively, often owing to physical limitations, can severely impact farm output.

Weather and climatic factors

Cocoa production in Ghana is highly sensitive to weather and climatic conditions, which increasingly constrain productivity as rising climate risks erode both agricultural output and ecological resilience (Parra-Paitan et al., 2024; Kalischek et al., 2023; Asante et al., 2021; Bunn et al., 2019). Cocoa thrives under average annual temperatures of 21–33°C and rainfall between 1,000–2,500 mm (Kosoe & Ahmed, 2022; Anim-Kwapong & Frimpong, 2004). Deviations from these thresholds, particularly prolonged heat and rainfall variability, negatively affect growth and yield.

Observed climatic trends in Ghana reveal a warming of over 1°C above the 1960 baseline (Awuni et al., 2023; World Bank, 2021; Klutse et al., 2020; Asante & Amuakwa-Mensah, 2015). At the same time, cumulative annual rainfall has declined by 2.4% per decade, with reductions most pronounced in the middle belt, while rainfall intensity has increased in the north and south (Anning et al., 2022; Afriyie-Kraft et al., 2020; Wongnaa & Babu, 2020; Hutchins et al., 2015). Projections indicate that average annual temperatures will rise by 1–3°C by 2060, reaching 1.5–5.2°C above current levels by 2090. Mean rainfall is projected to decline by about 12 mm, with significant changes occurring after 2030 (Anning et al., 2022; Afriyie-Kraft et al., 2020; Hutchins et al., 2015; Läderach et al., 2013; Wongnaa & Babu, 2020).

Cocoa cultivation is concentrated in areas once dominated by tropical forests, but many of these regions—particularly Bono, Bono East, Ahafo, and Ashanti, which form the northern cocoa belt—are undergoing ecological transformation. Dense forests are increasingly

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replaced by a forest–savanna transition zone marked by dry semi-deciduous vegetation and Guinea savanna grasslands. These zones experience longer dry seasons and recurrent wildfires that damage farms (Amisah et al., 2010). With annual rainfall ranging from 1,000–1,300 mm and temperatures between 26–37°C, projections indicate that unmitigated climate risks could render cocoa production unsuitable in these areas by 2050 (Asante et al., 2021; Bunn et al., 2019). More broadly, by 2050, up to 50% of currently suitable cocoa-growing areas in Ghana may no longer support cultivation (Addo-Danso et al., 2024; Läderach et al., 2013; Schroth et al., 2016, 2017).

The vulnerability of cocoa-growing regions is compounded by high climatic variability, dependence on rain-fed agriculture, and limited institutional and economic capacity for adaptation (Asante et al., 2025; Sultan & Gaetani, 2016). Such pressures may push farmers to expand into protected forests in search of suitable land, thereby accelerating deforestation and threatening critical biodiversity hotspots.

2.4 The Role of COCOBOD in the Cocoa Industry of Ghana

COCOBOD occupies a central position in the governance and sustainability of Ghana's cocoa industry, which constitutes a significant pillar of the national economy. Established in 1947, COCOBOD's mandate encompasses regulatory, developmental, and commercial functions aimed at ensuring the competitiveness and resilience of the cocoa sector. Its role can be broadly categorised into policy formulation and sector regulation, farmer support, cocoa marketing and price stabilisation, research, quality assurance, and value addition (Attipoe et al., 2021; Sonwa et al., 2018; Kolavalli & Vigneri, 2017; Baffoe-Asare et al., 2013).

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2.4.1 Policy formulation and sector regulation

COCOBOD is tasked with formulating and implementing policies that regulate and promote the growth of the cocoa industry. This includes licensing Licensed Buying Companies (LBCs), enforcing compliance with operational standards, and safeguarding the integrity of Ghana's cocoa supply chain. Through these regulatory functions, COCOBOD ensures stability and accountability within the sector.

2.4.2 Farmer support through extension services delivery

COCOBOD is the primary body that oversees cocoa production of cocoa beans in Ghana. COCOBOD provides extensive support to cocoa farmers through the distribution of subsidised inputs including fertilisers, pesticides, and hybrid seedlings. It also coordinates extension services, training farmers in good agricultural practices (GAPs) to boost yields and promote environmentally sustainable production. COCOBOD's recommended farm management practices form the foundation of good cocoa farming in Ghana. These include pest and disease control (e.g., strict application of fungicide for Black Pod Disease, and insecticide for capsids), fertilisation, regular hand weeding as well as chupon and mistletoe removal, pruning, and proper harvesting, fermentation, and drying (Asante et al., 2022; Wilson et al., 2019; Sonwa et al., 2018). Amongst these, capsid control and fertiliser application are critical for enhancing cocoa productivity (Sonwa et al., 2018; van Vliet & Giller, 2017). To promote these practices, COCOBOD has implemented some PEPs, including the Cocoa Diseases and Pest Control Programme (CODAPEC), Cocoa High Technology Programme (Hi-Tech), and National Cocoa Rehabilitation Programme (NCRP) (COCOBOD, 2022; Fountain & Hütz-Adams, 2022).

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2.4.2.1 The cocoa diseases and pest control (CODAPEC) programme

The CODAPEC programme aims to control Black Pod Disease and capsids (mirids), which significantly impact cocoa yields (Attipoe et al., 2021; Anang et al., 2013). Through the programme, subsidised agrochemicals and labour services are provided on credit to support farmers (Acheampong et al., 2023; Kolavalli & Vigneri, 2017). COCOBOD, through CRIG, recommends spraying insecticides four times a year (sequentially in August, September, October, December) to address peak capsid incidence (Kolavalli & Vigneri, 2017; Danso-Abbeam & Baiyegunhi, 2017). The recommended fungicide application for the treatment of Black Pod Disease involves spraying nine times annually, starting in March/April, to combat the humidity-driven fungal growth (Danso-Abbeam & Baiyegunhi, 2018). In addition, proper farm management practices, such as weeding, pruning, and the removal of infected pods and pod husks, are critical for disease control (Cilas et al., 2018; Opoku et al., 2000).

COCOBOD, through CRIG, recommended farmers to spray insecticides four times a year against capsids (Danso-Abbeam & Baiyegunhi, 2017; Antwi-Agyakwa et al., 2015; Dormon et al., 2007). This spraying is to be carried out in August, September, October and December to ensure they coincide with the period of peak capsid incidence for effective control (Kolavalli & Vigneri, 2017; Danso-Abbeam & Baiyegunhi, 2017; Abankwah et al., 2010).

2.4.2.2 The cocoa high technology (Hi-Tech) programme

The Cocoa Hi-Tech programme provides farmers with subsidised fertilisers and hybrid seedlings to farmers on credit. The programmes encourage the use of 375 kg of inorganic fertiliser per hectare annually, applied at the start of the rainy season (April/May). Additionally, COCOBOD supplies improved hybrid seedlings to support the establishment

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and rehabilitation of farms. These are distributed primarily during the major wet season (April to June). Farms are also pruned between February and April to maximise pod setting. COCOBOD supports this effort by providing motorised pruners and technical training to farmer associations.

Hand pollination

Hand pollination, introduced in 2017, supplements natural pollination in areas where it is insufficient, increasing the number of pods per tree (Wongnaa et al., 2021). The technique aims to boost pod production from 20–50 pods to 200 per tree (Toledo-Hernández et al., 2023; Wongnaa et al., 2021). Farms are expected to be pruned two months before pollination to ensure proper flower development, and fertiliser application is necessary to support pod setting (Wongnaa et al., 2021; Toledo-Hernández et al., 2020).

2.4.2.3 The national cocoa rehabilitation programme (NCRP)

After decades of cultivation, farmers must either rehabilitate by restoring the productivity of an ageing yet potentially viable orchard or renovate by removing existing trees, either all at once or gradually, and replanting to establish a new cycle of production (Somarriba et al., 2021). Renovation focuses on establishing a new cocoa orchard, often with distinct cocoa cohorts and a modified shade canopy. In Ghana, the National Cocoa Rehabilitation Programme (NCRP) focuses on rehabilitating farms affected by CSSVD. COCOBOD covers the full cost of the two-year rehabilitation process, which includes tree removal, farm treatment, and replanting with disease-resistant, high-yielding cocoa varieties. Farmers receive GH₵1000 per hectare to aid the rehabilitation process.

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2.4.3 Cocoa marketing and price stabilisation

COCOBOD, through its Cocoa Marketing Company, serves as the sole purchaser and marketer of cocoa beans from Ghana to both domestic and international processors (Boysen et al., 2021; Attipoe et al., 2021; Vigneri & Kolavalli, 2018; Bangmarigu & Qineti, 2018). To facilitate this, COCOBOD issues licences to Licenced Buying Companies (LBCs) that purchase cocoa beans from farmers on behalf of COCOBOD. It is particularly recognised for its forward sales system, which stabilises revenue flows in the face of global price volatility. Additionally, COCOBOD is responsible for determining the producer price of cocoa through the Producer Price Review Committee (PPRC) (Bangmarigu & Qineti, 2018; Vigneri & Kolavalli, 2018; Quarmine et al., 2014). The cocoa producer price refers to the farmgate price that farmers in Ghana receive per kilogram of cocoa beans produced and sold (Vigneri & Kolavalli, 2018; Quarmine et al., 2014). COCOBOD determines and guarantees the producer price of cocoa at the beginning of each crop season. The cocoa producer price is a key factor influencing farmers' decisions regarding investment in cocoa farming. A higher farmgate price, which covers or exceeds marginal production costs, results in increased profit margins and incomes for cocoa farmers (Boysen et al., 2021). According to Asante-Poku and Angelucci (2013) and Anim-Kwapong and Frimpong (2008), a higher producer price motivates farmers to invest more in regular farm management practices, such as controlling pests and diseases, applying fertilisers, controlling weeds, removing mistletoe, pruning, and ensuring thorough harvesting, fermentation, and drying processes.

2.4.4 Research and development

In collaboration with CRIG, COCOBOD invests in research to enhance productivity and sustainability. CRIG develops improved, high-yielding, and disease-resistant cocoa

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varieties, as well as innovations in pest and disease management. Such research underpins the long-term viability of cocoa farming in Ghana, particularly in the context of climate change and declining soil fertility.

2.4.5 Quality control

Maintaining the premium quality of Ghana's cocoa is a core function of COCOBOD, operationalised through the Quality Control Company. This subsidiary is responsible for the inspection, grading, and sealing of cocoa beans prior to export, ensuring that Ghana retains its international reputation for high-quality cocoa.

2.4.5.1 Quality of cocoa beans

The international cocoa market defines quality through four principal dimensions, as specified in exporter-buyer contracts: (1) physical quality, (2) bio-chemical quality, (3) process quality, and (4) origin quality (Quarmine et al., 2012). Physical quality concerns attributes such as moisture content, disease infestation, bean defects, mould, and foreign matter. Bio-chemical quality relates to butter content, flavour compounds, heavy metals, toxins, and chemical residues. Process quality considers production methods, such as organic or inorganic methods, and the use of child labour. In Ghana, a bag of cocoa beans is classified as Grade I cocoa if the beans are well fermented, have a moisture content not higher than 7.5%, and does not contain more than 3% beans with defects (Quarmine et al., 2012). Likewise, Grade II cocoa must contain only 4–8% beans with defects and not more than 8.5% moisture content (Quarmine et al., 2012). Thus, quality cocoa is characterised by well-fermented and properly dried beans that are free from disease, contamination, and physical defects (Quarmine et al., 2012).

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CHAPTER THREE

LITERATURE REVIEW

3.1 Introduction

This chapter is divided into four sections and presents a review of the literature. Section 3.2 provides brief definitions of the key concepts used in this study. Section 3.3 presents a review of the methods of analysis employed by past studies in answering questions related to the research questions in this study. This includes approaches for developing sustainable intensification indicators, analysing factors influencing adoption decisions, and evaluating multinomial treatment effects. A review of empirical literature related to the adoption of SCIPs and their impact on yield, farm income and food security in Ghana is presented in Section 3.4. This section reviews empirical studies on the development of sustainable intensification indicators, adoption of SCIPs, and the impact of sustainable intensification on productivity, household income, and household food security in Sub-Saharan Africa. Section 3.5 concludes the chapter by summarising the key insights from the literature and highlighting the research gaps this study aims to address.

3.2 Definition of Key Concepts

3.2.1 Conventional crop intensification

Struik et al. (2014) defined agricultural intensification as a rise in farming input per unit of land, encompassing both internal and external resources such as seed, manure, fertiliser, water, credit, labour, fossil fuels, mechanisation, knowledge, communication, and institutions, or a combination of these elements. Thus, agricultural intensification is typically characterised by the type and quantity of inputs and outputs, as well as the efficiency of converting inputs into outputs (Helfenstein et al., 2020). Crop intensification has consequently been defined as the process of increasing outputs either through increased

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use of inputs such as fertilisers and improved crop varieties (Helfenstein et al., 2020; Kuemmerle et al., 2013), or by maintaining outputs with reduced inputs (Petersen & Snapp, 2015; Mueller et al., 2012). It is often characterised by increased specialisation of production systems, frequently leading to a reduction in crop diversity and a shift towards monoculture (Matson et al., 1997).

Thus, conventional cocoa intensification entails the intensity of use of inputs and management practices, characterised by reduced crop diversity, and often supported by greater use of high-yielding varieties, advanced pollination techniques, chemical fertilisers and pesticides, increased crop density, and the expansion of irrigation infrastructure on existing farmland (Sadhu et al., 2020; Vanlauwe & Dobermann, 2020; Danso-Abbeam et al., 2014). These input-based metrics of intensification provide a means to gauge land-use intensity across several dimensions. While such approaches can substantially raise productivity, the excessive and indiscriminate use of these inputs frequently results in the degradation of soil resources and broader environmental harm. These adverse outcomes include water pollution, greenhouse gas emissions, soil acidification, biodiversity loss, elevated soil erosion, declining soil fertility, contamination of groundwater, and the eutrophication of rivers and lakes (Matson et al., 1997; Tetteh et al., 2018; Tothmihaly et al., 2019).

3.2.2 Agricultural sustainability

Agricultural sustainability is the capacity to continuously produce crop and animal products without depleting productive resources or harming the environment, while ensuring economic viability and social stability (Muhie, 2022; Smith et al., 2017; Vitunskiene & Dabkiene, 2016). The concept of sustainability encompasses three dimensions: environmental, economic, and social. The environmental dimension focusses on

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minimising adverse ecological footprints, the economic dimension aims to increase income, and the social dimension seeks to improve community and human well-being, including fair labour conditions, gender equity, good health and household food security (Smith et al., 2017; Dantsis et al., 2010).

3.2.3 Sustainable intensification

Sustainable intensification has been defined as a production process or system aimed at producing more output per unit area while minimising the negative environmental impacts of agricultural practices, and at the same time enhancing contributions to natural capital and the flow of environmental services (Smith et al., 2017; Struik et al., 2014; Pretty & Bharucha, 2014; Pretty, 2008). The combination of the terms 'sustainability' and 'intensification' is an indication of an attempt at realising the desirable outcomes of the two concepts, which are higher crop yield (under intensification) and improved environmental goods and services (under sustainability) through a variety of means. Thus, sustainable intensification is the state where agricultural yields are increased without adverse environmental impact and without the conversion of additional non-agricultural land (Jain et al., 2023; Petersen & Snapp, 2015; Garnett et al., 2013). The literature identifies three key outcome variables against which the success of sustainable intensification of every agricultural system can be measured. In line with the concept of sustainable agriculture, these outcome variables are improvement in farmers' productivity (both intensification and economic dimension of sustainability), preservation of the ecosystem (environmental dimension), and the enhancement of farmers' general wellbeing (social dimension) (Jain et al., 2023; Cassman & Grassini, 2020; Smith et al., 2017; Rockström et al., 2017; Garnett, et al., 2013).

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3.2.4 Sustainable intensification practices (SIPs)

SIPs are agricultural techniques that aim to increase yield while ensuring environmental sustainability, economic viability, and social well-being (Muhie, 2022; Smith et al., 2017). A review by Mockshell and Kamanda (2018) identified practices including the use of legumes as cover crops, living and residual mulches, worm composts, and planting high-yielding varieties as effective approaches to promote sustainable intensification. They also highlighted the role of "smart" farming techniques such as precision technologies, including variable rate application tools and satellite imagery, in improving irrigation and nutrient efficiency. Also, Martin-Guay et al. (2018) argued that water management practices and intercropping multiple crops on the same plot of land could play a vital role in achieving sustainable intensification. Jayne et al. (2019), Vanlauwe and Dobermann (2020), Adjei-Nsiah (2019) and Holden (2018) emphasised the importance of efficient fertiliser use in attaining sustainable intensification in Sub-Saharan Africa, given the significant nutrient gap and low per capita consumption of inorganic fertilisers. Vanlauwe and Dobermann (2020) and Holden (2018) emphasised efficient fertiliser use to minimise environmental and economic costs, while Jayne et al. (2019) and Adjei-Nsiah (2019) noted that increased usage must be accompanied by other agronomic and soil amendment practices that maintain or rehabilitate soil health, including organic matter inputs, mixed cropping, and reduced soil disturbance. Ciampi et al. (2022) and Krupnik et al. (2017) underscored the importance of both groundwater and surface water irrigation systems in fostering sustainable crop intensification at the farm level.

3.2.5 Sustainable cocoa intensification practices (SCIPs)

Sustainable cocoa intensification focusses on increasing the quantity and quality of cocoa beans produced by smallholder farmers in a cost-effective way, without expanding

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cultivation into non-agricultural lands. Its primary goals are to enhance the profitability and livelihoods of cocoa farmers while protecting the environment, including soil health, conserving biodiversity, and maintaining agroecological services to ensure cocoa production for future generations (Abdulai et al., 2020; Wilson et al., 2019). Thus, SCIPs refer to practices that increase cocoa yields while optimising resource use, improving soil health, reducing deforestation, and ensuring farmer well-being (Kongor et al., 2024; Ajibade et al., 2023; Mockshell & Kamanda, 2018). SCIPs can be categorised in alignment with the three key dimensions of sustainable intensification: economic, environmental, and social (Kongor et al., 2024; Abdulai et al., 2020).

3.2.5.1 Practices under the intensification and economic dimension of sustainable cocoa intensification

Whereas intensification focusses on increasing productivity, the economic dimension of sustainability encompasses increasing both the quantity and quality of dried cocoa beans produced while reducing production costs (Kongor et al., 2024; Mockshell & Kamanda, 2018). Practices like planting improved cocoa varieties, hand pollination, irrigation, fertiliser and pesticides application, weed control, and pruning are practices that could promote intensification. On the other hand, effective labour use and efficient application of agronomic practices according to standard scientific recommendations, including proper postharvest treatments like pulp pre-conditioning, fermentation and drying, could improve the quantity and quality of dried cocoa beans produced while reducing production costs. A high cocoa producer price at the farmgate and off-farm income opportunities could further support economic sustainability by enabling investment in quality inputs and ensuring decent living standards (Anim-Kwapong & Frimpong, 2008).

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3.2.5.2 Practices under the environmental dimension of sustainable cocoa intensification

Bandanaa et al. (2021) identified agronomic practices as having a significant impact on observed sustainability performance, particularly in relation to environmental outcomes. In their comparison of organic and conventional cocoa farming systems, they found that organic systems demonstrated superior environmental sustainability, specifically in areas such as water usage, species diversity, land degradation, genetic diversity, and greenhouse gas emissions. The environmental sustainability dimension encompasses a comprehensive strategy for managing pests and diseases, preserving soil moisture, enhancing soil fertility, and safeguarding biodiversity on cocoa farms (Bandanaa et al., 2021; Mockshell & Kamanda, 2018; Smith et al., 2017). This approach prioritises ecologically responsible practices that conserve resources while integrating natural biological cycles (Mockshell & Kamanda, 2018). It emphasises the use of locally available, cost-effective materials that effectively target pests, diseases, and soil health concerns, ensuring both efficiency and environmental integrity (Kongor et al., 2024; Mockshell & Kamanda, 2018). Previous studies (Miyittah et al., 2022b; Boeckx et al., 2020; Tetteh et al., 2018; Kongor et al., 2017; Alemagi et al., 2015; Ruf et al., 2006) suggested integrated pest and disease management practices including pruning, regular weeding and the use of the use of the African Weaver ants (*Oecophylla longinoda*) (van Wijngaarden et al. 2007) and beneficial endophytes, *Trichoderma spp* (Deberdt et al. 2008; Hanada et al. 2009) as biological agents to control cocoa capsids and black pod disease, respectively.

Other studies (including Kongor et al., 2024; 2017; Bandanaa et al., 2021; Quaye et al., 2021; Abdulai et al., 2020; Mockshell & Kamanda, 2018; Vanlauwe et al., 2014) suggested integrated soil fertility management practices including the use of locally generated materials such as cocoa pod husks, household organic residues, nitrogen fixing legumes,

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compost and green manure. Other studies (including Sassen et al., 2022; Boeckx et al., 2020; Alemagi et al., 2015; Gockowski et al., 2013; Gockowski & Sonwa, 2011) identified planting multi-purpose shade trees in cocoa orchards to extend the productive lives of cocoa trees and enhance carbon sequestration. Water management practices including water harvesting using micro-catchments, earth barriers, bunds, shallow surface drains, trenches, drainage dykes/ditches, underground clay pipes, and irrigation could also engender environmental sustainability in cocoa production systems (Kongor et al., 2024; Mockshell & Kamanda, 2018).

3.2.5.3 Practices under the social dimension of sustainable cocoa intensification

The social dimension of sustainable cocoa intensification prioritises the well-being, equity, and resilience of farmers, their households, and communities while ensuring long-term sustainability (Kongor et al., 2024; Mockshell & Kamanda, 2018). It seeks to uphold fair labour standards by eliminating child and forced labour and enforcing safe working conditions, such as promoting the use of personal protective equipment in agrochemical handling (Luckstead et al., 2019; Sadhu et al., 2020). Additionally, it emphasises social inclusion, knowledge transfer, and community empowerment through supporting alternative livelihoods like intercropping and livestock production (Mockshell & Kamanda, 2018). Without addressing social factors, sustainable intensification efforts may lead to increased productivity at the cost of inequality, exploitation, and environmental degradation.

3.2.6 Incentives that promote the adoption of agricultural innovations

Piñeiro et al. (2020) see incentives as policy instruments employed by both public and private sectors to encourage farmers to safeguard or enhance ecosystem services, such as

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water quality, soil health, and forestry, while simultaneously improving agricultural productivity and competitiveness. Thus, incentives are mechanisms designed to influence the behaviour of economic agents in ways that benefit them (Blackman et al., 2018; Quarmine et al., 2012). These mechanisms work by reducing the risks and uncertainties surrounding the use of new technologies, lowering transaction costs, or securing property rights (Tsai & Liao, 2017). Piñeiro et al. (2020) classified incentives into *market-based* and *non-market* incentives.

3.2.6.1 Market-based (economic) incentives

Market-based incentives promote behavioural change by offering economic rewards through market signals, including input and output prices, subsidies, compensation, income transfers, and other financial or in-kind benefits to farmers (Bakali et al., 2023; Piñeiro et al., 2020; Loconto & Vicovaro, 2016). Thus, market-based instruments are indirect regulatory tools that influence actors' behaviour by altering their economic conditions (Mazaheri et al., 2022; Quarmine et al., 2012). These mechanisms utilise markets, prices, and other economic factors to encourage farmers to adopt more sustainable production practices (Rosenow et al., 2019; Stiglitz & Rosengard, 2015). Common market-based incentives in Ghana's cocoa sector include the cocoa producer price, input subsidies, and price differentiation for specialty cocoa.

3.2.6.2 Non-market-based incentives

Non-market incentives comprise a broad array of measures, such as technical assistance, technology transfer, and fiscal instruments, including carbon pricing or environmental taxes designed to advance sustainability (Piñeiro et al., 2020; Laven and Boomsma, 2012). Regulatory measures involve rules or directives imposed by governments or private bodies

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to achieve environmental and economic outcomes through better farming practices; these are generally mandatory and include environmental standards, laws, and certification schemes (Piñeiro et al., 2020; Laven and Boomsma, 2012). They work through regulations or obligations that farmers must comply with, such as specific agronomic recommendations (e.g., regimented weeding, pruning, fertilisation and pesticide applications), or compliance with quality standards (Beiser-McGrath et al., 2022; Blackman et al., 2018). A typical example is cross-compliance incentives that link direct farm payments to compliance with environmental standards and land stewardship requirements (like subsidies granted on the condition that farmers adopt approved environmental practices) (Piñeiro et al., 2020; Laven and Boomsma, 2012).

3.2.7 Household Food security

Food security refers to a state in which all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life (Clapp et al., 2022; Walls et al., 2019; Maxwell, 1999, 1996; Staatz et al., 1990). Traditionally, food security is understood through four core dimensions; food availability, food access, food utilisation, and stability (Clapp et al., 2022; Walls et al., 2019). Availability refers to the presence of adequate quantities of food from domestic production, imports, or food aid (Dzanku, 2019; Prosekov and Ivanova, 2018). The access dimension focusses on individuals' ability to acquire food through physical or economic means, or through social networks (Dzanku, 2019). Also, utilisation emphasises the proper biological use of food, which depends on having a healthy diet, clean water, sanitation, and healthcare to ensure nutritional well-being (Walls et al., 2019; Prosekov and Ivanova, 2018). Finally, stability underlines the importance of

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consistent access to adequate food over time, safeguarding against short-term shocks and long-term risks (Walls et al., 2019; Dzanku, 2019).

Recently, two additional dimensions have been increasingly recognised. These are agency and sustainability (Mockshell & Ritter, 2024; Clapp et al., 2022; HLPE, 2020). The agency dimension highlights the ability of individuals and communities to make decisions about their food systems, including what to consume and how it is produced, underlining the importance of empowerment, rights, and inclusivity (Mockshell & Ritter, 2024; Clapp et al., 2022; HLPE, 2020). On the other hand, the sustainability dimension focusses on creating food systems that meet the needs of current generations without compromising the ability of future generations to meet theirs, emphasising environmentally sound agricultural practices, biodiversity conservation, and minimising waste and environmental impact (Mockshell & Ritter, 2024; Clapp et al., 2022; HLPE, 2020). According to Mockshell and Ritter (2024), and Clapp et al. (2022), this six-dimensional framework for food security provides a comprehensive understanding of addressing the food security challenges in a complex and interconnected world.

3.3 Review of Relevant Methods of Analysis

3.3.1 Estimation of composite sustainable intensification index

Composite indices simplify multidimensional data into a single, interpretable measure, aiding decision-making (Mutyasira et al., 2018; Vitunskiene & Dabkiene, 2016; OECD-JRC, 2008). An indicator is a single measurable variable that provides specific information about a particular phenomenon (OECD-JRC, 2008). A composite index, on the other hand, is created by combining multiple indicators, often using weighting or statistical methods (OECD-JRC, 2008; Saisana & Tarantola, 2002). Thus, composite indices summarise

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multiple dimensions into a single score, making comparisons and interpretations easier (OECD-JRC, 2008).

3.3.1.1 Five steps to estimating composite indices

The literature identifies a five-step approach to constructing composite indices: (1) establishing a theoretical framework, (2) selecting individual indicators, (3) normalising the indicators, (4) assigning weights, and (5) aggregating the weighted indicators into a composite score (Mutyasira et al., 2018; Vitunskiene & Dabkiene, 2016; Waney et al., 2014; Gómez-Limón and Sanchez-Fernandez, 2010; OECD-JRC, 2008; Saisana & Tarantola, 2002).

3.3.1.1.1 Establishing a theoretical framework

The first step is to establish a theoretical framework to guide indicator selection and combination, ensuring the composite index serves a clear purpose (Bathaei & Štreimikiene, 2023; Vitunskiene & Dabkiene, 2016; Gómez-Limón & Sanchez-Fernandez, 2010; OECD-JRC, 2008; Saisana & Tarantola, 2002). An example is the FAO's Sustainability Assessment of Food and Agriculture Systems (SAFA) framework, which offers a structured method to assess the sustainability of food and agriculture systems across four dimensions: Good Governance, Environmental Integrity, Economic Resilience, and Social Well-being.

3.3.1.1.2 Selection of individual indicators

The second step in constructing a composite index is to select indicators that are analytically sound, measurable, and relevant to the phenomenon under study, while also considering their interrelations (Mutyasira et al., 2018; Vitunskiene & Dabkiene, 2016;

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Gómez-Limón and Sanchez-Fernandez, 2010; Hayati et al., 2010; OECD-JRC, 2008; Saisana & Tarantola, 2002). Sustainable intensification indicators are measurable variables used to assess the extent to which agricultural systems increase productivity while ensuring the long-term environmental, social, and economic sustainability of farming practices (Smith et al., 2017). The selection of indicators is guided by a sound theoretical framework like the FAO's SAFA Framework (Robling et al., 2023; Bathaei & Štreimikiene, 2023).

Indicators of crop intensification

Teillard et al. (2012) developed an aggregated agricultural intensification indicator using input costs per hectare based on the French Farm Accountancy Data Network. This indicator was the ratio of total input costs, covering fertilisers, feed, pesticides, seeds, fuel, veterinary products, and irrigation water, to the total Utilised Agricultural Area. The use of cost data, rather than input quantities, facilitated comparison across various agricultural systems. In contrast, Dietrich et al. (2012) employed land-use intensity from a productivity perspective using the tau (τ) factor as an indicator of intensification. The τ factor compares actual yields with a reference yield, representing the potential yield under optimal management conditions. This approach isolated the effect of human activities such as research, infrastructure, and management, on agricultural productivity, offering a useful alternative to existing intensification measures by being independent of environmental conditions.

Indicators of agricultural sustainability

In their study, Hayati et al. (2010) highlighted a key limitation in existing agricultural sustainability indicators, noting that many fail to address the full range of sustainability dimensions: economic, social, and environmental. They suggested key economic

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indicators, such as crop productivity and farm income; social indicators, such as food self-sufficiency and farmers' resource access; and environmental indicators, such as pesticide use and water efficiency. Building on this, Dantsis et al. (2010) proposed a regional-scale framework for assessing sustainability by integrating economic, social, and environmental indicators using the Multi-Attribute Value Theory. Their framework, which included environmental indicators such as water consumption and crop rotation practices, sought to address the broader scope of sustainability by also incorporating social indicators such as farmer demographics and employment levels. Gómez-Limón and Sanchez-Fernandez (2010) developed a four-step process for creating a composite sustainability index. Their index included 16 indicators across all sustainability dimensions, and they emphasised the importance of data gathering, normalisation, and weighting in generating a useful sustainability measure. Further refining the concept of sustainability indices, Vitunskiene and Dabkiene (2016) introduced the Farm Relative Sustainability Index (FRSI), a model based on 23 indicators and used factor analysis to assign appropriate weights. Their work focused on important aspects like labour and land productivity, farm income, and environmental impact, aiming to provide a comprehensive evaluation of farm sustainability. Gadanakis et al. (2018) used Data Envelopment Analysis (DEA) to create an Eco-Efficiency index that combined economic value and environmental pressures. Their innovative approach identified practices and technologies such as integrated pest management, that can both improve sustainability and reduce environmental impacts. Likewise, Mutyasira et al. (2018) applied a similar methodology with DEA to create a composite farm sustainability index specifically for smallholder farms. Their model, based on 15 indicators, used endogenously determined weights to assess sustainability, avoiding external biases. Hammond et al. (2021) further expanded the scope of sustainable intensification assessments by quantifying 27 indicators grouped into five domains:

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agricultural production, economics, environment, human welfare, and social aspects. Their research found positive correlations between productivity and improved outcomes in economic, social, and agricultural areas, reinforcing the idea that sustainable intensification leads to comprehensive improvements.

Despite the attempt at developing a comprehensive index that captures all the dimensions of sustainability, results from a systematic review of sustainability indicators for African smallholder farming systems by Smith et al. (2017) underscored the need for more robust social dimension metrics, acknowledging a significant gap in the current sustainability frameworks. Mahon et al. (2018) adopted a holistic approach to sustainable intensification (SI), incorporating 110 indicators focused mainly on agricultural production and ecological factors. Their work, however, stressed that for SI to succeed, equal attention must be given to the social and cultural dimensions of the concept, aligning with the Social-Ecological Systems (SES) framework (McGinnis and Ostrom, 2014; Ostrom, 2007,2009). This approach emphasises the interconnectedness of ecological and social systems, advocating for governance and resource management that promotes sustainability. Mouratiadou et al. (2021) focused on the challenges of assessing SI, particularly the limitations of current models in capturing the social and ecological dimensions. They proposed a framework for ex-ante evaluation of SI options and trade-offs, which combined SI metrics with agricultural systems modelling. Their work emphasised the need for interdisciplinary collaboration to overcome these limitations and improve SI assessments. Robling et al. (2023) highlighted data gaps in sustainability assessments, particularly in the context of Swedish dairy farms. Their findings underscored the need for more integrated and comprehensive data sources, particularly for social and environmental indicators, in order to improve on-farm sustainability evaluations.

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3.3.1.1.3 Normalisation of selected indicators

Normalisation of the selected indicators is the third step in constructing a composite index (Mutyasira et al., 2018; Vitunskiene & Dabkiene, 2016; Gómez-Limón & Sanchez-Fernandez, 2010; Dantsis et al., 2010; OECD-JRC, 2008; Saisana & Tarantola, 2002). Since indicators often vary in scale, normalisation standardises them, ensuring comparability across indicators with different units of measurement. The Min-Max normalisation technique scales indicators to a [0,1] range by subtracting the minimum value and dividing by the range, maintaining relative distances for comparison (Gómez-Limón & Sanchez-Fernandez, 2010; OECD-JRC, 2008; Saisana & Tarantola, 2002). In contrast, the Max-Min normalisation technique reverses this process, assigning the lowest value a score of 1 and the highest a score of 0, which may be useful when higher raw values signify undesirable outcomes.

3.3.1.1.4 Assigning weights to the selected indicators

The fourth step in creating a composite index involves assigning weights to the selected indicators. Weighting is crucial as it determines the relative importance of each indicator, impacting the index's overall outcome and the policy recommendations derived from it. This process is often contentious, as it involves subjective judgments about what is most important. Weighting methods can be categorised into two main types: statistical models and expert judgment.

I. Statistical Models

Statistical techniques assign weights based on data variability and correlation. These methods identify which indicators most explain the variance of the data, providing an empirical basis for weighting. Principal Component Analysis (PCA) (Mutyasira et al.,

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2018; Barnes & Thomson, 2014), Factor Analysis (FA) (Vitunskiene & Dabkiene, 2016; Barnes & Thomson, 2014), Cluster Analysis (OECD-JRC, 2008), DEA (Mutyasira et al., 2018; Gadanakis et al., 2015), and Unobserved Components Models (UCM) (OECD-JRC, 2008) are examples of statistical techniques of assigning weights to indicators.

II. Participatory Methods

Participatory methods assign weights based on expert opinions or policy priorities, reflecting theoretical or policy-driven considerations rather than purely statistical relationships. Budget Allocation Processes (BAP) (OECD-JRC, 2008), Analytic Hierarchy Process (AHP) (Gómez-Limón & Sanchez-Fernandez, 2010; OECD-JRC, 2008), and Conjoint Analysis (CA) (OECD-JRC, 2008; Saisana & Tarantola, 2002) are examples of participatory methods of assigning weights to indicators.

III. Equal Weighting (EW)

The Equal Weighting (EW) method is used to assign the same weight to all indicators, treating them as equally important (Vitunskiene & Dabkiene, 2016; OECD-JRC, 2008; Saisana & Tarantola, 2002). Its simplicity facilitates implementation and aligns with the recommendations of Dantsis et al. (2010) and Cox et al. (1992), who advocate for straightforward weighting schemes over more complex multivariate methods that require expert knowledge.

3.3.1.1.5 Aggregation of the weighted indicators into a single composite score

The final step in constructing a composite index involves aggregating the weighted indicators into a single composite score (Vitunskiene & Dabkiene, 2016; Gómez-Limón & Sanchez-Fernandez, 2010; Hayati et al., 2010; OECD-JRC, 2008).

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Simple Arithmetic Mean (Equal Weighting) is the most straightforward method of aggregation, where all indicators are given equal weight (OECD-JRC, 2008; Saisana & Tarantola, 2002). In the Weighted Sum method, however, each indicator is assigned a specific weight (often based on expert judgment, statistical analysis, or participatory methods), and the weighted sum is computed (OECD-JRC, 2008; Saisana & Tarantola, 2002). On the other hand, the geometric mean is often used when the indicators are multiplicative or when the data is on a scale that needs to be considered as a proportion or ratio.

3.3.1.2 Sustainability and intensification index thresholds/ Cut-offs

Thresholds or cut-offs in agricultural intensification and sustainability indices refer to specific index levels where significant shifts in system behaviour occur (Syers et al., 1995). Notably, studies such as Uthes and Herrera (2019), Rigby et al. (2001), and Taylor et al. (1993) suggested a threshold/ cut-off value of 0.5 for indicators ranging between 0 and 1, offering a potential benchmark for future research. These boundaries delineate the transition of a plot from being classified as intensified or sustainable to no longer meeting those criteria. The concept of thresholds/ cut-offs itself is contested. Glenn and Pannell (1998) argued that thresholds/ cut-offs are not intrinsic to indicators but are shaped by economic decisions and contextual factors. In contrast, Moxey (1998) emphasised their importance, particularly in agri-environmental contexts, where ecosystems can abruptly shift between stable states upon crossing certain thresholds/ cut-offs – a phenomenon known as an ecological "flip." Thus, Moxey (1998) stressed the need for prioritising threshold identification and quantification in sustainability research, given the limited empirical evidence currently available.

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3.3.2 Estimating multinomial treatment effects

When technology adoption involves more than two options, studies commonly use either the multi-valued treatment effects (MVT) model (Ma et al., 2021; Issahaku & Abdulai, 2020; Tesfay & Tirivayi, 2018; Kotu et al., 2017) or the multinomial endogenous switching regression (MESR) model (Setsoafia et al., 2022; Nkegbe & Mumin, 2022; Issahaku & Abdulai, 2020; Kassie et al., 2015) to address selection bias. Although the MVT model is non-parametric and corrects for observed selection bias, it fails to account for unobserved bias (Issahaku & Abdulai, 2020; Kassie et al., 2015). In contrast, the MESR model, introduced by Bourguignon et al. (2007), effectively mitigates selection bias arising from both observed and unobserved factors (Issahaku & Abdulai, 2020).

The MESR model has been widely applied in empirical studies such as those by Di Falco and Veronesi (2013), Teklewold et al. (2013), and Ng'ombe et al. (2017). It addresses endogeneity, where treatment selection correlates with unobserved factors influencing outcomes, a common challenge in observational data. Specifically, the MESR model evaluates the effects of multinomial treatments, which are categorical variables with multiple levels, on outcomes while correcting for self-selection bias. It estimates separate outcome equations for each treatment category and models the treatment selection process using latent variables. To correct for endogeneity, the model incorporates instruments or control variables, with parameters typically estimated via Maximum Likelihood Estimation (MLE). The MESR model is particularly suited for analysing the adoption of SIPs in cocoa farming, where treatment choices depend on factors such as resource access and environmental conditions. By accounting for non-random treatment selection and unobserved influences, the MESR model ensures unbiased estimation of the effects of different practices on cocoa yields, farm income and household food security.

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3.4 Review of Empirical Literature on Sustainable Cocoa Intensification

3.4.1 Cocoa intensification

Cocoa intensification has been widely studied in relation to its impact on productivity, environmental sustainability, and farmer income. Gockowski and Sonwa (2011) examined trade-offs between productivity and deforestation across varying levels of input intensification for cocoa production systems across 4,458 households from 329 villages in the West African Guinea Rainforest. Their findings highlighted a strong potential for increasing cocoa yields through the adoption of improved varieties and fertiliser technologies. They argued that such intensification strategies could enhance productivity while simultaneously reducing deforestation and carbon emissions in Côte d'Ivoire, Ghana, Nigeria, and Cameroon. Focussing on Indonesia, Toledo-Hernandez et al. (2020) conducted field experiments to evaluate the effects of agrochemical inputs and pollination enhancement through hand pollination on cocoa yields. Their results demonstrated that hand pollination (both partial and complete), was the primary driver of increased yields per tree and higher annual income for farmers, while the use of fertilisers and insecticides showed no significant effect on yields. Similarly, Tothmihaly et al. (2019) examined environmental efficiency in Indonesian cocoa farms using data from 208 farmers and the Cocoa Production Frontier Model under a translog output distance function framework. Their findings suggested that cocoa intensification was associated with increased ecosystem degradation and that farmers exhibited low mean efficiency, underscoring the challenges of sustainable intensification.

Sassen et al. (2022) investigated the potential environmental risks of cocoa expansion and intensification by mapping areas critical for biodiversity and ecosystem services, such as carbon storage, water resources, and forest products. Their study revealed that further cocoa expansion could pose serious threats to ecologically important areas, with impacts varying

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across different regions. Additionally, they highlighted that these risks could be exacerbated by climate change, emphasising the need for context-specific strategies to mitigate environmental harm while supporting sustainable cocoa production. Toledo-Hernández et al. (2023) conducted a series of experiments in Bahia, Brazil, using cocoa trees grafted with high-yielding varieties along a shade gradient ranging from low (10–30%) to high (70–100%) canopy cover. The study found that hand-pollinating just 10% of the flowers per tree resulted, on average, in a 331% increase in fruit set and a 300% increase in mature fruits (ripe pods) per tree, compared to trees that relied solely on natural pollination. When examining labour inputs, minimal effort (approximately five minutes per tree to pollinate 10–30% of the flowers) under low canopy conditions led to an 871% increase in fruit set and a 750% increase in mature fruits. In contrast, intermediate effort (around 15 minutes per tree to pollinate 40–60% of the flowers) under high canopy cover produced a 629% increase in fruit set. The study concluded by recommending that future research explore a broader range of innovative strategies to support sustainable cocoa production on a global scale.

3.4.2 Sustainable cocoa intensification in Ghana

Ruf et al. (2006) used a quantitative approach with 20 m × 20 m density squares to assess farmers' perceptions of agroforestry by counting cocoa and non-cocoa trees by age class. The study identified promising shade tree species and highlighted that farmers required higher returns per hectare and more selective shade trees to enhance the yield of hybrid cocoa varieties. Gockowski et al. (2013) explored the impact of cocoa certification on productivity and income in Ghana, while preserving environmental services. They compared the Rainforest Alliance certified shade-grown cocoa system with both extensive shaded and full-sun systems under intensification. While the full-sun system under

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intensification was most profitable, the certified shade-grown cocoa system maintained environmental services, yielding positive returns. Similarly, Alemagi et al. (2015) advocated for tree integration in cocoa farming, suggesting that vegetative propagation and agroforestry could enhance productivity, biodiversity, and income in Cameroon.

Kongor (2017) conducted an in-depth examination of the determinants of cocoa productivity and profitability amongst smallholder farmers in Ghana, offering valuable insights to shape policies aimed at promoting sustainable cocoa intensification. The study found that educational attainment amongst cocoa farmers was relatively low, with the majority (50.9%) having only completed middle or junior high school, while secondary and tertiary education levels remained low at 9.6% and 4.0%, respectively. Household sizes were generally large, with 71.5% of farmers living in households comprising five to nine members. In terms of farming experience, 43.5% of cocoa farmers had been cultivating cocoa for 11 to 20 years, whereas only 12.3% had over three decades of experience. Land tenure emerged as a pivotal factor, with 63.9% of farmers owning their cocoa farms, while 25.5% and 5.6% operated under the '*Abunu'* and '*Abusa'* sharecropping arrangements, respectively, and just 5.0% cultivated cocoa on family-owned land. Farm sizes were predominantly small, with 65% of farmers cultivating plots of less than five hectares, while only 12.2% managed farms exceeding eight hectares. The study also revealed gaps in adherence to recommended agronomic practices. Only 35% of farmers implemented capsid control measures four times per season, while only 14% adhered to the recommended six treatments per season for black pod disease. Fertiliser application was also suboptimal, with 61% applying fertilisers once per season as advised, whereas 38.6% did not use any. In terms of farm age, 43.2% of cocoa farms were between 11 and 20 years old, while 26.8% were between one and ten years old.

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Contradicting earlier estimates by COCOBOD (2013), which suggested that 23% of cocoa farms in Ghana were over 30 years old, Kongor (2017) found this figure to be significantly lower at only 8.5%. Hybrid cocoa varieties developed by CRIG dominated cultivation, accounting for 57.7% of cocoa farms, although the Amazonia variety remained the most widespread in the Western (48.2%) and Ashanti (44.3%) regions. Additionally, 64% of cocoa farms were situated on flat terrain, while 23.8% and 7.7% were located on sloped and hilly landscapes, respectively. Lastly, Kongor (2017) cited CRIG's recommendation for optimal cocoa tree spacing of 3m x 3m, a planting arrangement that results in a density of 1,111 trees per hectare. In southwestern Ghana, Tetteh et al. (2018) examined how cocoa farming influences biodiversity and ecosystem services across various management systems. They found that intensification of cocoa farming systems reduced biodiversity and ecosystem services, such as tree species diversity and soil health, compared to traditional farming. Furthermore, Boeckx et al. (2020) investigated the link between poverty, climate change challenges, and sustainable cocoa intensification by testing three scenarios. The study found that agroforestry for climate change adaptation could enable cocoa farmers to achieve a living income while providing ecosystem services such as greenhouse gas mitigation. However, farmers' willingness to invest in tree planting was influenced by customary land tenure arrangements.

Heidenreich et al. (2022) evaluated the eco-efficiency of smallholder perennial cash crop production in Ghana and Kenya using cocoa, coffee, macadamia, and mango. Applying the DEA and order-m approaches, the study found significant variability in cocoa eco-efficiency, indicating potential for improvement within Ghana's cocoa production systems. Consistent with Boeckx et al. (2020), farmers' willingness to invest in tree planting was influenced by landownership, capacity development, and resource availability, including labour. Bandanaa et al. (2024) assessed organic and conventional smallholder cocoa

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farming systems in Ghana using the SAFA Guidelines and the Sustainability Monitoring and Assessment Routine (SMART)-Farm Tool. The study found that organic farming demonstrated notable synergies in environmental dimensions, such as improved soil quality and energy efficiency, as well as strong alignment between biodiversity conservation and risk management. In contrast, conventional farming was associated with potential vulnerabilities, including trade-offs related to long-term investments, particularly the reliance on chemical inputs, and diminished species diversity.

3.4.3 Determinants of sustainable intensification adoption

The adoption of SIPs has been widely studied across diverse agricultural contexts, highlighting both commonalities and unique drivers of adoption. Kassie et al. (2013) identified household-level and environmental factors that influence sustainable agricultural practices in Tanzania. Rainfall variability, pest and disease shocks, and plot characteristics were found to interact with institutional elements such as tenure security and extension services, shaping the adoption of intercropping, soil conservation, and other sustainable practices. Vanlauwe et al. (2014) highlighted the need for tailored sustainable intensification strategies suited to Africa's heterogeneous smallholder systems. This call for context-specific approaches was also echoed by Kassie et al. (2015), whose work in Eastern and Southern Africa revealed that SIPs such as improved maize varieties and crop rotation are often complementary, with adoption decisions influenced by social networks, education, and market access. Similarly, Kotu et al. (2017) explored SIPs adoption in Ghana, showing that access to capital, training programmes, and markets drives integrated technology adoption, leading to improved productivity and incomes. This diversity in adoption was further emphasised by Ortega et al. (2016), who analysed farmers' preferences for intercropping maize with groundnut, soybean, and pigeon pea, while identifying factors

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that hinder or promote adoption in Malawi. They found that labour constraints and market access influenced farmers' preferences for diversifying maize monocrops with legumes.

The importance of socio-economic and technical networks was further evidenced by Keil et al. (2017) in their study on zero-tillage adoption in the Indo-Gangetic Plains, where smallholders' reliance on social networks and the time-saving benefits of the practice was pivotal. This interconnection between social systems and sustainable practices was reinforced by Wuepper et al. (2018), who highlighted the role of training and peer learning in adopting organic fertilisers in Ghana's pineapple sector. Other studies, such as Rahn et al. (2018), focused on the interaction between ecological and socio-economic factors. Their findings on intercropping in Uganda's coffee systems revealed that altitude and perception of climate change significantly influenced adoption. Likewise, Owusu et al. (2022) examined farmers' perceptions regarding the economic and ecological benefits of varying cocoa agroforestry shade levels. Their findings revealed that, beyond market-driven factors, farmers' ecological perceptions significantly influence the establishment of shade levels. The authors advocated for policy interventions aimed at raising awareness and enhancing knowledge of cocoa agroforestry systems, highlighting these as critical components in promoting sustainable agroforestry practices. Heidenreich et al. (2022) found that eco-efficiency scores, derived from order-m analysis, were largely shaped by factors related to capacity development and resource endowments, such as labour and land, while the crop production environment had a smaller impact.

Maré et al. (2022) analysed land tenure and credit access as critical drivers of sustainable agricultural intensification in Burkina Faso, advocating for integrated credit policies. Similarly, Adams et al. (2024a) emphasised gender-specific drivers in Ghana, where female adoption decisions were shaped by perceived ease of adoption and group membership, while male decisions reflected a broader array of factors. Nyarindo et al. (2024) analysed

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adoption patterns and payoffs from 10 SI practices in Kenya using a three-wave panel survey and a random effects multinomial logit model. Results reveal that extension contacts, farm labour, household wealth, and education positively impact SI adoption, while rented plots and poor soil quality deter it. Crop yield, costs, revenue, and income varied significantly across SI clusters, suggesting the need for tailored extension approaches. Tennhardt et al. (2024) explored the effects of increased household labour availability on pest and disease management (PDM) practices in Ugandan cocoa farms during COVID-19 lockdowns. Increased labour availability, averaging 0.8 additional household members, facilitated the adoption of alternative PDM practices, reducing pesticide use and costs. Farmer training and trust in alternative practices were stronger adoption drivers than labour availability. Psychosocial factors were examined by Issaka et al. (2024) using a behavioural framework, identifying social influences and facilitating conditions as key predictors of SIP adoption amongst rice farmers in northern Ghana. Finally, Jumpah et al. (2024) emphasised the need to consider agroecological variables in explaining smallholder adoption behaviours, advocating for farm-level research to bridge current gaps.

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3.4.4 Incentives that motivate cocoa farmers to switch to sustainable practices

The literature highlights price premiums as the primary market-based incentive, encouraging cocoa farmers to adopt sustainable practices. Jambo et al. (2019) examined intrinsic and extrinsic motivations for adopting SIPs amongst farmers in Malawi and Tanzania. They found that decisions to adopt SIPs were influenced by both external incentives and intrinsic values associated with farming practices, with financial constraints being a significant barrier. Quarmine et al. (2012) examined the institutional factors limiting farmers' incentives to improve cocoa bean quality in Ghana, using data from three

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levels of the value chain: village, district, and national. Employing multi-stage cluster sampling, the study surveyed 120 farmers and 12 licensed buying company agents. The findings revealed that while all actors in the sector value quality, their interactions are undermined by information asymmetries, leading farmers to disregard recommended practices that enhance bean quality. Although cocoa sector policies safeguard the export of premium-quality beans, they have done little to resolve these information asymmetries, particularly between farmers and purchasing agents. The study recommended exploring self-selection mechanisms, such as quality testing with price premiums, to mitigate these asymmetries and incentivise better practices.

Mahrizal et al. (2012) analysed the price premiums needed to incentivise farmers in Ghana to switch from conventional to organic cocoa production. Their model suggested a price premium between 28% and 30% to compensate for a 30% yield loss. Tsiboe et al. (2018) extended this analysis, estimating yield differences amongst cocoa varieties and systems. Their results indicated that switching to an environmentally friendly production system resulted in a 20% yield loss, necessitating a 20% price premium. Using data from the Ghana Living Standards Survey and the Tulane Child Labour Survey, Luckstead et al. (2019) found that eliminating child labour would require an 11.81% price premium without affecting farm household welfare. Bandanaa et al. (2021) found that organic farming systems outperformed their conventional counterparts in terms of profitability (by approximately 20%), largely due to market premiums, as well as in promoting gender equity and demonstrating a verbal commitment to sustainability issues. Vanlauwe and Dobermann (2020) found that, for farmers to adopt SIPs in the short term, these must deliver a noticeable yield increase alongside a profit gain of at least USD 50 per hectare. Without such immediate, tangible benefits, alternative technologies are unlikely to succeed. They further argued that while incentive schemes like payments for environmental services

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(PES) can offer additional benefits, it is difficult to envision a sustainable intensification model for sub-Saharan Africa succeeding on that basis alone. On their part, Piñeiro et al. (2020) conducted a scoping review to examine how incentives offered to farmers influence the adoption of sustainable agricultural practices and whether these incentives lead to tangible outcomes. The review found that, irrespective of the type of incentive, programmes offering short-term economic benefits achieve higher adoption rates than those focused solely on delivering ecological services. It further underscored the critical role of technical assistance and extension services in fostering the uptake of sustainable practices. Jacobi et al. (2017) investigated key barriers to agroforestry adoption and the incentives proposed by farmers and civil society organisations, linking these to governance structures and international mechanisms that could support uptake. The study found that farmers required the greatest support during the initial phase, when investment costs are high and returns minimal, recommending affordable credit, subsidies for diversified farming systems, and fire insurance as priority incentives. Bakali et al. (2023) examined evidence on the impact of incentives in promoting the adoption of conservation agriculture practices. Their findings identified four types of incentives evaluated: Agri-Environment Schemes (AES)/Payments for Ecosystem Services (PES), input subsidies, direct subsidies, and market-based incentives. The study found that both PES and input subsidies had significant and positive effects on the uptake of conservation agriculture.

3.4.5 Impact of sustainable intensification on productivity, household income and household food security in Sub-Saharan Africa

The impact of sustainable intensification (SI) on farm productivity, household income, and food security has been examined across Sub-Saharan Africa, revealing its multifaceted benefits. Kotu et al. (2017) analysed data from Ghana using a multivalued semi-parametric

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treatment effect (MVTE) model to assess the effects of adopting multiple SIPs. Their findings demonstrated that integrating commercial inputs with cultural practices significantly enhanced farm productivity and household income, highlighting the effectiveness of a combined approach in improving farm performance in the region. Building on this, Nkomoki et al. (2018) explored the relationship between sustainable agricultural practices and food security in Zambia using a Probit model. Their study found that practices such as crop diversification and agroforestry positively influenced food security, as measured by the Food Consumption Score and the Household Hunger Scale. This connection underscores SI's role not only in boosting productivity but also in ensuring access to nutritious food for farming households. Extending the scope to child nutrition, Kim et al. (2019) utilised data from the Tanzania National Panel Survey to assess the impact of SI practices on rural Tanzanian households. The study categorised households into groups such as "Non-adoption" and "Sustainable Intensification" based on soil fertility management practices. The results revealed that "Sustainable Intensification," characterised by the combined use of inorganic and organic fertilisers or maize-legume intercropping, led to improved child nutrition outcomes compared to non-adopters, emphasising the broader societal benefits of SI beyond agricultural gains.

In a related context, Yahaya et al. (2018) examined the role of SI training programmes in North-western Ghana, employing an endogenous treatment effects model. The study highlighted that participation in SI training significantly enhanced household food access, as measured by the HFIAS. This finding emphasises the importance of knowledge transfer and capacity building in promoting sustainable agricultural practices that address food insecurity challenges. Similarly, Setsoafia et al. (2022) investigated the adoption of SI practices such as improved seeds, fertilisers, and soil and water conservation. The study revealed that the simultaneous adoption of these practices resulted in greater improvements

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in farm income and food security than adopting them individually. This reinforces the value of a holistic approach to sustainable intensification in achieving comprehensive agricultural and socio-economic benefits. Complementing these studies, Abdallah et al. (2021) utilised data from the Africa RISING project and the Afrint II survey to assess the effects of SI adoption on farm income and food security. By employing multinomial endogenous treatment effect models, the study confirmed that the joint adoption of SIPs yielded superior outcomes compared to adopting individual practices or none at all. This further affirms that integrated SI strategies are crucial for maximising both economic and food security benefits across Sub-Saharan Africa.

3.5 Chapter Summary

The literature review reveals critical insights and gaps regarding the adoption of SCIPs and their multidimensional impacts. Studies highlight the complexity of assessing sustainable intensification due to the multidimensional nature of the concept and the need to integrate economic, social, and environmental dimensions. The reviewed studies underscore the fragmented approach to the adoption of SCIPs, focusing predominantly on the incorporation of shade trees in cocoa orchards and organic farming while neglecting bundled adoption with critical practices such as water management, pest control, soil fertility improvement, and labour optimisation. Moreover, the lack of integration across multiple dimensions of the concept, particularly the underrepresentation of the social dimension, limits a comprehensive understanding of the adoption of SCIPs and their impacts. The determinants of the adoption of SCIPs remain insufficiently explored in the cocoa farming context. While studies on other crops provide valuable insights, they fail to highlight the bundled adoption of cocoa-specific practices such as shade management, pruning, tree rehabilitation, and hand pollination, which are vital for closing yield gaps.

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Addressing these gaps is essential for designing effective policies and strategies to promote SI adoption in cocoa farming. Also, the reviewed studies highlight the pivotal role of both price and non-price incentives in motivating farmers to adopt sustainable practices, but their relevance to cocoa farming remains inadequately explored. Studies on price incentives quantify premiums needed to offset yield losses but fail to link these incentives to broader SCIPs adoption. Similarly, non-price incentives such as technical assistance, land tenure security, and community management are discussed in general agricultural systems but lack direct application to the specific challenges of cocoa farming. Finally, the transformative potential of SI in Sub-Saharan Africa is well-documented, demonstrating improvements in productivity, income, and food security. However, the absence of cocoa-focused research reveals a significant gap in understanding how sustainable intensification impacts cocoa yield and household welfare. My research seeks to address these gaps by broadening the scope of SCIPs to cover the three main dimensions of the concept: economic, environmental, and social. It also seeks to provide robust, context-specific empirical evidence of their interdependencies and their impact on yield, farm income and household food security.

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CHAPTER FOUR

METHODOLOGY

4.1 Introduction

This chapter, divided into four sections, presents the methodology employed for this study. Section 4.2 presents the theoretical framework underpinning the study. This includes the random utility theory (RUT) and the modified technology acceptance model (modified TAM), which form the framework for the various analyses in this study. A description of the study design, which looks at the study area, sampling procedure, and data collection methods, is presented in section 4.3. This is followed by Section 4.4, which describes the method of analysis for each objective of this study. Finally, Section 4.5 presents the definitions of the dependent, outcome, and explanatory variables used in the various analyses in this study.

4.2 Theoretical Framework

4.2.1 Diffusion of innovations theory

Diffusion of Innovations Theory (Rogers, 2003), offers a comprehensive explanation of how new ideas, practices, or technologies are communicated and adopted within a social system over time. It posits that the adoption of innovation occurs through five stages (i.e. knowledge, persuasion, decision, implementation, and confirmation) and is influenced by five key attributes: relative advantage, compatibility, complexity, trialability, and observability. In this study, the theory provides a framework for understanding the full adoption process of SCIPs. The knowledge stage is linked to access to research and information. The persuasion stage is influenced by extension services, training, social networks, and farmer characteristics such as education, gender, age, and experience. The decision and implementation stages are shaped by socioeconomic, institutional, and

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agroecological factors, including risk perception, access to credit, labour availability, and farm characteristics. Finally, the confirmation stage is reflected in observed outcomes, particularly cocoa yield, farm income, and household food security, which reinforce continued adoption decisions.

However, the theory is not without its limitations. It assumes a relatively linear and rational adoption process, often underplaying the impact of structural and economic constraints, such as lack of access to credit, markets, or extension services, which are factors especially relevant in developing contexts. It also tends to overlook the role of institutional dynamics, policy environments, and socio-cultural factors like gender norms and land tenure systems. Regardless, it is relevant in explaining farmers' adoption of SCIPs in Ghana. Adoption of SCIPs such as hand pollination, organic fertilisers and pesticides, pruning, and shade tree management may follow patterns consistent with the theory's stages and adopter categories. Farmers may begin with limited knowledge gained through extension agents, cooperatives, or peer networks, and progress to adoption as they observe tangible benefits. Innovations that are less complex, trialable on a small scale, and visibly effective can spread more quickly. Moreover, early adopters in cocoa-growing communities may serve as local influencers who catalyse broader behavioural change.

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4.2.2 The random utility theory (RUT)

The RUT assumes that individuals are rational decision makers, maximising utility relative to their choices (McFadden, 2001;1974; Luce, 1959). It is conceptually dependent on utility-maximising behaviour based on the Lancaster Consumer Theory (Lancaster, 1966), which postulates that decision makers (e.g., farmers) are not interested in goods (e.g., crops or production technologies) per-se, but in the role of attributes or characteristics shared by more than one good that gives them utility (Walker and Ben-Akiva, 2002). Consequently,

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utility becomes a function of good or service attributes, and not the actual good or service. This implies that cocoa farmers would weigh among various attributes of available sustainable cocoa intensification options, and choose the option with the highest relative utility.

The RUT models the decision of farmers to use one or multiple SCIPs to be based on the utility or satisfaction gained by the individual farmer from the SCIP. A farmer, *i,* confronted with a choice amongst *J* SCIPs with option *j* associated with utility U_{ij} (where j = 1, …, J), will choose the SCIP if and only if $U_{ij} > U_{im} \ \forall j \neq m$. However, since it is impossible to observe or accurately predict the chosen SCIP by the farmer, probabilities can be attached to the chosen SCIP (U_{ij}) such that, $U_{ij} > U_{im} \ \forall j \neq m$. The utility of choosing alternative SCIPs is a latent variable that can be decomposed into an additive combination of observable (deterministic) and unobservable (random/ stochastic) components. This can be specified as:

$$U_{ij} = V_{ij}(X_{ij}, Z_i) + \varepsilon_{ij} \qquad (4.1)$$

where (U_{ij}) is the utility derived by farmer "i" from the alternative choice "j". The deterministic part (V_{ij}) is defined as a function of the attributes of the various alternatives (X_{ij}) as well as plot and farmer-specific characteristics (Z_i), and can be measured as a function of several predictor variables or through their interactions. The stochastic component (ε_{ij}) captures the unobserved heterogeneity across individuals and alternatives, defined as the difference between true utility (U_{ij}) and the observable component which is captured in V_{ij}. the distribution of ε_{nj} depends greatly on the specification of V_{nj}. Since we do not know $\varepsilon_{nj} \ \forall \ j$, we treat these terms as a random variable from our perspective. Thus,

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the joint density of the random vector is $\varepsilon_i = \{\varepsilon_{i1}, \ldots., \varepsilon_{ij}\}$, denoted as $f(\varepsilon_i)$. Therefore, we can rewrite equation (4.1) as:

$$U_{ij} = V(X_{ij}, Z_i) + \varepsilon(X_{ij}, Z_i) \tag{4.2}$$

However, the probability that a farmer (i) drawn randomly from the population would select SCIP *j* among a set of SCIPs *m* equals:

$$\begin{aligned} P_{ij} &= Prob(U_{ij} > U_{im} \; \forall \; m \neq j) \\ &= Prob\big(V_{ij} + \varepsilon_{ij} > V_{im} + \varepsilon_{ij} \; \forall \; m \neq j\big) \\ &= Prob\big(\varepsilon_{im} - \varepsilon_{ij} < V_{ij} - V_{im}\big). \end{aligned} \tag{4.3}$$

This probability is a cumulative distribution, that is, the probability that each random term $\varepsilon_{im} - \varepsilon_{ij}$ is less than the observed quantity $V_{ij} - V_{im}$. Various choice models are derived from various assumptions about the distribution of the unobserved fraction (error term) of utility. In this study, different choice models like the Multivariate Probit, Multinomial Logit and the Multinomial Endogenous Switching models were derived from the RUT by assuming different specifications of the probability density of the unobserved component (Train, 2009; Walker and Ben-Akiva, 2002; McFadden, 2001).

4.2.3 The modified technology acceptance model (modified TAM)

Technology acceptance is the voluntary choice of an individual to accept and use a new technology (Blasch et al., 2022). The technology acceptance model (TAM) (Davis, 1989) consists of two main constructs: *perceived usefulness* and *perceived ease of use* of the new technology (Davis et al., 1989). *Perceived usefulness* is generally defined as the extent to

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which a person believes that using a new technology will help in enhancing his/her performance (Blasch et al., 2022). Thus, cocoa farmers would shift from their business-as-usual (or conventional) production system to adopting SCIPs if they believe that the adoption of these practices would enhance their productivity and livelihood outcomes.

On the other hand, *perceived ease of use* refers to how a potential user of a new technology will bear minimum effort on his/her expense (Blasch et al., 2022). The implication of this construct to this study is that cocoa farmers would adopt SCIPs if they believe that the adoption of these practices would not lead to an increase in the cost of production or a loss in profitability.

Devaraj et al. (2008) incorporated other latent variables like *perceived risk* into the basic TAM framework based on the belief that the intention to use a new technology contains uncertainty about the outcome, and this uncertainty is a perceived risk. Thus, *Perceived risk* refers to the negative outcome that is expected to occur in the process of the farmer's implementation of the SCIPs, and the psychological expectation of the seriousness of the consequence if it occurs. Studies, including Blasch et al. (2022), Li et al. (2020), and Thompson et al. (2019), have confirmed that social influence and facilitating conditions have noteworthy effects on the intention of users to accept a new technology. *Social influence* refers to the extent to which an individual farmer believes that the adoption of SCIPs can enhance their profile and status in the social system (amongst peers and acquaintances). *Facilitating conditions*, on the other hand, refer to the extent to which farmers perceive that institutions would support their use of SCIPs. This is determined by the presence of adequate technological infrastructure and technical support to encourage the adoption of SCIPs.

The modified TAM framework serves as the theoretical basis for understanding the set of incentives that can encourage the transition from being a non-adopter to an adopter of

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SCIPs. This is justified by the narrative that smallholders need immediate returns on their investments, mostly in terms of increased yields to achieve greater profit (Vanlauwe & Dobermann, 2020). Thus, any new agronomic intervention (such as new and improved inputs, improved practices, and new technology) must lead to an immediate recognisable yield and profit increase to be of interest to farmers. Without such immediate benefits, any alternative input, practice or technology may not be adopted. Thus, smallholder cocoa farmers in Ghana may not be willing to opt for environmentally beneficial practices if appropriate incentives do not, at least, offset the short-term profit forgone as a result of adopting these practices (Vanlauwe & Dobermann, 2020; Tsiboe et al., 2018; Mahrizal et al., 2012).

4.2.4. Agricultural sustainable intensification assessment frameworks

The Sustainable Intensification Assessment Framework (SIAF) and the Sustainability Assessment of Food and Agriculture Systems (SAFA) are notable frameworks that provide structured approaches to evaluate and enhance the sustainable intensification of agricultural systems across environmental, economic, social, and institutional dimensions.

The Sustainable Intensification Assessment Framework (SIAF), proposed by USAID's Feed the Future programme, assesses plot-level sustainable intensification based on five dimensions: productivity, economic viability, environmental sustainability, social well-being, and resilience of farming systems (Hammond et al., 2021; Musumba et al., 2017). It has been applied to study nitrogen delivery methods in Malawi (Snapp et al., 2018) and forage innovations in Tanzania (Fischer et al., 2018). The development of indicators of sustainable intensification such as yield, economic returns, soil health, agroforestry practices, and adaptive measures like water harvesting and pest management have been guided by SIAF (Pollesch and Dale, 2015; Singh et al., 2012).

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On the other hand, the Sustainability Assessment of Food and Agriculture Systems (SAFA), developed by the FAO (FAO, 2014), evaluates food and agricultural systems across four dimensions: good governance, environmental integrity, economic resilience, and social well-being (Bandanaa et al., 2024; Leknoi et al., 2023). The *Good governance* dimension emphasises transparent decision-making, participatory processes, and equitable resource management, including alignment with national policies and farm transparency (Leknoi et al., 2023; Konefal et al., 2023). The *Environmental integrity* dimension focusses on biodiversity conservation, pollution control, greenhouse gas reduction, and sustainable land and water use (Bandanaa et al., 2024; Leknoi et al., 2023; FAO, 2014). The *Economic resilience* dimension evaluates financial viability, market integration, and income diversification to reduce the dependency of farm households on cocoa. *Social well-being* examines labour standards, gender equity, community impacts, and food security (Bandanaa et al., 2024; Robling et al., 2023; Leknoi et al., 2023).

4.3 Study Design

The study adopts a quasi-experimental research design within a mixed-methods framework to examine the adoption of SCIPs among cocoa farmers in Ghana during the 2022/2023 production season. Quantitative data were collected through a structured household questionnaire administered to cocoa farmers, enabling empirical analysis of adoption behaviour and outcomes. Complementary qualitative data were obtained through semi-structured interviews with key informants, including cocoa farmers, extension officers, agricultural researchers, and other industry stakeholders, to explore the incentives underpinning SCIP adoption. A triangulation approach was employed by integrating evidence from both quantitative and qualitative sources to enhance the robustness and validity of the findings.

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4.3.1 Study areas

The study was conducted across six political regions of Ghana: Ashanti, Ahafo, Bono, Bono East, Eastern, and Western North (Figure 4.1). These regions cover four cocoa regions (i.e, Eastern, Ashanti, Brong Ahafo and Western North cocoa regions) created by COCOBOD for effective input distribution and policy targeting. They are the leading cocoa-producing regions in Ghana. They represent diverse agroecological and socio-economic settings, providing an ideal backdrop to explore the adoption of SIPs. Known for their lush vegetation and fertile soils, the Western North as well as parts of the Ashanti, Ahafo, and Eastern regions form part of the wettest rainfall areas of Ghana. Their semi-equatorial climate features a bimodal rainfall pattern characterised by two rainy seasons (April–June and September–November) that provide ample rainfall to sustain cocoa growth, together with other food crops. Their annual rainfall ranges from 1,250–1,750 mm, with temperatures averaging between 21°C and 32°C. Characterised by fertile reddish-brown Ferric Acrisols and Lixisols, the soils in these regions which are dominated by low-activity kaolinite clays and sesquioxides of iron and aluminium, with a pH of 5.1–6.5, are well-suited to cultivating cocoa (Amponsah-Doku et al. 2022; Amfo et al., 2021; Abdulai et al., 2020; Lahive et al., 2019). Also, the presence of dense undergrowth and forest trees, including *Milicia excelsa* (African teak or Iroko or Odum), *Terminalia ivorensis* (Black Afara or Emeri), *Terminalia superba* (African limba wood or Ofram), *Triplochiton scleroxylon* (African White wood or Wawa), *Ficus exasperata* (Sandpaper tree or Nyankyerene), *Khaya ivorensis* (African mahogany or Odupon) makes these regions suitable since cocoa is a shade loving crop (Abdulai et al., 2018; Anim-Kwapong & Frimpong, 2008). Also, the bimodal rainfall distribution, coupled with the temperature ranges and forest features, is conducive for cocoa growing processes such as

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photosynthesis, leaf flushing, flower production, pod setting and pod maturation (Asante et al., 2022; Dzandu et al. 2021).

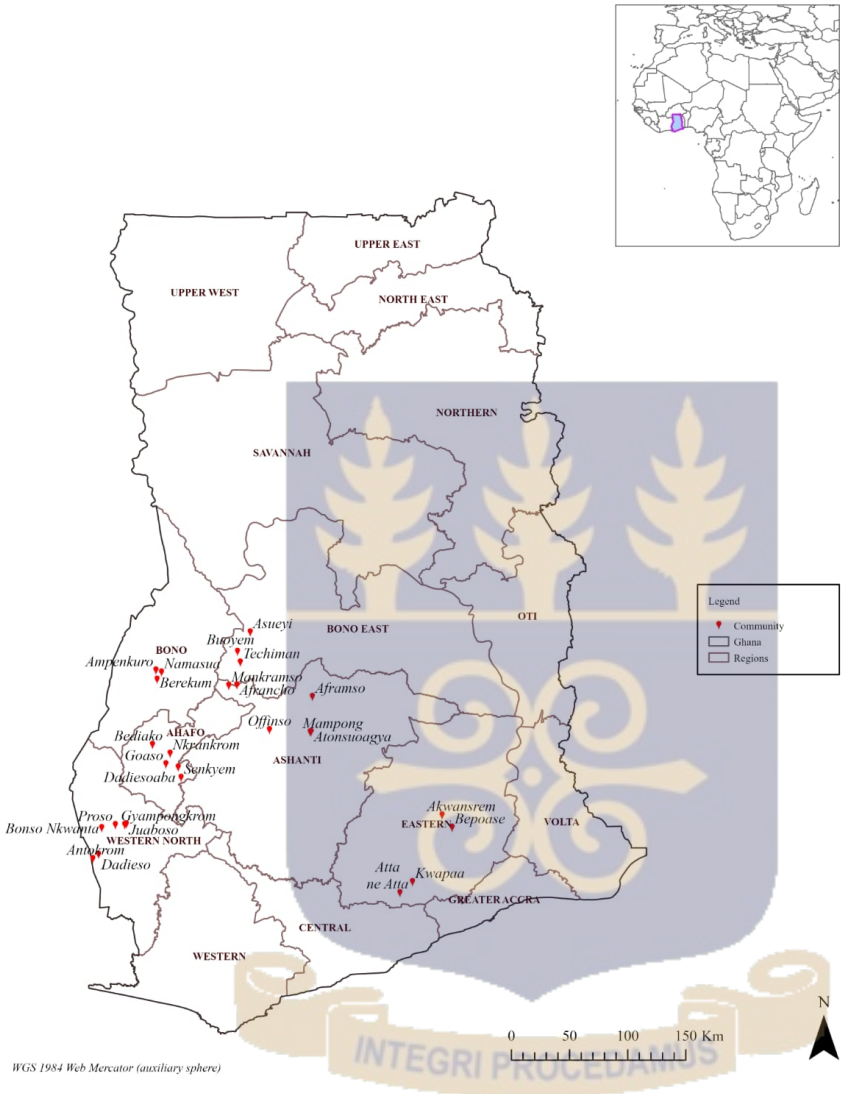


Figure 4.1: A map showing the study areas

However, these regions experience dry spells from July to August and harmattan winds from December to February, necessitating the adoption of SCIPs including efficient water management and irrigation systems to ensure continuity in agricultural production. In recent times, cocoa production in these regions has suffered from the adverse impact of climate change and variability. Parts of the Eastern, Ahafo, Ashanti, and Western North

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cocoa regions have recorded unpredictable rainfall characterised by either excessive rainfall leading to crop loss as a result of the escalation of Blackpod disease, or low rainfall leading to poor pod setting due to water stress. They are also hubs of recent cocoa expansion, illegal logging, and associated encroachment into protected areas. These regions are characterised by an annual deforestation rate of approximately 2.2%, compared to a 2% per annum national rate (Kalischek et al., 2023; Wainaina et al. 2021). This gives an indication that land, forest, wildlife and water resources remain under threat of degradation in these regions.

At the same time, parts of the Ahafo, Bono, Bono East and Ashanti regions lie along the northern cocoa belt with a climate gradient characterised by the Forest-Savanna transitional zone with dry semi-deciduous vegetation. They have undergone vegetation changes from dense forest to a Forest-Savanna transition, with intensifying savanna agroecological conditions characterised by a prolonged dry season with wildfires occasionally destroying farms (Amisah et al., 2010). This transitional agroecological zone serves as a critical intermediary between the dense forests of the south of Ghana and the drier savanna landscapes to the north, encompassing parts of the Bono, Bono East, Ahafo, and Ashanti regions. It experiences a moderate climate with annual rainfall between 1000 and 1300 mm and temperatures between 26 and 37°C. The vegetation is a mix of moist semi-deciduous forest and Guinea savanna, with scattered trees and grasslands. The region's soils, predominantly Ferric Luvisols and Acrisols, offer moderate fertility but necessitate deliberate soil management practices to maintain productivity. Deforestation, land degradation, and soil nutrient depletion, largely driven by continuous cropping and improper land-use practices, have contributed to declining agricultural yields. Climate variability further exacerbates these issues, as irregular rainfall patterns and prolonged dry spells disrupt traditional farming cycles. It is projected that unmitigated climate risks will

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render cocoa production in these areas unsuitable by 2050 (Asante et al., 2021; Bunn et al., 2019). The average annual mean temperature is projected to increase by 1–3°C and 1.5–5.2°C by the years 2060 and 2090 respectively. Likewise, the mean amount of rainfall is projected to fall by 12 mm, with most of the changes expected to take place after 2030 (Anning et al., 2022; Laderach et al. 2013; Wongnaa and Babu, 2020).

4.3.2 Sampling procedure

A four-stage sampling approach was employed to sample cocoa farming households in the six politically administered regions in Ghana. At the first stage, four regions with substantial cocoa production were purposively selected based on their production volumes and geographical diversity (to capture differences in agroecological zones and environmental conditions). They were the Eastern, Ashanti, Ahafo, and Western North political regions. In recent times, cocoa production in these regions has suffered from the adverse impact of climate change and variability as well as cocoa-driven deforestation. This gives an indication that land, forest, wildlife and water resources remain under threat of degradation in these regions. Over time, the Ahafo, Bono, Bono East, and the northern part of the Ashanti regions have experienced change in vegetation type from moist semi-deciduous to forest-savannah transition, with a large amount of Guinea Savannah vegetation. Most parts of this transition zone, which were originally forested and supported cocoa production, have lost most of their forest cover through degradation from both human and natural causes, and are now a derived savannah-forest mosaic unsuitable for cocoa production. Thus, purposively sampling these regions ensured that the study area covered the dry (Ahafo and Northern part of Ashanti regions) and wet (Western North and Eastern) zones, which aligned with the different climate suitability zones of the current cocoa-growing areas of Ghana.

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From each region, two districts were selected using stratified random sampling at the second stage of the sampling procedure. All the districts in each region were stratified into two strata (high, low yield) based on cocoa production intensity. Random sampling was then applied to select one district from within each stratum. This was to ensure representation of diverse production levels at the district level. Two additional districts, Berekum and Techiman, were purposively selected from the Bono and Bono East regions respectively. The criteria for purposively sampling them was their characteristic position in the Forest-Savanna transitional zone.

A comprehensive list of all cocoa-farming communities in each selected district was compiled, after which two communities were randomly selected per district at the third stage of the sampling procedure. This was to avoid any geographical or production-level bias. In each community, a comprehensive sampling frame of cocoa-farming households was compiled at the fourth stage of the sampling procedure. The list of cocoa farmers was obtained from the agricultural extension offices at the Cocoa Health and Extension Division (CHED) of COCOBOD in the study districts. The households were then stratified into subgroups based on key demographic characteristics such as gender of household head, youth status, and whether the household head was a migrant farmer, as these factors were deemed relevant to the research objectives. This approach is supported by Bisseleua et al. (2018), Kent and MaRee (2010), and Brockington (2001), who argued that there is uneven male and female participation in agricultural innovation and suggested a stratified sampling approach to enhance the representativeness of the sample with respect to these critical variables. Within each stratum, a simple random sampling technique was employed to select farm households – *members living together and eating from the same pot regularly, including those temporarily absent* (Simpson, 2012; Burch, 2001).

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4.3.3 Sample size determination

The minimum sample size estimation procedure through a power analysis was done to ascertain the minimum sample size required to detect the expected approximate impact of at least a 12% increase in yield and farm income with 95% confidence and 90% power (Luckstead et al., 2019; Tsiboe et al., 2018; Mahrizal et al., 2012). The Sullivan and D'Agostino (2003) formula was specified as:

$$n = (Z_{1-\alpha/2} + Z_{1-\beta})/ ES \quad (4.4)$$

Where: n = sample size

α = the selected level of significance

Z = Z-score corresponding to the 95% confidence level

$Z_{1-\alpha/2}$ = the value from the standard normal distribution holding 1- $\alpha/2$ below it. For α=0.05, 1- $\alpha/2$ = 0.975 and Z=1.960.

1- β = the selected power of 90%

$Z_{1-\beta}$ is the value from the standard normal distribution holding 1- β below it. Thus, $Z_{0.90}$ = 1.28

ES = effect size [which is assumed to be 12% increase yield, farm income and household food security (Luckstead et al., 2019; Tsiboe et al., 2018; Mahrizal et al., 2012)]

Thus,

$$n = \frac{(1.96 + 1.28)^2}{(0.12)^2} = 729$$

This implies that a sample size of approximately 729 households would be required to detect an effect size of 12% increase in yield or farm income with 95% confidence and 90% power. As explained by Barlett et al. (2001), this estimate indicates the minimum sample size and that there is the need for oversampling in order to cater for attrition. Thus, the sample size was increased to 739. This sample size was chosen to ensure a broad coverage

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of a representative sample of cocoa farmers. The proportional sample size determination method was used to distribute the sample size amongst the communities based on the population size of cocoa farmers in each sampled community obtained from district offices of CHED. Thus, through the four-stage sampling technique, the distribution of the final sample of 739 cocoa farmers from the various districts is provided in the table 4.1.

Table 4.1: Distribution of sampled respondents

Region	District	Community	Sample distribution	Percentage
Ashanti	Offinso	Afrancho	37	5.01
		Mankramso	35	4.74
	Mampong	Atonsuagya	39	5.28
		Aframso	38	5.14
Ahafo	Goaso	Bediako	45	6.09
		Nkrankrom	44	5.95
	Dadiesoba	Senkyem	30	4.06
		Dadiesoaba	32	4.33
Bono	Berekum	Ampenkuro	42	5.68
/Bono East		Namasua	29	3.92
	Techiman	Buoyem	35	4.74
		Asueyi	40	5.41
Eastern	Osino	Bepoase	34	4.60
		Akwansrem	33	4.47
	Asamankese	Atta ne Atta	31	4.19
		Kwapaa	36	4.87
Western	Sefwi	Proso	49	6.63
North	Juaboso	Bonso Nkwanta	55	7.44
	Dadieso	Gyampokrom	30	4.06
		Antokrom	25	3.38
Total			739	100.00

Source: Author's calculation (2024)

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4.3.4 Data and data collection method

This study employed primary cross-sectional data collected from cocoa farmers in Ghana for the 2022/2023 production season, utilising a structured household questionnaire as the primary data collection instrument, complemented by an interview guide. Data collection was conducted using the KoBoCollect software, with a team of 15 trained enumerators and 5 supervisors. Informed written consent was obtained from household heads or their representatives before conducting confidential interviews at times and locations of their preference. Ethical approval was granted by the Ethics Committee for the College Basic and Applied Sciences (ECBAS) at the University of Ghana (ECBAS 063/23-24), alongside permissions from relevant stakeholders, including COCOBOD district coordinators, Touton Ghana, ECOM Ghana, and local community leaders. This research was fully funded by the Partnership for Skills in Applied Sciences, Engineering and Technology (PASET) through its Regional Scholarship and Innovation Fund (RSIF).

The survey instrument comprised five sections (See Appendix 1). Section A captured household socioeconomic characteristics, including demographic variables such as age, sex, residential status (whether the household head was an indigene or a migrant farmer), education, and membership of farmer-based organisations. Section B focused on plot characteristics, focusing on two major cocoa plots per household during the 2022/2023 cropping season. Data included plot profiles (size, distance, landownership status, soil fertility, topography), cocoa tree attributes (variety, age, planting density), and exposure to drought and flood risks. SCIPs – such as pruning, hand weeding, chupons removal, hand pollination, mulching, planting of shade trees, intercropping with food crops and animals, and cocoa tree renovation – were documented, alongside the types, quantities and costs of organic and inorganic fertilisers, organic and inorganic pesticides and labour used. Agrochemical safety practices as well as harvesting and post-harvest activities, including

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fermentation and drying practices, were also recorded. Section C elicited responses about farmers' perceptions of SCIPs using a Likert scale. Section D covered access to extension and other support services, exploring interactions with extension agents, participation in training, access to credit, farm succession planning, and inventory of assets, land, and livestock. Section E covered household food security using three validated measures: the Household Food Insecurity Access Scale (HFIAS) for food access, the Household Food Consumption Score (HFCS) for dietary diversity, and the reduced Coping Strategies Index (rCSI) for food shortage management.

4.4 Methods of Analysis

4.4.1 Analysis of the level of adoption of sustainable cocoa intensification practices in Ghana

A five-step approach was followed to estimate separate composite indices for intensification and sustainability, respectively, for each plot in the study sample (Mutyasira et al., 2018; Vitunskiene and Dabkiene, 2016; Waney et al., 2014; Gómez-Limón and Sanchez-Fernandez, 2010; OECD-JRC, 2008; Saisana and Tarantola, 2002). The steps included selection and estimation of respective individual indicators for intensification and sustainability; normalisation of the selected indicators; the assignment of weights to the normalised indicators; and the aggregation of the weighted indicators into single composite scores for intensification and sustainability respectively.

4.4.1.1 Selection of intensification indicators

In the first stage of estimation, this study selected indicators based on their relevance to plot level cocoa intensification and sustainability of cocoa production, consistent with the

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three main dimensions of agricultural sustainability. The selected indicators are discussed in subsections 4.4.1.1.1 and 4.4.1.1.2 below.

4.4.1.1.1 Cocoa intensification indicators at the plot level

While crop intensification has been defined as the process of increasing outputs through increased use of inputs on existing plots (Helfenstein et al., 2020; Struik et al., 2014; Kuemmerle et al., 2013; Matson et al., 1997), conventional cocoa intensification entails the intensity of use of inputs and management practices, characterised by reduced crop diversity, often supported by greater use of high-yielding varieties, advanced pollination techniques, chemical fertilisers and pesticides on existing farmland. It also involves quantity of labour deployed and increased crop density (Sadhu et al., 2020; Vanlauwe & Dobermann, 2020; Danso-Abbeam et al., 2014). These input-based metrics of intensification provide a means of gauging land-use intensity across several dimensions. In line with previous studies, including Mahon et al. (2016), Teillard et al. (2012), and Dietrich et al. (2012), various inputs-based agricultural intensification indicators were selected to measure cocoa intensification at the plot level. These intensification indicators are presented in Table 4.2.

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Use of improved cocoa varieties

Use of improved cocoa varieties was measured as a binary variable coded 1 if a hybrid cocoa variety was planted, and 0 if traditional varieties such as *Amelonado*, *Amazonia*, *Criollo*, or *Trinitario* were planted (Kongor et al., 2024; Kongor, 2018).

Improved varieties are bred for higher productivity compared to traditional or local varieties (Obeng-Bio et al., 2022; Ofori et al., 2015). In Ghana, the hybrid cocoa varieties typically mature faster than traditional *Amelonado, Amazonia, Criollo, or Trinitario*

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Table 4.2: Cocoa plot level intensification indicators

Indicator	How it was measured	Contribution to the index
Use of improved cocoa varieties	1 if hybrid variety were planted, 0 if *Amelonado*, *Amazonia*, *Criollo*, or *Trinitario* were planted (Kongor, 2018)	+
Planting density	Approximate number of cocoa trees per ha	+
Proportion of trees hand pollinated	The proportion of cocoa trees on the farm that were hand pollinated out of the total number of trees	+
Solid fertiliser application rate	Quantity of inorganic fertiliser used (kg/ha)	+
Liquid fertiliser application rate	Quantity of inorganic fertiliser used (litres/ha)	+
Insecticide application rate	Quantity of insecticide applied (litres/ha)	+
Fungicide application rate	Quantity of fungicide applied (number sachet/ha)	+
Hired Labour use	Total hired labour used per hectare (person-days/ha) (Barnes & Thomson, 2014)	+
Family Labour use	Total family labour used per hectare (person-days/ha) (Mutyasira et al., 2018)	+
Communal Labour use	Total number of non-household members who worked as unpaid labour (person-days/ha)	+

Source: Author's literature review (2024)

varieties, and they can produce more pods and, consequently, more cocoa beans per hectare (Obeng-Bio et al., 2022; Ofori et al., 2015). Again, due to their resistance to common cocoa diseases and pests, the use of hybrids reduces the need for chemical inputs like pesticides and fungicides, reducing the cost of production. Thus, a higher proportion of hybrid cocoa tree varieties may maximise land use, leading to increased production without the need for expanding land area (Helfenstein et al., 2020; Struik et al., 2014; Kuemmerle et al., 2013; Matson et al., 1997). This implies that the higher the proportion of hybrid cocoa tree varieties on the plot, the higher the level of cocoa intensification.

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Planting density

Planting density refers to the approximate number of cocoa trees planted per unit area, usually measured as the number of trees per hectare (Asante et al., 2022; Souza et al., 2009). Experimental evidence confirms that cocoa yield per hectare increases with planting density (Smith, 2015; Souza et al. 2009; Dias et al. 2000), although exceeding the optimal threshold intensifies competition, suppressing tree growth and reducing fruit production in residual trees (Wood 1964). Therefore, an optimal balance in planting density is likely to ensure that output per tree remains high, leading to increased production without the need for expanding land area (Helfenstein et al., 2020; Matson et al., 1997).

Proportion of trees hand pollinated

In natural conditions, cocoa pollination rates are relatively low due to reliance on natural pollinators, including midges (Wongnaa et al., 2021), whose population is often reduced through the use of agrochemicals. Hand pollination has been found to dramatically increase the rate of cocoa pod setting by ensuring that more flowers are successfully fertilised (Asante et al., 2023; Toledo-Hernandez et al., 2023; Wongnaa et al., 2021; Toledo-Hernandez et al., 2020). This maximises the number of cocoa pods per tree, significantly increasing overall production per hectare (Asante et al., 2023; Toledo-Hernandez et al., 2023; Wongnaa et al., 2021; Toledo-Hernandez et al., 2020). Thus, the proportion of cocoa trees on the farm that were hand pollinated out of the total number of trees may ensure a higher number of pods produced per tree, leading to increased production without the need for expanding land area.

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Fertiliser application rate

Intensification through agrochemical use involves applying chemical fertilisers, insecticides, and fungicides to optimise yields on the same land area (Helfenstein et al., 2020; Struik et al., 2014; Kuemmerle et al., 2013; Matson et al., 1997). Fertiliser application rate was measured as the quantity of inorganic fertiliser used. Chemical fertilisers help replenish soil nutrients that are depleted over time due to continuous cropping. Thus, the higher the quantities of chemical fertilisers used on the plot, the higher the level of cocoa intensification. Hayati et al. (2010), Dantsis et al. (2010), Vitunskiene and Dabkiene (2016), and Mutyasira et al. (2018) employed the quantity of chemical fertilisers applied per hectare (kg/ha) as an indicator in their analyses.

Insecticide application rate

Insecticide application rate was measured as the quantity of insecticide applied (litres/ha). Intensive use of insecticides ensure that pests are managed effectively, leading to healthier crops and higher productivity. Thus, the higher the quantities of insecticides used on the plot, the higher the level of cocoa intensification (Helfenstein et al., 2020; Struik et al., 2014; Kuemmerle et al., 2013; Matson et al., 1997). Hayati et al. (2010), Dantsis et al. (2010), Robling et al. (2023), Vitunskiene and Dabkiene (2016), and Mutyasira et al. (2018) employed the quantity of pesticides applied per unit of cultivated land as an indicator in their studies.

Fungicide application rate

Fungicide application rate was measured as the quantity of fungicide applied (number sachet/ha). Intensive use of fungicides ensure that diseases are managed effectively, leading to healthier crops and higher productivity. Thus, the higher the quantities of fungicides used

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on the plot, the higher the level of cocoa intensification (Helfenstein et al., 2020; Struik et al., 2014; Kuemmerle et al., 2013; Matson et al., 1997).

Family Labour use

Practices such as regular weeding, pruning, hand pollination, and the application of agrochemicals, which are essential for maximising cocoa yield, are labour-intensive. In Ghanaian cocoa farming households, family members are often mobilised to meet the increased labour demands on cocoa plots. Family labour is generally more flexible compared to hired labour. Family members can work whenever needed, including early mornings, late evenings, or weekends, allowing for more precise timing of farm activities. This is particularly important since cocoa farming involves critical windows of time for labour-intensive activities such as weeding, pruning, application of agrochemicals, harvesting and postharvest processing. Often, missing the optimal window for applying fungicides or harvesting could lead to significant pod losses. The regular availability of family labour for timely implementation of critical operations on a plot can maximise cocoa production without the need for expanding land area (Helfenstein et al., 2020; Struik et al., 2014; Kuemmerle et al., 2013; Matson et al., 1997). Vitunskiene and Dabkiene (2016) and Mutyasira et al. (2018) used the proportion of family labour, measured as the ratio of hours worked by family members to the total farm labour hours.

Hired Labour use

Hired labour could become essential when the area of cocoa cultivation exceeds what the family can manage on their own. The regular availability of hired labour for timely implementation of critical operations on a plot can maximise cocoa production without the need for expanding land area (Helfenstein et al., 2020; Struik et al., 2014; Kuemmerle et

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al., 2013; Matson et al., 1997). Barnes and Thomson (2014) employed the ratio of hired labour to total hours worked as an indicator.

Communal Labour use

In rural communities, exchange or communal labour systems which are built on traditional practices of reciprocity, where farmers leverage social networks and community-based efforts to help each other on their respective farms (Kissi and Herzig, 2023), are often relied upon when resources such as cash for hired labour may be limited. Regular availability of communal labour for timely implementation of critical operations on a plot can maximise cocoa production without the need for expanding land area (Helfenstein et al., 2020; Struik et al., 2014; Kuemmerle et al., 2013; Matson et al., 1997).

4.4.1.1.2 Cocoa plot level sustainability indicators

While cocoa intensification strategies can boost productivity, they are associated with high user-costs. Thus, inefficient use of these strategies will lead to an erosion of economic returns. Also, their excessive application frequently leads to significant environmental harm, and adverse health impacts on farmers and farm workers (Matson et al., 1997; Petersen & Snapp, 2015; Mueller et al., 2012). Cocoa plot level sustainability entails the efficiency in converting farm inputs into outputs (Helfenstein et al., 2020). Thus, agricultural practices that ensure the long-term viability of farming operations on cocoa plots by balancing economic profitability, environmental health, and social responsibility lead to plot-level sustainability (Jain et al., 2023; Cassman & Grassini, 2020; Smith et al., 2017; Rockström et al., 2017; Garnett, et al., 2013). Plot-level sustainability focusses on three core pillars: economic, environmental, and social sustainability in line with the Sustainable Intensification Assessment Framework (SIAF) and the Sustainability

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Assessment of Food and Agriculture Systems (SAFA) framework (Bandanaa et al., 2024; Robling et al., 2023; Leknoi et al., 2023; Hammond et al., 2021; Musumba et al., 2017).

4.4.1.1.2.1 Economic sustainability indicators

Economic sustainability involves increasing the productivity and farm income of cocoa farm systems to sustain their economic viability and efficiency (Kongor et al., 2024; Mockshell & Kamanda, 2018). Consistent with studies like Robling et al. (2023); Mutyasira et al. (2018); Vitunskiene and Dabkiene, (2016); Barnes and Thomson (2014); Waney et al. (2014); Gómez-Limón and Sanchez-Fernandez (2010); Dantsis et al. (2010); and Hayati et al. (2010), various indicators that measure economic sustainability at the plot level were selected. These economic sustainability indicators are presented in Table 4.3.

Table 4.3: Economic sustainability indicators

Indicator	How it was measured	Contribution to the index
Weighted average age of cocoa tree	(3/25) if age was greater than 35 years; (4/25) if age was 25-35 years; (5/25) if age was 16-25 years; (6/25) if age was 8-15 years; (5/25) if age was 5-7 years; and (2/25) if age was less than 5 years (Atkins & Eastin, 2012)	+
Cocoa bean quality	1 if pods were stored for 3–5 days, fermentation was 6-7 days (with at least two turnings), and drying was 7 days (with at least two stirrings per day); 0 otherwise (Adams et al., 2024b; Afoakwa, 2016; Afoakwa et al., 2008)	+
Number of cocoa plots per farmer	The number of cocoa plots managed by household	+
Crop diversification on cocoa plot	Total number of different crops cultivated on the cocoa plot aside cocoa	+
Labour productivity	Farm gross income per person day of labour (Struik et al., 2014; Kuemmerle et al., 2013)	+
Input Cost Efficiency	The farm's gross income divided by the total cost of variable inputs expended	+
Proportion of cocoa trees renovated	Ratio of total number of cocoa trees replanted to trees needing renovation per ha	+

Source: Author's literature review (2024)

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Weighted average age of cocoa tree

The productivity of cocoa has been found to be influenced by the age of the tree (Abdulai et al., 2020; Kongor et al., 2017). Thus, the age of the cocoa tree is a critical factor for economic sustainability, as younger trees in their productive years produce higher yields with fewer maintenance costs and are likely to be more profitable. This study assigned scores to trees based on the Atkins and Eastin (2012) classification. Atkins and Eastin (2012) classified cocoa into different classes based on the correlation between the age of the tree and cocoa productivity per unit of land. Class A cocoa ranges from ages 5–7 years. Class B cocoa ranges from age 8–15 years and signifies the most productive period of the cocoa tree. Class C cocoa falls within the age range of 16–25 years, and is characterised by a drop in yield. Class D, which ranges from 25–35 years, is characterised by a further drop in yield. Classes E and F are old and highly unproductive trees. At this stage, these old trees could become susceptible to disease, pests, and environmental stress and may require rehabilitation practices such as pruning, grafting, or replanting, leading to increased cost of production.

To translate these classes into a quantitative index, weights were assigned to age categories in a way that reflects relative productivity potential while ensuring that the total weight sums to one for consistency in aggregation. The following weights were applied: (2/25) for trees <5 years, (5/25) for 5–7 years, (6/25) for 8–15 years, (5/25) for 16–25 years, (4/25) for 25–35 years, and (3/25) for >35 years (Atkins & Eastin, 2012). This weighting scheme emphasizes the higher contribution of trees in their most productive phase while accounting for the diminished economic value of younger immature trees and older senescent trees.

Cocoa bean quality

A binary indicator taking the value 1 if the following best practice post-harvest processing conditions were met: (i) pods stored for 3–5 days before fermentation; (ii) fermentation for

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6–7 days with a minimum of two turnings; and (iii) drying for 7 days with at least two stirrings per day. Coded 0 if any of these conditions were not met (Adams et al., 2024b; Afoakwa, 2016; Afoakwa et al., 2008). Bean quality has been found to be determined by genotypic credentials of the variety, age of cocoa tree, and proper farm management practices including harvesting, and postharvest treatments such as pulp pre-conditioning, fermentation and drying (Oberrauter et al., 2018; Afoakwa, 2016; Afoakwa et al., 2008). According to Afoakwa et al. (2016), storing cocoa pods for 3–7 days followed by 6 days of fermentation and 7 days of drying could improve the flavour attribute of cocoa beans. This is consistent with studies like Adams et al. (2024b); Kotey et al., (2022), Afoakwa et al. (2015; 2013; 2012); and Baker et al. (1994), which recommended a harvesting interval of 3–5 days with pulp pre-conditioning for 3–5 days to be followed by 6 days of fermentation and 7 days of drying. Farmers producing high-quality cocoa often receive higher prices in the market, especially if they are selling to specialty or fair-trade markets. These premiums can increase farm profitability and provide more stable incomes, allowing farmers to reinvest in sustainable farming practices. Thus, plots that followed these recommendations are likely to attract a bean quality-related premium, which will in turn improve their profitability.

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Number of cocoa plots per farmer

The number of cocoa plots per farmer was measured as the total number of distinct cocoa plots managed by the household. More plots per farmer allow for better portfolio diversification. Although managing multiple plots could reduce the time allocated to each plot for efficient management, it ensures that cocoa farmers diversify their portfolio as a risk-spreading strategy against climate impacts, pests, and diseases. This reduces the risk of total crop failure in times of extreme environmental stress. This reduces the overall risk

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to the farmer and enhances resilience and income stability. Thus, the higher the number of plots managed by the household, the higher the likelihood of economic sustainability. Dantsis et al. (2010) used the number of plots per farmer as an indicator of economic sustainability.

Crop diversification on cocoa plot

Crop diversification on cocoa plot was measured as the total number of different crop species cultivated on the cocoa plot in addition to cocoa. It refers to the practice of growing a variety of crops, including plantains, yam, cocoyam, bananas, etc, on the same farm, instead of focusing solely on cocoa. Having other crops to sell ensures a steady income even when cocoa prices drop, and during lean seasons, since income from cocoa is seasonal. Furthermore, growing a variety of crops can provide a wider range of nutrients, contributing to better household nutrition and food security. Dantsis et al. (2010) and Mutyasira et al. (2018) employed the number of different crops cultivated on each farm, excluding the primary target crops, as an indicator of crop diversification.

Labour productivity

Labour productivity, the farm's gross income per person-day of labour used, gives an indication of how efficiently human labour is used to produce cocoa. High labour productivity imply that the farm can generate more income with the same or less investment in labour, which gives an indication of operational cost efficiency, and a higher likelihood of economic sustainability. This is consistent with Hayati et al. (2010), Vitunskiene and Dabkiene (2016), Mutyasira et al. (2018), and Robling et al. (2023), who employed labour productivity, measured as the total value of crops per person-day of labour, as an indicator of economic sustainability.

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Input cost efficiency

Input cost efficiency, measured as the ratio of the farm's gross income to the total expenditure on variable inputs, gives an indication of the efficiency with which a farm uses its variable inputs such as fertilisers, pesticides and water to produce cocoa beans. It is an important indicator of how well the resources invested in variable inputs are being utilised to generate returns. High input cost efficiency imply that the farm can generate more income with the same or less investment in variable inputs, which gives an indication of operational cost efficiency, and a higher likelihood of economic sustainability. Vitunskiene and Dabkiene (2016), Mutyasira et al. (2018), and Robling et al. (2023) likewise employed capital productivity, measured as the ratio of gross value added to capital inputs, as an indicator of economic sustainability.

Proportion of cocoa trees renovated

Renovation of old, moribund and unproductive cocoa trees involves pruning, replacing unproductive trees, or grafting new varieties onto old rootstocks (Somarriba et al., 2021; Djuideu et al., 2021; Asare et al., 2018). This improves the health and productivity of existing trees, allowing farmers to increase cocoa yield per hectare without expanding the land area (Djuideu et al., 2021). Thus, the higher the proportion of cocoa trees replanted out of the total number of trees identified as needing renovation per hectare, the higher the level of economic sustainability.

4.4.1.1.2.2 Environmental sustainability indicators

Environmental sustainability involves a holistic approach to controlling pests and diseases, conserving soil water, increasing soil nutrients and conserving biodiversity on cocoa farms using practices that are environmentally sound, preserve resources and integrate natural

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biological cycles (Kongor et al., 2024; Mockshell & Kamanda, 2018). Consistent with studies such as Robling et al. (2023); Mutyasira et al. (2018); Vitunskiene and Dabkiene, (2016); Barnes and Thomson (2014); Waney et al. (2014); Gómez-Limón and Sanchez-Fernandez (2010); Dantsis et al. (2010); and Hayati et al. (2010), various indicators that measure environmental sustainability at the plot level were selected. These environmental sustainability indicators are presented in Table 4.4.

Table 4.4: Environmental sustainability indicators

Indicator	How it was measured	Contribution to the index
Organic fertiliser application rate	Quantity of organic fertiliser applied per hectare (kg/ha)	+
Proper use of inorganic fertiliser	Whether farmer used more than 375 kg/ha of inorganic fertiliser (1 = yes, 0 = no)	_
Proper use of inorganic insecticide	Whether farmer did not apply inorganic insecticide four times per season (1 = yes, 0 = no)	_
Proper use of inorganic fungicide	Whether farmer applied more than 45 sachets of inorganic fungicide per hectare and/or not at a rate of six to nine times per season (1 = yes, 0 = no)	_
Frequency of inorganic weedicide applications	Total number of weedicide applications per season (number/season)	_
Use of organic pesticides	Whether organic pesticides were applied on the cocoa plot (1 = yes, 0 = no)	+
Farm sanitation	Whether pruning and removal of base chupons, mosses and mistletoes were done at least once, and hand weeding was done at least thrice per season (1 = yes, 0 = no)	+
Recommended shade trees density	Plot did not have 16-20 shade trees per hectare (1 = yes, 0 = no)	-
Proportion of cocoa trees mulched	The proportion of cocoa trees on the plot that were mulched per hectare	+
Use of water harvesting	Whether water was harvested for work on plot (1 = yes, 0 = no)	+
Proper handling of agrochemicals	Agrochemicals were properly stored and container were properly disposed of (1 = yes, 0 = no)	+
Optimal planting density	Whether plot had, on average, more than 1250 cocoa trees per ha (1 = yes, 0 = no) (Asante et al., 2022; Abdulai et al., 2020)	-

Source: Author's literature review (2024)

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Organic fertiliser application rate

Organic fertilisers improve soil structure and provide essential nutrients, including nitrogen, phosphorus, and potassium in a more natural and gradual manner, which could help maintain soil fertility and encourage healthier cocoa trees over the long term. Organic fertiliser also stimulates microbial activity in the soil, which is beneficial for nutrient cycling and overall soil health, leading to improved root growth and tree productivity. They can help to reduce over-dependence on synthetic fertilisers, thereby leading to low soil degradation and water contamination since they are less likely to cause runoff or leaching. Thus, the higher the quantity of organic fertilisers used per hectare, the higher the likelihood of attaining environmental sustainability. Vitunskiene and Dabkiene (2016), Dantsis et al. (2010), and Mutyasira et al. (2018) used the quantity of organic manure applied as an indicator of environmental sustainability in their analyses.

Proper use of inorganic fertiliser

Proper use of inorganic fertiliser was measured as whether a farmer used more than 375 kg/ha of inorganic fertiliser on cocoa plot (1 = yes, 0 = no). Chemical fertilisers help replenish soil nutrients that are depleted over time due to continuous cropping. Thus, the higher the quantities of chemical fertilisers used on the plot, the higher the level of cocoa intensification. However, excessive use of inorganic fertiliser can raise production costs and the constituent chemicals can leach into the soil and contaminate nearby water bodies, harming aquatic ecosystems and reducing soil fertility over time. Proper application of agrochemicals at the correct dosage and timing for the target soil can ensure effective remedy, protect the health of farmers and workers, and minimise adverse impacts on the surrounding ecosystem. In Ghana, COCOBOD recommends a one-time application at the rate of 375 kg/ha to ensure nutrient sufficiency while avoiding the environmental harms of

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over-application (Amponsah-Doku et al., 2022). Thus, excessive use of inorganic fertiliser beyond the recommended dosage is equivalent to environmental pollution and diminishing environmental sustainability.

Proper use of inorganic insecticide

Farmers are advised to adopt a four-time application of insecticides, with the quantities to be used determined by the brand and chemical composition (Danso-Abbeam & Baiyegunhi, 2017; Antwi-Agyakwa et al., 2015; Dormon et al., 2007). Excessive use of inorganic insecticide beyond the recommended dosage is equivalent to environmental pollution and diminishing environmental sustainability. Gómez-Limón and Sanchez-Fernandez (2010) employed the potential lethality of biomass, measured in kilograms, as an environmental indicator to assess pesticide risk.

Proper use of inorganic fungicide

The recommended fungicide application rate is 1 sachet (either 50g/75g/100g depending on the brand and chemical composition) of fungicide per 15L tank to be sprayed twice at once per acre at a rate of 6–9 times per year depending on the severity of incidence (Danso-Abbeam & Baiyegunhi, 2018). This adds up to a maximum of 45 sachets per hectare. Excessive use of inorganic fungicide beyond the recommended dosage is equivalent to environmental pollution and diminishing environmental sustainability.

Frequency of inorganic weedicide applications

The frequency of weedicide applications was measured as the total number of inorganic weedicide applications made during the farming season. The increased use of weedicides often reduces the need for manual weeding, which can be labour-intensive. This allows

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farmers to allocate labour to other critical farm activities, improving overall farm efficiency. However, excessive use of chemical weed control methods can affect non-target plant species and soil organisms, disrupting farm biodiversity and ecosystem health. Over-reliance on chemical weedicides can lead to a build-up of chemical residues in the soil, negatively affecting soil structure and long-term productivity. Due to these challenges, there is a ban on the use of weedicides on cocoa farms in Ghana (Bandanaa et al., 2021). Instead of chemical weedicides, COCOBOD encourages farmers to adopt alternative weed management practices, such as hand weeding and/or the use of cover crops, which are more environmentally sustainable and help maintain soil fertility (Bandanaa et al., 2021). Thus, the use of any form of inorganic weedicide could have negative consequences on environmental sustainability.

Use of organic pesticides

The use of organic pesticides (a binary indicator coded 1 if organic pesticide was applied on the cocoa plot, and 0 if not) refers to the application of natural or minimally processed substances to manage pests in a way that is environmentally friendly and less harmful to human health. Organic pesticides used in cocoa farms may include aqueous neem extract, garlic extract, pheromone sex traps, and the spread of the predatory African Weaver ants (*Oecophylla longinoda*) (Tanga et al., 2016; van Mele, 2008; Ayenor et al., 2007; Holldobler and Wilson, 1990). Organic pesticides are typically biodegradable and are less likely to persist in the environment compared to synthetic pesticides (Ayenor et al., 2007). This could reduce the risk of pollution to soil, water, and nearby ecosystems. Also, organic pesticides are usually more selective and are less likely to harm beneficial organisms such as natural pollinators (e.g., midges), natural predators (e.g., ladybugs), and soil

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microorganisms that contribute to healthy soil ecology (Ayenor et al., 2007). Thus, their use could have positive consequences on environmental sustainability.

Farm sanitation

Proper sanitation practices such as regular hand weeding, pruning, removal of base chupons, mosses, mistletoes, and infected or diseased pods and pod husks have been recommended to farmers by COCOBOD to help minimise the pest load and the spread of diseases on cocoa plots (Cilas et al., 2018; Opoku et al., 2000). It is recommended for cocoa farmers to undertake mechanical weeding of their plots four times per season (Kolavalli & Vigneri, 2017; Dormon et al., 2007). They are further required to prune their plot at least once per season, and remove base chupons, mosses and mistletoes regularly (Opoku et al., 2000). Regular implementation of these farm sanitation practices could reduce the need for chemical pesticides, thereby reducing environmental contamination and maintaining soil health (Kolavalli & Vigneri, 2017; Danso-Abbeam & Baiyegunhi, 2017).

Recommended shade trees density

Cocoa is a shade-loving understory tree that thrives in tropical rainforests (Asitoakor et al., 2022; Blaser et al., 2017). By providing cover from direct sunlight, shade trees can help moderate temperatures and protect cocoa trees from heat and water stress (Oliveira et al., 2023; Asitoakor et al., 2022). This can help improve pod setting. Shade trees can also contribute to nutrient cycling by shedding leaves that decompose and enrich the soil with organic matter (Oliveira et al., 2023; Blaser et al., 2017). They can also capture and store carbon dioxide from the atmosphere, contributing to carbon sequestration efforts (Hawkins et al., 2024; Blaser et al., 2017). In addition, shade trees can provide additional economic benefits to farmers since tree species produce timber, or other non-timber forest products

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that can be harvested and sold, offering farmers a diversified income stream (Hawkins et al., 2024; Blaser et al., 2017). However, excessive shade or dense tree canopies can trap moisture beneath their canopies that could create a damp microclimate on cocoa farms, which can increase the risk of black pod disease (Kongor et al., 2017). Dense shade could also obstruct air circulation around cocoa trees and reduce sunlight penetration, which could lead to the rotting of cocoa pods. COCOBOD recommends an optimum number of 16-20 shade trees per hectare to maintain a balanced canopy cover that provides benefits without overly dampening the farm environment (Asitoakor et al., 2022; Hawkins et al., 2024; Oliveira et al., 2023). Thus, planting the recommended 16-20 shade trees per hectare could have positive consequences on environmental sustainability.

Proportion of cocoa trees mulched

Mulching helps to reduce water loss from the soil by covering the surface and protecting it from direct sunlight. This is especially important in cocoa farming, as cocoa plants require consistent moisture to thrive. Also, mulches create a physical barrier that prevents the germination and growth of weeds. This reduces competition for nutrients and water between the cocoa plants and weeds, reducing the need for inorganic fertilisers. In addition, organic mulches, such as leaves, straw, and cocoa pod husks, decompose over time and add organic matter to the soil. This enhances soil structure, improves nutrient content, and increases microbial activity, all of which contribute to environmental sustainability.

Use of water harvesting

Water harvesting refers to the collection and storage of rainwater or surface water for agricultural use, particularly in regions where water is scarce or rainfall is seasonal. Effective water harvesting systems ensure that rainwater is not wasted but is stored and

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used efficiently. Thus, water harvesting can help cocoa farms become more resilient to drought and irregular rainfall, ensuring a steady water supply during dry periods.

Proper handling of agrochemicals

Proper handling of agrochemicals entails storing agrochemicals (such as inorganic pesticides, fungicides, herbicides, and fertilisers) in their original, labelled containers in a secure, well-ventilated area that is safe from contamination (with food supplies, water sources, and animal feeds), access by unauthorised persons, and environmental exposure (e.g., heat, sunlight, and moisture). It also entails proper disposal of agrochemical containers by ensuring that empty agrochemical containers are disposed-off in a manner that prevents environmental contamination and harm to humans and other animals. Triple-rinsing of containers after use to ensure effective removal of remaining residues is a major recommendation in the literature. After rinsing, it is further recommended that the containers be punctured or crushed to prevent reuse. Also, the containers could be kept at a designated collection point. The burning, burying and littering of containers in the open has been prohibited to prevent soil, water, and air pollution. Thus, proper handling of agrochemicals measured as a binary indicator coded 1 if agrochemicals (including inorganic pesticides, fungicides, herbicides, and fertilisers) were stored in their original, labelled containers in a secure, well-ventilated area away from food, water, animal feed, and unauthorised access, and protected from environmental exposure (heat, sunlight, moisture); and their empty containers were disposed of safely through triple-rinsing, puncturing or crushing to prevent reuse, or keeping them at a designated collection point. Burning, burying, or open littering of containers is considered unsafe disposal. The indicator was coded 0 if either proper storage or proper disposal (or both) were not practiced.

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Optimal planting density

Planting density refers to the number of cocoa trees planted per unit area, usually measured as the number of trees per hectare (Asante et al., 2022; Souza et al., 2009). Extremely high planting densities can lead to overcrowding which may result in the rapid transmission and spread of diseases (Asante et al., 2022&2021; Abdulai et al., 2020; Sonwa et al., 2018; Daymond et al., 2017; Souza et al., 2009), and increase competition for resources such as light, nutrients, and water (Sonwa et al., 2018; Souza et al., 2009). This may ultimately increase the need for inorganic pesticides and fertilisers. However, intensive farming through optimal planting density may maximise land use, leading to increased production without the need for expanding land area, and without excessive strain on environmental resources. The literature acknowledges a standardised planting density of 1246 trees per hectare (Asante et al., 2022; Abdulai et al., 2020).

4.4.1.1.2.3 Social sustainability indicators

The social dimension of sustainable cocoa intensification facilitates the well-being of farmers, their households, and communities by enforcing safe working conditions and upholding fair labour standards, including eradicating child and forced labour. It also entails the use of personal protective equipment in agrochemical handling. Moreover, it fosters social inclusion, knowledge transfer, and community empowerment by promoting alternative livelihoods such as intercropping and livestock production (Luckstead et al., 2019; Sadhu et al., 2020; Mockshell & Kamanda, 2018; Kongor, 2018). Consistent with studies like Robling et al. (2023); Mutyasira et al. (2018); Vitunskiene and Dabkiene, (2016); Barnes and Thomson (2014); Waney et al. (2014); Gómez-Limón and Sanchez-Fernandez (2010); Dantsis et al. (2010); and Hayati et al. (2010), various indicators that

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measure social sustainability at the plot level were selected. These social sustainability indicators are presented in Table 4.5.

Table 4.5: Social sustainability indicators

Indicator	How it was measured	Contribution
Weighted age of farmer	Assigned (3/12) if farmer was under 36 years old; (4/12) if farmer was 36-50 years old; (3/12) if farmers was 51-65 years old; and (2/12) if farmer was 66 years and older (Vitunskiene & Dabkiene, 2016)	+
Isolation risk	Whether farmer lived alone (1 = yes, 0 = no) (Robling et al., 2023)	-
Farm continuity	Whether farmer had plans to reduce the size of cocoa plot or exit cocoa farming (1 = yes, 0 = no) (Vitunskiene & Dabkiene, 2016)	-
Generational Renewal	Whether farmer was over 60 years of age and had not identified a successor (1 = yes, 0 = no) (Robling et al., 2023)	-
Use of personal protective equipment (PPEs)	Whether farmer used essential/common PPEs, including gloves, masks, goggles, and protective clothing (1 = yes, 0 = no)	+
Workload exceeded	Whether farmer worked in excess of 45 hours per week (1 = yes, 0 = no) (Vitunskiene & Dabkiene, 2016)	-

Source: Author's literature review (2024)

Weighted age of the farmer

Farmer age is an important determinant of agricultural sustainability, as it influences attitudes, managerial capacity, openness to innovation, and the scale of operations (Dantsis et al., 2010). Cocoa production is labour-intensive, requiring physically demanding tasks such as pruning, weeding, harvesting, and shade management. Younger farmers (under 36 years old) often have the physical ability to undertake such tasks and are generally more open to adopting new technologies and sustainable practices. However, they may lack financial resources, social capital, or access to credit, which can limit their ability to maintain operations under economic stress.

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In contrast, older farmers (51–65 years old) may experience physical limitations, making it harder for them to manage labour-intensive practices on their farms. Also, much as they have years of practical experience and accumulated knowledge about cocoa farming, they could be more risk-averse, preferring traditional methods over experimental or innovative approaches that could boost sustainability. They may be less inclined to invest in practices that take many years to yield results. Also, farmers aged 66 and above are generally less likely to sustain labour-intensive practices due to declining physical capacity, despite their long-standing knowledge of cocoa farming.

On the other hand, middle-aged farmers (36–50 years old) are generally experienced and possess valuable knowledge about cocoa farming, which are vital for sustaining productivity. They are typically in their prime working years, with a balance of experience and willingness to invest in long-term sustainable practices. They are often at the peak of their economic productivity and may have better access to resources such as credit and inputs, which can drive farm-level sustainability. To reflect these differences, weights were assigned to age categories based on their relative contribution to sustainable cocoa production, following the approach of Dantsis et al. (2010), Vitunskienė and Dabkienė (2016) and Robling et al. (2023). The weights were normalized to sum to one and assigned as follows: (3/12) for farmers under 36 years, (4/12) for those aged 36–50 years, (3/12) for 51–65 years, and (2/12) for 66 years and above. This scheme emphasises the higher capacity and sustainability potential of middle-aged farmers, while still accounting for the relative strengths and constraints of younger and older age groups.,

Isolation risk

Isolation risk was measured as a binary indicator coded 1 if the farmer lives alone (i.e. has a household size of 1), and 0 if the farmer lives with others (household size greater than 1).

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Sustainable cocoa farming requires ongoing sharing of labour and knowledge services, and sometimes cooperative efforts. Farmers living alone may have limited capacity to carry out labour-intensive tasks, leading to lower productivity (Simpson, 2012; Burch, 2001). Without a support network to share the workload, isolated farmers may overexert themselves, and neglect key farming activities. Social isolation can also have detrimental effects on a farmer's mental and physical wellbeing. Loneliness can lead to depression and lower morale, which can directly impact farm operations and decision-making. Thus, the risk of social isolation would have a negative consequence on social sustainability. Robling et al. (2023) employed isolation risk as a social sustainability indicator, assigning a value of 1 where a farmer lives alone.

Farm continuity

Farm continuity was measured as a binary indicator coded 1 if the farmer had plans to reduce the size of cocoa plot (substitute cocoa with other crops on the plot) or exit cocoa farming entirely, and 0 if no such plans were reported. Cocoa farmers without continuity plans may lack motivation to invest in long-term sustainability measures, leading to overexploitation of resources and degradation of the land. A farmer's decision to reduce the size of cocoa plot or exit farming may also reduce cocoa output, which could have negative implications for the rural labour market, as farm workers may either lose jobs or suffer reduced income, affecting their ability to support their families. This can have a cascading effect on the community, leading to economic decline in rural areas. Thus, the absence of a farm continuity plan would have a negative consequence on social sustainability. Gómez-Limón and Sanchez-Fernandez (2010) and Vitunskiene and Dabkiene (2016) employed an index ranging from 1 (representing farmers under 55 years with above-average income) to

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0 (for those over 70 with below-average income), to measure the continuity of farming or the risk of agricultural abandonment as a social sustainability indicator.

Generational renewal

Generational renewal was measured as a binary indicator coded 1 if the farmer was over 60 years of age and had not identified a successor to take over the cocoa farm, and 0 otherwise. As farmers age and become less physically capable of managing farms, the absence of a mentored successor means that necessary farming activities might be neglected, leading to reduced yields. Also, in Ghana, as in most developing countries, indigenous knowledge about farming is mostly passed on from one generation to the other through endogenous learning. This knowledge is typically shared orally, through observation, imitation, and direct participation in agricultural activities. The absence of a mentored successor means this knowledge could be lost, leading to unsustainable methods. Thus, the absence of a mentored successor would have a negative consequence on social sustainability. Robling et al. (2023) used the availability of a succession plan, which was measured as whether a potential farm successor had been named, as a measure of social sustainability.

Use of personal protective equipment (PPEs)

Use of personal protective equipment (PPEs) was measured as a binary indicator coded 1 if the farmer used all essential or commonly recommended personal protective equipment such as gloves, goggles, nose mask, long-sleeved clothing, boots, and head cover during the application of agrochemicals, and 0 otherwise. Proper use of PPEs protects farmers and workers from harmful exposure to agrochemicals. This may minimise the health risks associated with chemical exposure. The use of PPEs may promote decent working

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conditions by ensuring that farmers and labourers on cocoa farms are protected from workplace hazards. This is crucial for maintaining a healthy and motivated workforce.

Workload exceeded

Workload exceeded was measured as a binary indicator coded 1 if the farmer worked more than 45 hours per week on cocoa plot, and 0 otherwise. Farmers and labourers who consistently work excessive hours may experience burnout, poor health, or diminished family life, which may limit a farmer's ability to maintain the farm over time. When farmers or labourers consistently work long hours, they may not receive adequate rest or pay, undermining the principle of decent work, which includes providing fair wages and reasonable working hours. The Labour Act, Act 651(2003) stipulates that any extra hours worked beyond a maximum of forty hours of work a week or 8 hours of work per day must be paid for as overtime. Thus, cocoa farmers working in excess of 45 hours per week could have a negative consequence on social sustainability. Vitunskiene and Dabkiene (2016) and Robling et al. (2023) used workload exceeded, measured as annual hours worked on the farm by each family member exceeding 1.5 AWU (Annual Work Unit), as an indicator of social sustainability.

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4.3.1.2 Normalisation of the intensification and sustainability indicators

In line with studies like Vitunskiene and Dabkiene (2016), Barnes and Thomson (2014), Gómez-Limón and Sanchez-Fernandez (2010) and OECD-JRC (2008), the Min-Max and Max-Min normalisation techniques were employed to normalise the estimated indicators to ensure comparability and allow for summing across different measurement units. The Min-Max normalisation technique scales the indicators to a [0, 1] range by subtracting the minimum value and dividing by the range of values (equation 4.5) (Mutyasira et al., 2018).

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The Min-Max normalisation technique was specified as:

$$I_{ij} = \frac{(y_{ij} - y_{imin})}{(y_{imax} - y_{imin})} \quad (4.5)$$

Where I_{ij} is the normalised value of the indicator and y_{ij} is the original value of indicator *i* for plot *j*. The elements y_{imin} and y_{imax} are, respectively, the minimum and maximum of the non-normalised values of indicator *i* in the sample. This approach was applied to indicators that contribute positively to the intensification and sustainability indices.

On the other hand, the Max-Min normalisation technique was applied to indicators that contributed negatively to the intensification and sustainability indicators. It also scales the indicators to a [0, 1] range by subtracting the maximum value and dividing by the range of values (equation 4.6) (Mutyasira et al., 2018). The Max-Min normalisation technique was specified as:

$$I_{ij} = \frac{(y_{imax} - y_{ij})}{(y_{imax} - y_{imin})} \quad 4.6$$

Unlike the Min-Max normalisation technique, the Max-Min normalisation approach assigns a normalised value of 1 to the lowest original value and 0 to the highest, effectively inverting the scale (Mutyasira et al., 2018). Thus, this technique was employed when higher raw values of an indicator signify undesirable outcomes (e.g., pollution levels and environmental degradation) and when the aim is to make lower values more favourable in the composite indicator (OECD-JRC, 2008; Saisana and Tarantola, 2002).

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4.4.1.3 Aggregation of the weighted indicators into a single composite score

In the final step, the weighted indicators were aggregated into single intensification and sustainability composite scores for each plot (Vitunskiene and Dabkiene, 2016; Gómez-Limón and Sanchez-Fernandez, 2010; Hayati et al., 2010; OECD-JRC, 2008). This was done using the Simple Arithmetic Mean approach, which is a straightforward method of aggregation where all indicators are given equal weights (equation 4.7).

$$CI = \sum_{i=1}^{n} w_i \, . \, X_i \qquad (4.7)$$

Where CI is the composite index, w_i is the weight of indicator i

X_i is the normalised score for indicator i

n is the total number of indicators.

4.4.1.4 Development of cocoa farm typologies based on intensification and sustainability indices

The intensification and sustainability indices were used to group cocoa plots in the study sample into four (4) farm typologies. This was done using an index threshold/ "cut-off point" of 0.5 based on the recommendation of Uthes and Herrera (2019), Rigby et al. (2001), and Taylor et al. (1993), who suggested a threshold value of 0.5 for indicators ranging between 0 and 1. Plots that scored below 0.5 for both the intensification and sustainability indices were classified as conventional cocoa plots that were neither sustainable nor intensified. On the other hand, plots that scored above 0.5 for both the intensification and sustainability indices were classified as cocoa plots that are both sustainable and intensified or simply 'sustainably intensified cocoa plots". Thus, the four farm typologies developed based on their intensification and sustainability scores were:

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1. Conventional cocoa plots that are neither sustainable nor intensified (NSNI; plots that scored below 0.5 for both the intensification and sustainability indices)
2. Sustainable cocoa plots that are not intensified (SNI; plots that scored above 0.5 for the sustainability index and below 0.5 for the intensification index)
3. Intensified cocoa plots that are not sustainable (INS; plots that scored above 0.5 for the intensification index and below 0.5 for the sustainability index)
4. Sustainably intensified cocoa plots (SI; plots that scored above 0.5 for both the intensification and sustainability indices)

This typology is in line with Helfenstein et al. (2020) who proposed a conceptual framework to support the navigation of sustainable agricultural intensification pathways. Helfenstein et al. (2020)'s framework was designed by integrating the multiple dimensions of land-use intensity and sustainability, and identified four distinct typologies of sustainable agricultural intensification: (1) those that enhance only agricultural production (conventional intensification); (2) those that improve only sustainability (sustainable dis-intensification); (3) those that result in the decline of both; and (4) those that advance both simultaneously (sustainably intensified pathways).

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4.4.2 Identifying the factors that influence the adoption of individual and bundled SCIPs among cocoa farmers in Ghana

The Multivariate Probit (MVP) model was used in line with Ehiakpor et al. (2021), Ochieng et al. (2021), Marfo et al. (2021), Kotu et al. (2017), and Kassie et al. (2015;2013) to identify the factors influencing the adoption of individual and bundled SCIPs amongst cocoa farmers in Ghana. The MVP model is particularly suitable for this analysis as it accounts for the possibility of interdependencies and trade-offs in the adoption of multiple practices. Unlike univariate models, the MVP model accommodates the correlation

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structure amongst adoption decisions, reflecting the reality that farmers may adopt multiple practices simultaneously or in bundles. The dependent variables in the model represent the 10 most widely adopted SCIPs in the study sample, which were selected through frequency analyses. These practices were hand pollination, renovation of cocoa trees, planting of multipurpose shade trees, planting of improved cocoa varieties, use of organic fertiliser, use of organic pesticides, use of inorganic fertiliser, use of inorganic insecticides, use of inorganic fungicides and farm sanitation measured by a farmer's concurrent adoption of regular hand weeding, pruning and removal of base chupons, mosses and mistletoes. The MVP model specifies a system of 10 equations where each equation corresponds to one SCIP. Thus, each of these practices was treated as a binary variable, where a value of 1 indicates adoption, and 0 indicates non-adoption.

The factors that influence farmers' choices of SCIPs in Ghana were modelled following a random utility framework. An *ith* farm household (*i=1, 2, ..., 739*) facing a decision on whether to adopt the *jth* SCIP (*j=1, 2, ..., 10*) on plot *p, p*(*p=1, 2, ..., P*), is expected to adopt SCIP *j*, if the expected net benefit and/or utility from its adoption implies a higher pay-off compared with non-adoption.

Firstly, a system of equations with latent (unobservable) dependent variables is described by a linear function of a set of observed household, plot, and location characteristics (X), in addition to multivariate normally distributed stochastic terms (ε_{ji}). Each of the ten (10) adoption decision is modelled as:

$$Y^{*}_{ji} = \beta_{j0} + \beta_{j1}X_{1i} + \beta_{j2}X_{2i} + \beta_{j3}X_{3i} + \cdots + \beta_{jk}X_{ki} + \varepsilon_{ji} \quad \text{for } j = 1, 2, \ldots\ldots 10, \qquad (4.8)$$

And observed as:

$$Y_{ji} = \begin{cases} 1, & if\ Y^{*}_{ji} > 0, (farmer\ adopted\ practice\ j) \\ 0, & if \quad otherwise \end{cases}$$

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where Y^{*}_{ji} denotes level of expected benefits associated with the *j*th SCIP as a linear function of a set of observed household, plot and institutional characteristics (X). The explanatory variables were chosen based on theoretical and empirical literature, as well as the specific context of cocoa farming in Ghana.

The error terms ($\mathcal{E}_{ji}$) jointly follow a multivariate normal distribution, each with a zero conditional mean, a variance normalised to unity (for identification of the parameters) (i.e. ($\mathcal{E}_A, \mathcal{E}_B, \mathcal{E}_C, \mathcal{E}_D, \mathcal{E}_E, \mathcal{E}_F, \mathcal{E}_G, \mathcal{E}_H, \mathcal{E}_I, \mathcal{E}_J$)~MVN(0, Ω)), and a symmetric variance–covariance matrix Ω, where Ω has values of 1 on the principal diagonal, and correlation coefficients $\rho_{jk} = \rho_{kj}$ as off-diagonal elements as presented below, where *k* is an alternative to the *jth* SCIP (Ehiakpor et al., 2021; Kotu et al., 2017; Kassie et al., 2015).

$$\Omega = \begin{vmatrix} 1 & \rho_{AB} & \rho_{AC} & \rho_{AD} & \rho_{AE} & \rho_{AF} & \rho_{AG} & \rho_{AH} & \rho_{AI} & \rho_{AJ} \\ \rho_{BA} & 1 & \rho_{BC} & \rho_{BD} & \rho_{BE} & \rho_{BF} & \rho_{BG} & \rho_{BH} & \rho_{BI} & \rho_{BJ} \\ \rho_{CA} & \rho_{CB} & 1 & \rho_{CD} & \rho_{CE} & \rho_{CF} & \rho_{CG} & \rho_{CH} & \rho_{CI} & \rho_{CJ} \\ \rho_{DA} & \rho_{DB} & \rho_{DC} & 1 & \rho_{DE} & \rho_{DF} & \rho_{DG} & \rho_{DH} & \rho_{DI} & \rho_{DJ} \\ \rho_{EA} & \rho_{EB} & \rho_{EC} & \rho_{ED} & 1 & \rho_{EF} & \rho_{EG} & \rho_{EH} & \rho_{EI} & \rho_{EJ} \\ \rho_{FA} & \rho_{FB} & \rho_{FC} & \rho_{FD} & \rho_{FE} & 1 & \rho_{FG} & \rho_{FH} & \rho_{FI} & \rho_{FJ} \\ \rho_{GA} & \rho_{GB} & \rho_{GC} & \rho_{GD} & \rho_{GE} & \rho_{GF} & 1 & \rho_{GH} & \rho_{GI} & \rho_{GJ} \\ \rho_{HA} & \rho_{HB} & \rho_{HC} & \rho_{HD} & \rho_{HE} & \rho_{HF} & \rho_{HG} & 1 & \rho_{HI} & \rho_{HJ} \\ \rho_{IA} & \rho_{IB} & \rho_{IC} & \rho_{ID} & \rho_{IE} & \rho_{IF} & \rho_{IG} & \rho_{IH} & 1 & \rho_{IJ} \\ \rho_{JA} & \rho_{JB} & \rho_{JC} & \rho_{JD} & \rho_{JE} & \rho_{JF} & \rho_{JG} & \rho_{JH} & \rho_{JI} & 1 \end{vmatrix}$$

A, B, C, D, E, F, G, H, I, and J denote farm sanitation, hand pollination, renovation of cocoa trees, shade trees, improved cocoa varieties, organic fertiliser, organic pesticides, inorganic fertiliser, inorganic insecticides, and inorganic fungicides, respectively. The correlation coefficient, ρ (rho), denotes the pairwise correlation of the error terms corresponding to any two SCIPs adoption equations to be estimated in the model. Thus, the off-diagonal

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elements, ρ_{jk}, represent unobserved correlations between the disturbance terms associated with the *j*th and *k*th SCIPs. A significant positive correlation between the two practices suggests complementarity, implying that the adoption of one practice increases the likelihood of adopting the other (Ehiakpor et al., 2021; Kotu et al., 2017; Kassie et al., 2015). Conversely, a significant negative correlation indicates a trade-off or substitution effect.

The likelihood ratio (LR) test was used to assess the null hypothesis that a set of parameters is equal to zero. In the context of the MVP model, the null hypothesis that all the pairwise correlations amongst the error terms are jointly equal to zero was tested as follows:

$$H_0: \rho_{BA} = \rho_{CA} = \rho_{DA} = \ldots = \rho_{JI} = 0 \quad (4.9)$$

The full MVP model was estimated by allowing for all correlations (ρ) between the equations. The restricted MVP model was also estimated under the null hypothesis where all correlations are constrained to zero ($\rho=0$). The log-likelihood of both the full (LL_{Full}) and restricted ($LL_{\text{Restricted}}$) models were then used to calculate the likelihood ratio statistic (LR Statistic) as follows:

$$LR = -2\,(LL_{\text{Restricted}} - LL_{\text{Full}}) \quad (4.10)$$

The degree of freedom for the test was equal to the number of correlation parameters ρ being tested, and was given by:

$$df = k(k-1)/2 \quad (4.11)$$

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where *k* is the number of equations in the MVP model. Thus, for *10* equations, the number of correlations would be:

$$df=10(10-1)/2=45.$$

The *LR* statistic follows a chi-square (χ^2) distribution. Rejection of the null hypothesis implies that the error terms of the equations are correlated, indicating 45 interdependencies amongst the adoption decisions. Robust standard errors were calculated to account for intra-household correlations in the error terms.

4.4.3 Identifying the factors that influence the attainment of sustainable intensification of cocoa plots in Ghana

This study employed the multinomial logit (MNL) model to identify the factors influencing the level of sustainable intensification of cocoa plots in Ghana. The dependent variable was the farm typology that categorises cocoa plots into four distinct groups: (1) conventional cocoa plots that are neither sustainable nor intensified (NSNI), (2) sustainable cocoa plots that are not intensified (SNI), (3) intensified cocoa plots that are not sustainable (INS), and (4) sustainably intensified cocoa plots (SI). The "conventional cocoa plots that are neither sustainable nor intensified (NSNI)" category serves as the base category in the analysis. The multinomial logit model was specified as follows:

For the sustainable cocoa plots that are not intensified (SNI):

$$\log\left(\frac{P(\mathbf{Y}_{i=\mathrm{SNI}})}{P(\mathbf{Y}_{i=\mathrm{NSNI}})}\right) = \beta_{\mathrm{SNI},0} + \beta_{\mathrm{SNI},1}X_{i1} + \beta_{\mathrm{SNI},2}X_{i2} + \beta_{\mathrm{SNI},3}X_{i3} + \cdots + \beta_{\mathrm{SNI},k}X_{ik} \quad (4.12)$$

For the intensified cocoa plots that are not sustainable (INS):

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$$\log\left(\frac{P(Y_{i=INS})}{P(Y_{i=NSNI})}\right) = \beta_{INS,0} + \beta_{INS,1}X_{i1} + \beta_{INS,2}X_{i2} + \beta_{INS,3}X_{i3} + \cdots + \beta_{INS,k}X_{ik} \quad (4.13)$$

For the sustainably intensified cocoa plots (SI):

$$\log\left(\frac{P(Y_{i=SI})}{P(Y_{i=NSNI})}\right) = \beta_{SI,0} + \beta_{SI,1}X_{i1} + \beta_{SI,2}X_{i2} + \beta_{SI,3}X_{i3} + \cdots + \beta_{SI,k}X_{ik} \quad (4.14)$$

β is the vector of coefficients to be estimated for each category relative to the base. X is a set of observed household, plot and institutional characteristics.

4.4.4 Estimating the effects of sustainable cocoa intensification practices adoption on the yield, farm income and food security of cocoa farming households in Ghana

The multinomial endogenous switching regression (MESR) model was employed to estimate the effects of the adoption of SCIPs on yield, farm income and food security of cocoa farming households in Ghana. The effects of adoption are often assessed by comparing variables across plots with different SCIP adoption statuses. While suitable for controlled experiments, this approach may be inappropriate for observational data due to self-selection or selection bias. For instance, farmers' SCIPs adoption decisions could be influenced by unobservable factors, such as intrinsic motivation based on positive perception about SCIPs regarding expected yield gains, or technical skills, which may correlate with outcomes such as yield (Nkegbe and Abdul Mumin, 2022; Yahaya et al., 2018). To address the problem of selection bias, the study employed MESR treatment effect approach, in line with Setsoafia et al. (2022), Abdallah et al. (2021), and Issahaku and Abdulai (2020) and as outlined by Bourguignon et al. (2007). Four farm typologies based

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on the intensification and sustainability indices scores were employed as the multinomial treatment variable as follows:

1. Conventional cocoa farms that are neither sustainable nor intensified (NSNI).
2. Intensified cocoa farms that are not sustainable (INS).
3. Sustainable cocoa farms that are not intensified (SNI).
4. Sustainably intensified cocoa farms (SI).

The MESR model was estimated in three stages.

Stage I: Multinomial adoption selection model

In the first stage, the probability that farmer *i*, with X characteristics will belong to treatment group *J* (P_{ij}) was modelled using a multinomial logit model (Setsoafia et al., 2022; Ma et al. 2022; Teklewold et al. 2013; McFadden, 1974) as follows:

$$P_{ij} = p(\varepsilon_{ij} < 0|X_i) = \frac{\exp(X_i\beta_j)}{\Sigma_{M=1}^{j}\exp(X_i\beta_M)} \quad (4.15)$$

where X_i captures the observed exogenous variables (household, farm and location characteristics as well as institutional variables), while the error term ε_{ij} captures unobserved characteristics. β_j is a vector of parameters to be estimated. The covariate vector X_i was assumed to be uncorrelated with the idiosyncratic unobserved stochastic component ε_{ij}, that is, $E(\varepsilon_{ij}|X_i) = 0$, whereby error terms ε_{ij} were assumed to be identical and independently Gumbel distributed under the independent irrelevant alternatives (IIA) assumption.

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Stage II: Estimation of a system of regime equations to account for selection bias

In the second stage, an ordinary least squares (OLS) model was employed to examine the relationship between outcome variables (cocoa yield, farm income and household food security) and a set of exogenous variables (Z) for each treatment category or potential regime (Kumar et al., 2018; Tesfaye and Tirivayi, 2018). In order to properly account for selection bias in the MESR model, outcome response equations for each possible regime were specified as follows:

$$\begin{cases} Regime\ 1:\ Q_{i1} = Z_i\alpha_1 + \mu_{i1} \quad if \quad I = 1 \\ . \\ . \\ . \\ Regime\ J:\ Q_{iJ} = Z_i\alpha_J + \mu_{iJ} \quad if \quad I = J, \quad with\ J = 4 \end{cases} \qquad \text{(4.16a) to (4.16d)}$$

The base treatment category (i.e. conventional cocoa farms that are neither sustainable nor intensified) was denoted as $J = 1$, with the other treatment categories (i.e, intensified cocoa farms that are not sustainable, sustainable cocoa farms that are not intensified, and sustainably intensified cocoa farms) denoted as $J = 2$, 3, and 4 respectively.

I is an index that denotes farmer i's choice of adopting a type of SCIP combination that determines their classification into a farm typology; Q_i is the outcome variable (cocoa yield, farm income or household food security status) for the *i-th* farmer; Z_i is a vector of exogenous variables (household, farm and institutional characteristics); α_1 to α_J are parameters to be estimated; μ_{i1} to μ_{iJ} are the error terms with expected values of zero and constant variance.

Using a vector of observed covariates (Z_i), equations (4.16a) to (4.16d) address observed selection bias. However, if unobserved factors, such as farmers' motivations to adopt SCIPs, simultaneously influence both adoption decisions and outcome variables, the error

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terms in equations (4.16a) to (4.16d), and Eq. (4.15) would become correlated, leading to unobserved selection bias (Kumar et al., 2018; Tesfaye and Tirivayi, 2018). Failing to address this would result in biased estimates of the treatment effects. Therefore, a consistent estimation of α_1 to α_J required the inclusion of selection correction terms of the alternative choices in equation (4.15). Within the MESR framework, selectivity correction terms were derived from Eq. (4.15) and incorporated into equations (4.16a) to (4.16d) to correct for this selection bias (Kumar et al., 2018; Tesfaye and Tirivayi, 2018). Thus, the selection bias correction mechanism led to a re-specification of equations (4.16a) to (4.16d) as:

$$\begin{cases} Regime\ 1:\ Q_{i1} = Z_i\alpha_1 + \lambda_i\sigma_1 + \omega_{i1} \quad if \quad I = 1 \\ . \\ . \\ . \\ Regime\ 4:\ Q_{i4} = Z_i\alpha_4 + \lambda_i\sigma_4 + \omega_{i4} \quad if \quad I = 4 \end{cases} \qquad (4.17a) \text{ to } (4.17d)$$

where Q_i and Z_i are as defined earlier; λ_1 to λ_J are selectivity correction terms to be used to address the problem of unobserved selection bias; σ_1 to σ_J are covariance between the error terms (ε's and μ's,) in equations (4.15), (4.16a) to (4.16d). ω_{i1} to ω_{iJ} are error terms with an expected value of zero. In the multinomial choice setting of this study, there were three (3) selectivity correction terms (i.e. $J - 1$), one for each alternative treatment group (Wooldridge, 2010). λ_J is the Inverse Mills Ratio (IMR) computed from the estimated probabilities in Eq. (4.13) as follows:

$$\lambda_{ij} = \sum_{m\neq 1}^{j} \rho_j \left(\ln\left(\hat{p}_{ij}\right) + \frac{\hat{p}_{im}\ln(\hat{p}_{im})}{1-\hat{p}_{im}} \right) \qquad (4.18)$$

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$\hat{p}_{ij}$ represents the estimated probability that farmer *i* with characteristic X_i belong to treatment group *J*. ρ in equation (4.18) represents the correlation coefficient of the covariance terms between the error components in the selection equation (i.e. ε's in 4.15) and outcome equations (i.e. μ's in 4.16a to 4.16d) (Bourguignon et al., 2007).

In MESR estimation, the correlation coefficients of the covariance terms between the error components in the selection equation possess distinct econometric interpretations. A statistically significant ρ signals selection bias from unobservable factors, necessitating the consideration of both observable and unobservable influences to obtain unbiased treatment effect estimates (Issahaku and Abdulai, 2020; Ma and Abdulai, 2016). Also, if ρ has opposite signs, farmers select treatments based on comparative advantage, while identical signs indicate 'hierarchical sorting', where SCIPs adopters consistently outperform non-adopters regardless of the treatment regime or SCIPs adoption decision (Ma and Abdulai, 2016). Furthermore, a positive ρ (ρ>0) suggests negative selection bias, meaning farmers with below-average outcomes are more likely to adopt SCIPs, whereas a negative ρ (ρ<0) implies positive selection bias (Ma and Abdulai, 2016). The standard errors in Eq. (4.17a) to (4.17d) were bootstrapped to address heteroskedasticity resulting from the generated regressors λ_J(Setsoafia et al., 2022; Abdallah et al., 2021; and Issahaku and Abdulai, 2020).

Stage III: Estimation of treatment effects

In the third stage of the estimation procedure, the Average Treatment Effects on the Treated (ATT) were calculated by comparing the expected outcomes (cocoa yield and food security) of the different multinomial treatment groups after switching from their regime to

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base regime (i.e. ATT in the observed and the counterfactual scenarios). Following previous studies (including Setsoafia et al., 2022; Abdallah et al., 2021; and Issahaku and Abdulai, 2020), the outcome variables (cocoa yield, farm income and household food security) for SCIPs adopters with adoption (observed) was estimated as:

$$\begin{cases} E(Q_{i2}|I=2) = Z_i\alpha_2 + \lambda_2\sigma_2 \\ . \\ . \\ . \\ E(Q_{i4}|I=4) = Z_i\alpha_4 + \lambda_4\sigma_4 \end{cases} \quad \text{(4.19b) to (4.19d)}$$

Likewise, the outcome variables for SCIPs adopters had they decided not to adopt (Counterfactual) was estimated as:

$$\begin{cases} E(Q_{i1}|I=2) = Z_i\alpha_1 + \lambda_2\sigma_1 \\ . \\ . \\ . \\ E(Q_{i1}|I=4) = Z_i\alpha_4 + \lambda_4\sigma_4 \end{cases} \quad \text{(4.20b) to (4.20d)}$$

The difference between equations (4.19b) and (4.20b), (4.19c) and (4.20c) or (4.19d) and (4.20d) was the ATT for treatments groups *J*=2,3,4 respectively. Thus, the ATT was defined as the difference between, for instance, equations (4.19b) and (4.20b) which is given by:

$$\text{ATT} = E(Q_{i2}|I=2) - E(Q_{i1}|I=2) = Z_i(\alpha_2 - \alpha_1) + \lambda_2(\sigma_2 - \sigma_1) \quad (4.21)$$

λ_2 is the selection term that captured all potential effects of difference in unobserved variables.

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Through this systematic approach, the MESR approach ensures consistent and efficient estimation of α_J, and effectively corrects selection bias in the outcome equations, even when the IIA assumption is violated (Kumar et al., 2018; Tesfaye and Tirivayi, 2018; Bourguignon et al., 2007).

Falsification test for validity of instruments

Unobservable factors influencing the adoption of SCIPs may also affect cocoa yield, farm income and household food security, leading to non-zero covariances between the error terms in the adoption equation (ϵ) (equation 4.15) and the outcome equation (μ) (equation 4.16a-d) (Kumar et al., 2018; Tesfaye and Tirivayi, 2018). This creates endogeneity, which renders OLS estimates inconsistent. To address this issue and ensure consistent estimates of α_J, instrumental variables (IVs) that are correlated with SCIPs adoption decisions but do not directly influence cocoa yield, farm income or household food security outcomes were incorporated into the selection equations (*Xi* in the MNL) (equation 4.15) (Kumar et al., 2018; Tesfaye and Tirivayi, 2018). By excluding these IVs from the outcome equations (equation 4.16a-d), exogenous variations in the endogenous regressors were isolated, enabling consistent estimation (Bourguignon et al., 2007). This exclusion restriction was essential for improving the identification of the MESR and endogenous model and was informed by economic theory and empirical studies (Tesfaye and Tirivayi, 2018; Di Falco et al., 2011; Bourguignon et al., 2007).

To identify the model, a composite score of farmers' perceptions about SCIPs was employed as the primary IV, as it satisfies the exclusion restriction by potentially influencing adoption decisions without directly affecting cocoa yield, farm income or food security. Additional variables, specifically access to credit, training workshop attendance, and extension access were considered potentially endogenous to the adoption of SCIPs. For

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example, extension visits may be endogenous if adopters attract more visits from extension agents. To address this, specific IVs were selected: receipt of financial literacy training was used as an IV for credit access; active membership in a cocoa farmer association served as an IV for extension access; contact with NGOs or projects providing training on SCIPs was employed as an IV for training attendance; and the number of alternative livelihood activities engaged by household members was employed as IV for off-farm income. These IVs were chosen based on their expected influence on adoption decisions without directly affecting cocoa yield, farm income or food security outcomes (Ma and Abdulai, 2016; Di Falco and Veronesi, 2013).

Instrument validity was then confirmed through a falsification test, which examined whether a variable influenced adoption decisions without affecting the outcome variables amongst non-adopters (Tesfaye and Tirivayi, 2018; Di Falco et al., 2011). Specifically, it tests the hypothesis that the instruments have no effect on SCIPs adoption, but directly affect the outcome variables such as cocoa yield, farm income and household food security. A rejection of the hypothesis implies that unobserved factors that determine adoption decisions are uncorrelated with the outcome variables.

Control function approach for correcting potential endogeneity

The control function approach, via a two-stage residual inclusion procedure was then used to address the endogeneity problem (Ma and Abdulai, 2016; Wooldridge, 2015; Terza et al., 2008). In the first stage, each potentially endogenous variable was modelled, using a Probit regression, as functions of an appropriate instrument and exogenous controls (Terza et al., 2008). Instead of substituting predicted residuals from the first-stage regressions, the observed values of the endogenous variables and their generalised residuals were included as covariates in the MESR model (equation 4.17a-d) (Wooldridge, 2010; Terza et al.,

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2008). The inclusion of residuals served as a control function, facilitating consistent estimation within the MESR framework (Ma and Abdulai, 2016; Wooldridge, 2010). This was to ensure that the endogenous variables attain exogeneity in the second-stage estimation after incorporating the residuals as control functions in line with the robust regression-based Hausman test for endogeneity (Ma and Abdulai, 2016; Wooldridge, 2015; Terza et al., 2008). To ensure the robustness of the standard errors in light of the complex error structure inherent to MESR models, the estimation applied the bootstrapping technique using the variance-covariance estimator [i.e. *vce(bootstrap, reps(1000))*], generating bootstrapped standard errors across 1,000 replications (Bourguignon et al., 2007).

4.4.5 Analysing incentives that could encourage cocoa farmers to adopt sustainable cocoa intensification practices

Thematic Network Analysis (TNA) was employed as the qualitative method to analyse the incentives that promote the adoption of SCIPs amongst cocoa farmers in Ghana. TNA is a structured analytical approach that facilitates the exploration, interpretation, and visualisation of complex themes within textual data, such as interview transcripts, open-ended survey responses, or observational notes (Braun and Clarke, 2022; Kiger and Varpio, 2020; Braun and Clarke, 2006). It is inherently explanatory and interpretive, and it allows for an in-depth examination of the diverse and interconnected incentives shaping farmers' decision-making processes (Braun and Clarke, 2006).

The analytical framework of TNA employed in this study consisted of a hierarchical structure of themes, categorised into three levels: *basic themes*, *organising themes*, and *global themes* (Kiger and Varpio, 2020; Nowell et al. 2017; Braun and Clarke, 2006). The *basic themes* represented the most granular units of meaning, emerging directly from the

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data through repeated phrases, ideas, or specific experiences shared by respondents (Kiger and Varpio, 2020; Braun and Clarke, 2006; Attride-Stirling 2001). These themes were then clustered into *organising themes* to provide broader conceptual groupings that revealed patterns and relationships amongst the *basic themes* (Kiger and Varpio, 2020; Nowell et al., 2017). Finally, the *organising themes* were integrated into a *global theme*, which encapsulated the overarching meaning of the data, synthesising multiple layers of insights into a cohesive narrative (Braun and Clarke, 2022).

4.4.5.1 Analytical procedure of the thematic network analysis

The TNA in this study was conducted through a six-step procedure (Kiger and Varpio, 2020; Braun and Clarke, 2006; Attride-Stirling 2001). The first step involved data coding, which entailed a systematic reading of the interview transcripts to identify and label specific segments of text related to the incentives for the adoption of SCIPs. This initial coding was performed to break down the textual data into manageable units, facilitating the identification of emerging patterns and themes. This stage allowed for the initial organisation of the raw data into meaningful units, capturing key concepts embedded in the respondents' narratives. These meaningful units are incentives that emerged from the respondents' narratives. This ensured that a wide range of incentives were systematically captured.

The second step focused on theme identification, in which similar codes were clustered into basic themes. Axial coding was employed to refine and structure the analysis by determining dominant themes and their interrelationships (Braun and Clarke, 2019). The codes were categorised in alignment with the framework provided by the modified Technology Acceptance Model and the research question "Which incentives could promote the adoption of SCIPs among cocoa farmers in Ghana?" to ensure coherence. In the third

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step, basic themes were aggregated into organising themes. This step involved identifying broader conceptual categories that encapsulated groups of related *basic themes*, thereby structuring the data into higher-order analytical units. The fourth step integrated the *organising themes* into a *global theme*, which served as the overarching conceptual framework that unified the various strands of the analysis (Braun and Clarke, 2022). The global theme emerged as "Incentives for the Adoption of SCIPs in Ghana", representing the core analytical construct that synthesises the *organising themes* into a singular, cohesive narrative.

The fifth step involved visual representation of the thematic network (Kiger and Varpio, 2020; Braun and Clarke, 2022; 2019; 2006). The hierarchical relationships between basic, organising, and global themes were mapped out using a network diagram, which illustrated the linkages between different levels of themes and how they contribute to understanding the "Incentives for the Adoption of SCIPs in Ghana" (Byrne, 2022). The final step involved interpreting the thematic network, in which the relationships between different themes were systematically analysed to uncover the underlying narratives and explanatory patterns (Braun and Clarke, 2022; Byrne, 2022). This stage moved beyond mere categorisation and visualisation to offer a deeper theoretical and empirical interpretation of how different incentives interact to influence the adoption of SCIPs.

4.4.5.2 Data collection and processing

Data collection for the qualitative analysis of the incentives that promote the adoption of SCIPs amongst cocoa farmers was conducted through semi-structured interviews with key informants in the cocoa sector of Ghana. The use of semi-structured qualitative interviewing was essential in eliciting rich, nuanced responses, allowing participants to articulate their perspectives, experiences, and motivations regarding the adoption of SCIPs

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(Braun and Clarke, 2022). This adaptability ensured that the analysis was responsive to the lived experiences of cocoa farmers, capturing incentives and motivations that may have been overlooked in existing studies (Braun and Clarke, 2022).

4.4.5.3 Sampling and participant selection

Two primary key informant groups of interview participants were identified: experts and cocoa farmers. The qualitative data collection process engaged key experts from various sectors of the cocoa industry through semi-structured interviews, offering critical insights into the incentives driving SIPs amongst cocoa farmers in Ghana. Participants represented diverse roles, including District Extension Coordinators providing field-level expertise, District Directors of COCOBOD offering institutional perspectives, and COCOBOD researchers contributing scientific insights on sustainability and innovation. A tabulation of the respondents interviewed is presented in Table 4.6.

Table 4.6: Frequency distribution of Key Informants interviewed

Role in the Cocoa Sector	Frequency	Percentage (%)
Cocoa farmers	22.00	55.00
Extension Officer	1.00	2.50
District Director of COCOBOD	2.00	5.00
Researcher at COCOBOD	3.00	7.50
Researcher with Other State Institution or Academia	5.00	12.50
NGO Representative	1.00	2.50
District Coordinator of Cocoa Rehabilitation Programme	2.00	5.00
District Extension Coordination Officer	3.00	7.50
Regional Manager of ECOM	1.00	2.50
Total	40.00	100.00

Source: Field data (2024)

With the consent of all interviewees, audio recordings of the interviews were made and subsequently transcribed verbatim in Microsoft Word. To maintain confidentiality and

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anonymity, transcripts were de-identified, with respondents assigned unique coded identifiers (e.g., R01 to R40) (Nguyen et al., 2020). The transcripts were then systematically organised into Microsoft Excel for structured qualitative analysis.

4.5 Definitions of the Study Variables

4.5.1 Outcome variables

The outcome variables for this study are cocoa yield per plot, farm income and household food security.

4.5.1.1 Estimation of cocoa yield

Cocoa yield was measured as the quantity of cocoa output per hectare (t/ha). Cocoa yield was calculated by converting the total quantity of dried cocoa beans sold by the farmer per plot during the 2022/23 production year into kilograms. This value was then divided by the size of the cocoa plot, measured in hectares, to obtain the yield per plot in kilograms per hectare (kg/ha) which was subsequently converted to tonnes per hectare using the conversion rule:

$$\text{tonnes per hectare (t/ha)} = \frac{\text{kilograms per hectare (kg/ha)}}{1000} \quad (4.22)$$

4.5.1.1 Estimation of cocoa farm income

Subsidy-adjusted gross profit was used as the measure of cocoa farm income. It was estimated by subtracting both the total variable cost of production and the total value of subsidies from cocoa revenue. This metric represents a farm's gross profit after accounting for the influence of government or other subsidies, which may reduce production costs or

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enhance revenue. Adjusting for subsidies provides a more accurate picture of a farm's financial performance by isolating the effect of external financial support, thereby enabling more realistic assessments of profitability, operational efficiency, and investment viability. Revenue was computed by multiplying cocoa yield by the producer price per kilogram, using the official cocoa producer price of GHC 800 per 64-kg bag for the 2022/2023 production season. The total value of subsidy support was estimated by first determining the unit costs (per kg, litre, or sachet) of fertilisers, insecticides, and fungicides, and then multiplying these by the quantities of subsidised inputs received. The aggregate of these values represented the total value of subsidy allocation.

The estimation of production costs included two main components: input and labour expenditures. Input costs comprised expenditures on inorganic and organic fertilisers, insecticides, fungicides, herbicides, and organic pesticides during the 2022/2023 season. Labour costs were obtained by aggregating expenditures on hired, family, and exchange labour. Additionally, expenditures on key agronomic activities, including hand pollination, water harvesting, irrigation, drainage, and farm renovation, were included in the total variable cost of production per hectare. All variables were normalised by plot size (in hectares).

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4.5.1.2 Measurement of household food security

Food security was measured using three standardised indices: the HFCS, HFIAS, and rCSI. These metrics capture distinct and complementary dimensions of food security. For instance, the HFCS evaluates the frequency of food consumption across various food groups over a seven-day recall period. It provides insights into dietary diversity and nutritional quality, reflecting the dimensions of food access, availability, and utilisation (Dompreh et al., 2021). On the other hand, the HFIAS measures food access, availability

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and stability by assessing household experiences of food insecurity, including anxiety about food, insufficient quantity or quality of food, and behaviours to mitigate access challenges (Dompreh et al., 2021). The rCSI focusses on food access and stability by examining behavioural responses to food shortages, such as reducing meal sizes or altering consumption patterns, which can also impact nutritional well-being and food utilisation (Dompreh et al., 2021). Together, these metrics offer a comprehensive assessment of household food security of cocoa farmers in Ghana.

Household food consumption score (HFCS)

The HFCS is a weighted score based on dietary diversity, food frequency and the relative nutritional frequency or nutritional importance of food groups consumed at the household level (Wekesa et al., 2018). They capture the consumption of nine food groups in the seven (7) days prior to the survey, and then summed up and weighed accordingly for each food group (Dompreh et al., 2021). The person who is responsible for food preparation in the household was asked about the number of days that at least one of the household members (members living together and eating from the same pot regularly, including those temporarily absent) had consumed at least one food item in each food group during the seven (7) days preceding the survey. Foods taken during ceremonies and major occasions were excluded. The HFCS of each household was then calculated by multiplying the frequency of foods consumed within the seven-day period with the weighting of each food group provided in the WFP framework (See Appendix 3) (Wekesa et al., 2018). The weighted food group scores were then summed, with high HFCS denoting higher food diversity, and thus higher household food security.

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Household food insecurity access scale (HFIAS)

The HFIAS measures the severity of food insecurity through household behaviours and perceptions, providing a continuous indicator of food access (Manda et al., 2021; Ballard et al., 2011; Coates et al., 2007). It comprises nine sets of questions addressing progressively severe food insecurity experienced in the four weeks preceding the survey. Each question had two parts: an occurrence question (*yes/no*) and a frequency-of-occurrence question (*rarely, sometimes, or often*). Responses were scored from 0 to 3, with 3 indicating the highest frequency of occurrence (i.e. *often*) (Dompreh et al., 2021; Otekunrin et al., 2021). The total HFIAS score was calculated by summing the scores for all nine questions, resulting in a range from 0 to 27, with higher scores reflecting greater food insecurity and heightened perceptions of hunger (Yahaya et al., 2018; Ballard et al., 2011; Coates et al., 2007).

Reduced coping strategy index (rCSI)

The reduced coping strategy index (rCSI) is an index that was measured by scoring coping strategies that households used, and their frequency of use in times of food shortfalls (Setsoafia et al., 2023; Dompreh et al., 2021; Maxwell and Caldwell, 2008). The index employed five standardised questions on the coping strategies with their associated weights (Maxwell and Caldwell, 2008). The rCSI score ranges from 0 to 63 (Setsoafia et al., 2023; Maxwell and Caldwell, 2008). A high rCSI score denotes extensive use of coping strategies and hence low food security (Dompreh et al., 2021; Maxwell and Caldwell, 2008).

4.5.2 Explanatory variables

Drawing upon previous empirical studies on the adoption of SIPs and related agricultural innovations (including Kassie et al. 2013; Teklewold et al. 2013; Manda et al. 2015; Ma

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and Wang 2020; Ehiakpor et al. 2021), this study identified and selected a range of control variables that may influence the adoption of SCIPs. These variables include farm characteristics, household demographic characteristics, asset endowments, access to own capital and other resource constraints, and institutional factors. Tables 4.7-4.9 present the explanatory variables used for the various econometric analyses in this study.

Table 4.7: Description of variables depicting household characteristics

Variables	Description	Expected sign
Farming experience	Number of years in cocoa farming (number)	+
Household size	Total number of household members (number)	+
Gender	Gender of household head (1=male,0=otherwise)	+
Residential status	Residential status of household head (1=indigene, 0=migrant)	+
Education	Education level of household head (number of years of schooling)	+
Farm asset	Total Farm Assets estimated using Principal Component Analysis	-
Land holding	Total size of all non-cocoa plots owned by household (in hectares)	+
Religion	Farmer will not adopt a new technology that conflicted their religious beliefs (1=yes, 0=otherwise)	-
SCIP perception	A composite score of farmers' perceptions about SCIPs whereby higher scores indicate a more negative perception of SCIPs	-

Source: Author's literature review (2024)

Experience

Experience was measured as the number of years a household head has spent in cocoa farming. It reflects the level of knowledge and expertise a farmer has accumulated over the years. Farmers with more years in cocoa farming are likely to have a better understanding of cocoa cultivation challenges, such as pests, diseases, and declining yields. This

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experience can positively influence their decision to adopt SCIPs as a way to address these challenges and increase productivity.

Table 4.8: Description of variables depicting plot characteristics

Variables	Description	Expected sign
Plot ownership	Cocoa farm plot is owned and cultivated by the household (1=yes, 0=otherwise)	+
Farm distance	Walking distance from home to plot (in minutes)	+
Soil fertility	Farmer perceives soil fertility to be poor (1=yes, 0=otherwise)	+
Topography	Farmer perceives land surface to be flat (1=yes, 0=otherwise)	+
Drought risk	Farmer perceives drought to be a major problem on plot (1=yes, 0=otherwise)	+
Transition zone	Plot is located in the Forest-Savanna transitional zone of Ghana	+

Source: Author's literature review (2024)

Table 4.9: Description of institutional variables

Variables	Description	Expected sign
Usefulness of extension	Farmer perceives extension advice to be useful (1=yes, 2=No, 3=No access)	+
Fertiliser subsidy	Value of fertiliser subsidy received by household (GHC)	+
Insecticide subsidy	Value of insecticide subsidy received by household (GHC)	+
Fungicide subsidy	Value of fungicide subsidy received by household (GHC)	+
Access to credit	Access to agricultural credit when needed (1=yes, 0=otherwise)	+
Training	Number of cocoa production workshop/seminar attendance (number)	+

Source: Author's literature review (2024)

Household size

Household size was measured as the total number of persons living together and eating from the same pot regularly, including those temporarily absent. A larger household size

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can provide additional labour for farm operations, including adopting labour-intensive SCIPs such as hand pollination, pruning, or mulching (Asamoah, 2015). However, larger households may also strain household resources, limiting the ability to invest in SCIPs (Asamoah, 2015). The effect will depend on the balance between labour availability and resource constraints. Tennhardt et al. (2024) showed that increased household labour availability (averaging 0.8 additional members during COVID-19 lockdowns) influenced pest and disease management practices in Ugandan cocoa farms, showcasing household size as a factor in adoption dynamics. Thus, a larger household size is expected to have a positive effect on the decision to adopt SCIPs if the larger household provides labour for adoption.

Gender of household head

Gender of household head (1 = male, 0 = otherwise) plays a critical role in adoption decisions. Male household heads are often more likely to adopt new agricultural technologies due to better access to inputs, credit, extension services, and decision-making power. Female-headed households may face challenges such as limited access to productive resources, which could hinder the adoption of SCIPs. Adams et al. (2024a) and Benitez-Altuna et al. (2021) found being a male-headed household to positively affect the adoption of SIPs. Thus, male-headed households are expected to have a positive relationship with the adoption of SCIPs.

Residential status of household head

Household heads who are indigenes of the communities within which their cocoa plots are located are more likely to have stronger ties to the community and their local institutions, leading to better access to land, support networks, and information about new farming

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practices. Migrant farmers may face social exclusion or weaker tenure security, reducing their ability or willingness to adopt SCIPs. Thus, indigenes are expected to be more likely to adopt SCIPs.

Education level of household head

Education, measured as the number of years of formal schooling, enhances a farmer's ability to acquire, process, and apply knowledge, making them more likely to adopt innovative and sustainable agricultural practices. Asamoah (2015) asserted that education enhances farmers' comprehension of technologies, fostering a deeper appreciation, acceptance, and effective implementation of innovations. Educated farmers may better understand the benefits of SCIPs, or could have greater awareness of environmental issues, and so may be more open to adopting SCIPs. Kassie et al. (2015) found that education significantly influenced the adoption of SIPs. Other previous studies (like Nyarindo et al., 2024; Jumpah et al., 2024; Marfo et al., 2021; Kotu et al., 2017) also highlighted that education was a key determinant of adopting sustainable intensification technologies, emphasising their role in enhancing productivity and livelihoods. Thus, higher education levels are expected to be associated with a greater likelihood of adopting SCIPs.

Farm asset

Farm assets, such as tools, machinery, and other capital resources, provide the means to implement SIPs. Mutyasira et al. (2018) and Kotu et al. (2017) highlighted that access to capital and mechanisation promoted sustainable intensification among smallholder farmers, implying the importance of capital resources. Thus, a higher number of farm assets is expected to increase the likelihood of adopting SCIPs by reducing the drudge associated with their implementation.

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Land holding

Land holdings, measured as the total size of all non-cocoa plots owned by a household, serve as an indicator of wealth. The size of non-cocoa land holdings can significantly influence the adoption of cocoa production practices by shaping farmers' economic stability, resource availability, and decision-making priorities. Larger holdings allow households to diversify income, reducing reliance on cocoa farming and enabling investment in improved practices. A positive relationship is expected if larger land holdings increase financial stability and investment in SCIPs.

Religion

Religion was measured as whether a farmer will adopt a new technology that conflicts with their religious beliefs. Cultural or religious beliefs that conflict with new technologies can significantly influence farmers' decision-making processes, particularly in Sub-Saharan Africa, especially when such practices or technologies are viewed as inappropriate or forbidden within a farmer's religious framework. Religious demands may prevent farmers from visiting farms on sacred or taboo days to attend to important SCIPs that demand frequent monitoring. Thus, religion is expected to have a negative effect on the likelihood of cocoa farmers to SCIPs if it conflicts with these practices.

Favourable perception about SCIPs

In line with the modified technology acceptance model (TAM), the perception of farmer regarding SCIPs in this study was estimated as a composite index of various perception indicators measured using a likert-type scale. The composite score of farmers' perceptions of SCIPs was derived from responses to nine Likert scale questions. These questions assessed farmers' agreement or disagreement with various attributes of SCIPs, ranging from

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perceived yield impacts, concerns about initial yield reductions, long-term benefits, environmental contributions, labour and expertise requirements, and land tenure implications. Respondents rated their perceptions on a scale of 1 (Strongly Disagree) to 5 (Strongly Agree). The composite score was calculated by aggregating the responses across the nine questions, capturing the overall perception of SCIPs. Higher scores indicate a more negative perception of SCIPs, reflecting scepticism or barriers perceived by the farmer, while lower scores suggest more favourable views of these practices.

Benitez-Altuna et al. (2021) indicated that perceptions shaped by economic resources, trust, and training influenced the adoption of ecological intensification practices in Chilean vegetable farming. Owusu et al. (2022) examined farmers' perceptions regarding the economic and ecological benefits of varying cocoa agroforestry shade levels. Their findings revealed that, beyond market-driven factors, farmers' ecological perceptions significantly influence the establishment of shade levels. Adams et al. (2024a) showed that perceived ease of adoption significantly influenced female farmers' decisions to adopt SIPs in northern Ghana. Conversely, Issaka et al. (2024) identified that performance expectancy and attitudes, both reflecting farmer perceptions, negatively influenced behavioural intention toward SIPs adoption. Thus, a favourable perception of SCIPs, captured by a lower perception index, is expected to increase the likelihood of adopting SCIPs by reducing the perceived negative risks associated with their implementation.

Plot ownership

Plot ownership (i.e. whether a cocoa farm plot is owned and cultivated by the household) increases tenure security and may encourage farmers to make long-term investments in their land, such as adopting SCIPs that enhance productivity and sustainability. Households engaged in sharecropping may be less willing to invest in long-term SCIPs due to insecure

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land rights and fear of losing access to the land. Land tenure arrangements have been recognised as a key socio-cultural and economic factor affecting cocoa productivity in Ghana (Asamoah and Owusu-Ansah, 2017). Ertiro (2006) noted that land tenure security significantly influences farmers' investment decisions and attitudes toward cocoa production. When land tenure is uncertain, farmers are less likely to invest in soil conservation measures, fearing that they may not reap the long-term benefits. Maré et al. (2022), Mutyasira et al. (2018), and Kassie et al. (2013) emphasised that tenure security is crucial for achieving sustainable agricultural intensification amongst smallholder farmers. Likewise, Nyarindo et al. (2024) noted that rented plots negatively impacted the adoption of sustainable agricultural intensification. Plot ownership is therefore expected to increase the likelihood of cocoa farmers adopting SCIPs.

Farm distance

Farm distance, measured as walking distance from home to farm in minutes, can affect the time and energy required for farmers to access their plots. Longer walking distances may discourage frequent farm visits and monitoring, reducing the likelihood of adopting labour-intensive SI practices. A longer walking distance is expected to reduce the likelihood of adopting SCIPs due to time and labour constraints.

Topography

Topography was measured as the extent to which farmers perceived the land surface of their plots to be flat. Topography is a critical factor in agriculture, as it directly influences soil fertility, water retention, and erosion control, all of which affect crop productivity. Flat lands are generally easier to manage and cultivate, reducing the cost and effort of adopting labour-intensive SCIPs. In contrast, sloped and hilly terrains pose challenges such as

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increased runoff, soil erosion, and uneven water distribution, which can lead to nutrient depletion and reduced yields. Steep or uneven land surfaces may pose challenges to the adoption of SCIPs due to labour demands, or limited access to machinery. Thus, understanding and adapting to the topographical characteristics of farmland is essential for sustainable cocoa production and long-term agricultural productivity. Rahn et al. (2018) and Kassie et al. (2015&2013) highlighted topography as one of the factors influencing the adoption of SIPs. Thus, topography is expected to positively influence the decision to adopt SCIPs due to easier land management.

Transition zone

Transition zone was measured as whether the plot was located within the Forest-Savanna transition zone of Ghana. The transition zone of Ghana is characterised by unique agroecological conditions where farmers may face moderate soil fertility and greater risks of drought compared to the forest zones in the south. Farmers in this zone may be more likely to adopt SCIPs, such as soil fertility management and water conservation measures, to adapt to these challenging conditions. Maré et al. (2022), Mutyasira et al. (2018), and Kassie et al. (2015&2013) mentioned drought and climate risks as a factor influencing the adoption of SIPs. Thus, the transition zone is expected to have a positive influence on the likelihood of adopting SCIPs.

Number of extension visits and usefulness of extension service

Extension services provide critical knowledge and technical support for farmers, which can help them adopt SCIPs. According to Binam et al. (2008), contact with extension agents help farmers adopt better agricultural practices and improve cocoa productivity. Also, when farmers perceive the advice from extension officers as useful, they are more likely to

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implement recommended practices. Jumpah et al. (2024), Maré et al. (2022), Rahn et al. (2018), Kassie et al. (2015&2013) noted that extension service access was one of the key determinants for the adoption of sustainable intensification technologies through enhancing farmer knowledge and support. Also, Kassie et al. (2013) identified the quality of extension services as a significant factor influencing the adoption of sustainable agricultural practices. Brown et al. (2021) demonstrated that innovation platforms, which often involve extension services, play a role in promoting the adoption of conservation agriculture in South Asia. Thus, both the number of extension visits and the perceived usefulness of extension service are expected to increase the likelihood of adopting SCIPs.

Agrochemical subsidy

Fertiliser subsidies reduce the cost of fertilisers, a critical input to cocoa production, making them more affordable for farmers and encouraging their use. Likewise, subsidies on fungicides and insecticides lower the cost of pest management. Higher agrochemical subsidies are expected to increase the use of these inputs.

Access to credit

Access to credit may alleviate financial constraints, enabling farmers to purchase farm input and hire labour needed for the effective adoption of SCIPs. Jumpah et al. (2024), Maré et al. (2022), Ehiakpor et al. (2021) and Kassie et al. (2015) identified credit access as a key determinant for the adoption of sustainable intensification technologies. Thus, farmers with access to agricultural credit are more likely to adopt SCIPs.

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Training

Training could equip farmers with knowledge and skills to implement SCIPs effectively. Regular training improves awareness of new technologies and builds confidence in adopting sustainable farming methods. According to Binam et al. (2008), participation in training programmes help farmers adopt better agricultural practices and improve cocoa productivity. Ehiakpor et al. (2021), Brown et al. (2021), Benitez-Altuna et al. (2021), and Wuepper et al. (2018) highlighted training and peer learning as positive factors influencing the adoption of SIPs. Farmer training was shown by Tennhardt et al. (2024) to be a strong driver of the adoption of alternative pest and disease management practices in Ugandan cocoa farms. Thus, higher numbers of training sessions attended by farmers is expected to increase the likelihood of adopting SCIPs.

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CHAPTER FIVE

RESULTS AND DISCUSSION

5.1 Introduction

This chapter is divided into five sections. Section 5.2 presents results on the descriptive statistics of the data. Results from the analysis of the level of adoption of SCIPs by cocoa farmers are presented in section 5.3. This is followed by the results on the factors that influence farmers' adoption of SCIPs presented in section 5.4. Section 5.5 presents results on the effects of the adoption of SCIPs on the yield, farm income and food security of cocoa farming households in Ghana. Finally, results and discussion of the analysis of incentives that promote the adoption of SCIPs in Ghana are presented in section 5.6.

5.2 Descriptive Statistics of the Data

5.2.1 Socio-economic characteristics of cocoa farmers

The socio-economic characteristics of cocoa farmers in the various cocoa regions of Ghana highlight differences in gender, age, education, residential status, household size, cocoa farming experience, and the number of cocoa plots managed by households. Table 5.1 presents an overview of the socio-economic characteristics of cocoa farmers in various regions of Ghana. The values presented in Table 5.1 are percentages and reflect the distribution of these characteristics across the pooled sample and region-specific subsets.

The majority of cocoa farmers across all the regions were males, constituting between 74.50% and 85.71% of household heads in the regional subsets. This indicates a male-dominated farming landscape, which is consistent with gender norms in cocoa production in West Africa, where men often control the land and farming decisions (Suh & Molua, 2022). This aligns with Kongor (2017), who found that the majority of cocoa farmers in

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Table 5.1: Summary of socio-economic characteristics of cocoa farmers

Variable	Pooled (N=739)	Ahafo (N=151)	Ashanti (N=149)	Bono (N=70)	Bono East (N=75)	Western North (N=160)	Eastern (N=134)
Gender of household head							
Female	20.70	17.22	25.50	14.29	24.00	19.38	22.39
Male	79.30	82.78	74.50	85.71	76.00	80.62	77.61
Age of household head							
Not more than 35	9.61	13.25	8.72	11.43	8.00	6.88	9.70
36-50	41.14	34.44	28.19	58.57	61.33	28.75	55.97
51-65	43.84	50.33	61.07	28.57	28.00	51.88	26.12
More than 65	5.41	1.99	2.01	1.43	2.67	12.50	8.21
Education of household head (Years in school)							
No education	6.63	2.65	12.08	5.71	8.00	5.62	5.97
Primary	48.31	36.42	53.02	52.86	64.00	49.38	44.03
JSS/JHS/Middle	26.79	35.10	26.85	28.57	17.33	25.00	23.88
Secondary	17.46	25.83	8.05	11.43	9.33	19.38	23.88
Tertiary	0.81	0	0	1.43	1.33	0.62	2.24
Residential status of household head							
Indigene	48.31	31.79	59.73	44.29	62.67	46.25	34.33
Migrant	51.69	68.21	40.27	55.71	37.33	53.75	65.67
Household size (Number of persons)							
1-3	51.83	58.94	48.99	55.71	61.33	58.13	32.09
4-7	46.14	41.06	48.32	40.00	38.67	38.12	66.42
8-12	1.76	0	2.01	4.29	0	3.12	1.49
More than 12	0.27	0	0.67	0	0	0.62	0
Experience of cocoa farmer (Years of cocoa farming)							
Less than 5	0.41	0.66	0.67	0	0	0.62	0
5-10	17.05	20.53	12.08	24.29	21.33	13.12	17.16
11-20	61.03	68.21	55.70	51.43	48.00	71.25	58.96
21-30	18.40	7.95	30.20	21.43	24.00	12.50	19.40
More than 30	3.11	2.65	1.34	2.86	6.67	2.50	4.48
Number of cocoa plots managed by household							
One	74.56	76.16	89.26	81.43	60.00	62.50	75.37
Two	15.97	13.91	6.71	14.29	25.33	25.00	13.43
Three	5.55	5.30	1.34	2.86	9.33	8.75	5.97
Four	2.84	2.65	2.01	1.43	5.33	2.50	3.73
More than four	1.08	1.99	0.67	0	0	1.25	1.49

Source: Field data (2024)

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Ghana (76.6%) was male. Also, the results presented in Table 5.1 indicate that the majority of cocoa farmers were old, with 43.84% of household heads aged between 51 and 65 years in the pooled sample. This age group was dominant in most regions, except for Bono (28.57%), Bono East (28%) and Eastern (26.12%). This age distribution suggests that cocoa farming in Ghana is managed predominantly by ageing farmers, with younger farmers (under 35 years) being the minority. This raises concerns about the sustainability of the cocoa sector since the youth do not engage in cocoa farming. This result is corroborated by Kongor (2017), who reported that the majority of farmers in Ghana (58.0%) were between 41 and 60 years old.

Furthermore, a significant portion of the cocoa farmers (61.03% in the pooled data) had 11–20 years of experience in cocoa farming. This was consistent across the regions, indicating that cocoa farms in Ghana are managed by experienced farmers. The concentration of cocoa farmers with many years of experience (11–20 years) also suggests stability in the workforce but raises concerns about succession planning, as fewer younger farmers are entering the cocoa sector. This finding aligns with Kongor (2017), who reported that most farmers (43.5%) possessed 11–20 years of experience.

Also, the majority of cocoa farmers had primary education (48.31% overall), with considerable regional variation (Table 5.1). In Bono East, a higher percentage of the farmers (64%) had primary education, while in Ashanti, the percentage was lower (53.02%). Very few cocoa farmers had tertiary education (0.81% overall), and this percentage was relatively consistent across the regions. Conversely, secondary education was common in regions such as Western North (19.38%) and Eastern (23.88%). This is consistent with Kongor (2017), who observed that cocoa farmers exhibited low educational attainment, with the majority (50.9%) having only a Middle or Junior High School education, while only 4.0% attained tertiary education. The relatively low level of formal

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education, particularly the absence of farmers with higher education, could affect the adoption of advanced farming techniques or technologies. Asamoah (2015) emphasised that education enhances farmers' understanding of technologies, enabling them to better appreciate, adopt, and implement innovations. Education level may also impact the ability to access support services like credit and extension services.

Further, the proportion of migrant cocoa farmers (51.69%) exceeded that of cocoa farmers who were indigenes of the communities within which their cocoa farms were located (48.31%). This suggests a substantial movement of people into cocoa farming regions, particularly in areas like Ahafo (68.21% migrant farmers) and Eastern (65.67% migrant farmers). However, some regions, like Ashanti (59.73% indigenes), reported a higher proportion of indigenes. The higher proportion of migrant farmers in cocoa farming regions suggests a high number of absentee farmers, who own cocoa farms but do not manage them directly. This may hinder the implementation of optimal farming practices like SCIPS, leading to reduced crop yields and lower quality produce. For instance, without direct involvement, absentee farmers may not respond promptly to pest and disease outbreaks. Also, the reliance on external contractors or caretakers may lead to increased costs of production, reduced transparency, and potential exploitation.

The results in Table 5.1 further indicate that the majority of cocoa farmers lived in households with 1–7 members (97.97% in the pooled data). Larger households with more than 12 members were low (0.27%). Smaller household sizes suggest that cocoa farming in Ghana is being managed by nuclear families rather than extended families, which may reduce family labour availability for critical timebound and regimented agronomic practices. The results in Table 5.1 further indicate that the majority of cocoa farmers (74.56%) managed only one plot, which is especially common in Ashanti (89.26%) and Eastern (75.37%). The proportion of farmers managing more than one plot was higher in

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regions like Bono East (25.33%) and Western North (25.00%). The prevalence of single-plot farming indicates limited access to land, perhaps due to the menace of small-scale mining operations in the Ashanti and Eastern regions of Ghana. It also suggests that households are diversifying into other crops, which may be a sign of decreasing investments in cocoa farming.

5.2.2 Descriptive analysis of cocoa plot characteristics

Table 5.2 presents the characteristics of cocoa plots based on frequency analysis using percentages. The results of the analysis of cocoa plot characteristics provide insights into the plot characteristics, including plot size, land rights, approximate age of cocoa trees, topography, and distance from residence to plot, highlighting regional variations.

The majority of cocoa farmers (99.35%) operated plots whose sizes were below 5 hectares. Most of these farmers, however, operated plots between 1–5 hectares, accounting for 71.20% of the pooled data. This aligns with Kongor (2017), which found that most farmers cultivated cocoa on land parcels smaller than 5 hectares, while only 12.2% farmed on plots exceeding 8 hectares. This reinforces the fact that cocoa production in Ghana is dominated by smallholders managing cocoa plots that are less than 5 hectares in size. Also, sharecropping arrangements (i.e. '*Abunu*' and '*Abusa*') accounted for the majority of land tenure arrangements across the regions. Freehold land tenure was relatively low (17.75% in the pooled data), with Ahafo having the highest proportion (26.20%). *'Abunu'*, which represents 50% sharecropping between the farmer and the landowner, was the most prevalent (39.05% in the pooled data). '*Abusa'*, which represents 33.3% sharecropping between the farmer and the landowner, was more common in Bono East (27.62%) compared to the pooled average of 14.35%. This contradicts Kongor (2017), which found that most cocoa farmers (63.9%) cultivated on owned land, while 25.5% and 5.6% operated

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Table 5.2: Summary of plot characteristics of cocoa farmers

Variable	Pooled (N=927)	Ahafo (N=187)	Ashanti (N=165)	Bono (N=83)	Bono East (N=105)	Western North (N=220)	Eastern (N=167)
Plot size (Hectares)							
Less than 1	28.16	28.88	35.15	27.71	46.67	17.27	23.35
1-5	71.20	70.05	64.24	69.88	53.33	82.27	76.65
More than 5	0.65	1.07	0.61	2.41	0	0.45	0
Plot ownership							
Freehold	17.75	26.20	10.30	15.66	12.38	15.67	22.75
Family	28.68	31.55	28.48	27.71	18.09	24.88	37.72
Squatting	0.11	0	0	0	0.95	0	0
Sharecropping							
Abunu (50%)	39.05	39.04	46.67	42.17	40.95	41.48	26.95
Abusa (33.3%)	14.35	2.70	14.55	14.46	27.62	18.89	12.58
Abunan (25%)	0.11	0.54	0	0	0	0	0
Age of cocoa trees (years)							
Less than 5	1.08	0.53	1.21	6.02	0.95	0	2.40
5-7	2.49	0.53	2.42	0	0	5.45	3.59
8-15	22.29	31.55	20.00	16.87	13.33	17.73	28.14
16-25	45.78	44.39	50.30	53.01	45.71	44.09	40.72
26-35	16.02	8.56	11.52	10.84	28.57	22.27	14.97
More than 35	12.34	14.44	14.55	13.25	11.43	10.45	10.18
Topography of plot							
Flat	63.21	61.50	58.79	56.63	65.71	63.18	71.26
Part sloped part flat	26.97	31.55	32.12	28.92	17.14	26.36	22.75
On a slope	4.96	3.74	6.06	0	6.67	6.82	4.19
Part hill part sloped	3.45	1.60	0.61	13.25	7.62	3.18	1.20
On a hill	1.40	1.60	2.42	1.20	2.86	0.45	0.60
Quality of the soil fertility							
Very poor	10.36	10.16	10.91	14.46	11.43	12.73	4.19
Poor	71.41	68.45	65.45	60.24	53.33	78.64	88.02
Fair	16.61	18.72	23.64	25.30	34.29	7.73	3.59
Good	1.62	2.67	0	0	0.95	0.91	4.19
Distance from home to farm (minutes)							
Less than 30	32.48	37.97	29.70	28.92	17.14	30.91	33.53
30-60	58.19	56.15	56.97	60.24	73.33	60.00	61.08
More than 60	9.34	5.88	13.33	10.84	9.52	9.09	5.39

Source: Field data (2024)

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under the '*Abunu'* and '*Abusa'* sharecropping systems, respectively, with only 5.0% farming on family land. It also contrasts with Asamoah and Owusu-Ansah (2017), who reported that 62.7% of cocoa farms were owner-managed, while 22.7% and 14.5% operated under '*Abunu'* and '*Abusa'* arrangements, respectively. The high proportion of sharecroppers to freeholders reinforces the prevalence of migrant farmers in the cocoa sector of Ghana. Customary land tenure systems in Ghana, such as the '*Abunu*', and '*Abusa*' sharecropping arrangements, have been identified as factors that disincentivize migrant farmers from making long-term investments in cocoa farming (Acheampong et al., 2023; Asaaga et al., 2020). This can also have implications on long-term investment in SCIPs due to the fear that the land may revert to the owner after some time (Asamoah and Owusu-Ansah, 2017).

The results further indicate that most of the plots (45.78% pooled) had matured cocoa trees (16–25 years). This trend was consistent across regions, with Bono having the highest proportion (53.01%). About 28.36% of the trees were older than 25 years, with Bono East showing the highest proportion (40%), followed by Western North (32.72). Only 24.78% of cocoa plots in the study sample were within the optimal productive years of 5–15 years. This is consistent with Kongor (2017), which reported that the majority of cocoa farms (43.2%) were between 11 and 20 years old, while 8.5 % had exceeded 30 years. This result indicates that cocoa plots in Ghana are characterised by ageing trees. Several studies, like Abdulai et al. (2020), Kongor et al. (2017), Aneani et al. (2017) and Ofori-Bah and Asafu-Adjaye (2011), and Gotsch and Burger (2001), have noted a decline in cocoa tree productivity as the trees age. While age 15 is recognised as the peak productive stage for cocoa trees (Atkins and Eastin, 2012; Ofori-Bah and Asafu-Adjaye, 2011; Gotsch and Burger, 2001), yield has been observed to decline between 15 and 20 years, with a sharp reduction after 30 years, rendering plots nearly unproductive by year 40 (Aneani et al.,

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2017; Assiri et al., 2003; Ahenkorahh et al., 1987; Laryea, 1969). Laryea (1969) reported a 20% decline in yield for plots exceeding 30 years of age. The ageing tree population emphasises the need for replanting or renovation efforts.

The results also show that the majority (63.21%) of cocoa plots had flat topography, with Eastern reporting the highest proportion (71.26%) and Bono, the lowest (56.63%). This is consistent with Kongor (2017), which found that approximately 64% of cocoa cultivation in Ghana occurs on flat lands, while 23.8% and 7.7% take place on sloped and hilly terrains, respectively, with around 2% of farms located on mixed flat-sloped or sloped-hilly landscapes. Flat terrain is advantageous for farm management but may require careful soil management to prevent degradation. The results further indicate that the majority of farmers (90.67% pooled) have plots within walking distance of 60 minutes of their homes, with Bono East showing the highest proportion (90.47%). Only 9.34% of farms were more than 60 minutes away, with Ashanti having the highest proportion (13.33%). Proximity to farms reduces travel time, which may positively influence farm management and productivity.

5.2.3 Sustainable cocoa intensification practices adopted by farmers in Ghana

Table 5.3 (a&b) presents the summary description of various SCIPs across different regions in the study sample, with values expressed as percentages. The majority of farmers (74.22%) adopted improved cocoa varieties. In recent years, COCOBOD has distributed hybrid seedlings from improved cocoa varieties developed by CRIG. These varieties deliver higher yields in less time and offer enhanced disease resistance under appropriate agronomic practices (Obeng-Bio et al., 2022; Dzandu et al., 2021; Ofori et al., 2015; Asare et al., 2010; Dormon et al., 2004). Studies by Asante et al. (2022), Abdulai et al. (2020), and Asare et al. (2010) further confirm that increasing the proportion of hybrid

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Table 5.3a: Summary statistics of sustainable cocoa intensification practices

Practice	Pooled (N=927)	Ahafo (N=187)	Ashanti (N=165)	Bono (N=83)	Bono East (N=105)	Western North (N=220)	Eastern (N=167)
Planting improved cocoa varieties							
Yes	74.22	78.07	64.24	72.29	59.05	80.91	81.44
No	25.78	21.93	35.76	27.71	40.95	19.09	18.56
Hand weeding (Number of times per season)							
No weeding	12.94	5.35	9.70	9.64	29.52	15.00	13.17
Once	21.90	17.65	29.70	26.51	17.14	10.91	34.13
Twice	22.01	19.25	22.42	16.87	23.81	26.82	19.76
Three times	36.89	44.92	36.36	44.58	23.81	40.91	27.54
Four times	6.04	12.83	1.82	2.41	4.76	5.91	5.39
Five times	0.22	0	0	0	0.95	0.45	0
Removal of chupons, mosses and mistletoes (Number of times per season)							
None	23.30	18.18	30.30	18.07	35.24	18.18	23.95
Once	57.39	64.71	53.33	65.06	45.71	62.27	50.30
Twice	12.41	9.09	11.52	10.84	17.14	10.91	16.77
Three times	3.78	3.74	1.82	4.82	0.95	4.09	6.59
At least four	3.13	4.28	3.03	1.20	0.95	4.55	2.40
Pruning (Number of times per season)							
None	55.12	63.10	43.64	46.99	44.76	63.18	57.49
Once	40.13	31.02	52.73	46.99	53.33	35.00	32.93
Twice	4.10	4.81	3.03	4.82	1.90	0.91	9.58
Three times	0.65	1.07	0.61	1.20	0	0.91	0
Shade trees per hectare (Number)							
None	40.88	30.48	55.15	48.19	54.29	29.34	38.64
1-15	14.89	14.97	12.73	15.66	16.19	19.16	12.27
15-20	39.16	49.20	26.06	30.12	23.81	47.90	44.55
More than 20	5.07	5.35	6.06	6.02	5.71	3.59	4.55
Inorganic fertiliser application							
Yes	30.20	34.76	21.82	33.73	22.86	26.36	41.32
No	69.80	65.24	78.18	66.27	77.14	73.64	58.68
Organic fertiliser application							
Yes	22.33	26.74	18.18	19.28	13.33	19.55	32.34
No	77.67	73.26	81.82	80.72	86.67	80.45	67.66
Inorganic insecticide application (Number of applications per season)							
None	54.64	44.39	63.41	55.42	65.71	59.55	43.71
Once	2.16	1.60	0	0	1.90	1.82	6.59
Twice	2.70	2.67	1.22	0	0.95	4.09	4.79
Three	4.10	7.49	1.83	3.61	3.81	4.55	2.40
Four times	35.64	41.71	32.93	40.96	25.71	30.00	42.51
Five times	0.76	2.14	0.61	0	1.90	0	0

Source: Field data (2024)

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cocoa trees per hectare can substantially boost yields on smallholder farms. The adoption rate was highest in the Western North (80.91%) and Eastern (81.44%) regions, reflecting regional differences in the availability or promotion of improved varieties. The lowest adoption was in Bono East (59.05%) and Bono (59.05%). This aligns with Kongor (2017), which found that while the CRIG-developed hybrid was the dominant cultivar (57.7%), the Amazonia cultivar prevailed in the Western (48.2%) and Ashanti (44.3%) regions.

The results in Table 5.3a further shows that the majority of farmers practised hand weeding, with a substantial portion (36.89%) performing it three times per season according to the recommendation of COCOBOD. Also, the practice of removing base chupons, mosses, and mistletoes was highly prevalent, with 76.70% of farmers doing so at least once per season. However, over half of the farmers (55.12%) did not practice pruning. The Ahafo and Western North regions had the highest proportions of farmers practising pruning once (63.10% and 63.18%, respectively). In contrast, Bono East recorded the highest rate of no pruning (53.33%). This could be due to lower access to technical support from the mass pruning programme of COCOBOD.

Overall, 39.16% of cocoa plots in the study sample had the recommended 15-20 shade trees per hectare (Table 5.3a), showing an inclination toward promoting tree cover for cocoa sustainability. Western North and Eastern regions showed a strong preference for maintaining 15-20 shade trees per hectare of cocoa plot (47.90% and 44.55%, respectively). In contrast, Ashanti (55.15%) and Bono (54.29%) had a higher number of plots with no shade trees. This implies that farmers in these areas prioritise cocoa production under the open sun system. The results presented in Table 5.3a further indicate that about 30.20% of farmers used inorganic fertilisers, with Eastern (41.32%) and Ahafo (34.76%) showing the highest rates of adoption. However, the Bono East (22.86%) and Bono (22.86%) regions recorded the least rates of inorganic fertiliser applications, indicating potential regional

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gaps in the access to chemical inputs. This contradicts Kongor (2017), which reported that 61% of cocoa farmers applied inorganic fertiliser once per season as recommended by COCOBOD, while 38.6% did not apply any fertiliser. The results presented in Table 5.3a further reveal that a smaller proportion of plots in the study sample (22.33%) applied organic fertilisers, with Eastern (32.34%) and Ahafo (26.74%) showing the highest percentage of adoption. Furthermore, a large percentage of farmers did not apply insecticides, with 54.64% of the plots reporting no application. Western North (65.71%) and Eastern (59.55%) showed the highest rates of insecticide application, while Ahafo (44.39%) was the region with the least application rate. However, 35.64% of cocoa farmers applied insecticides four times per season as recommended by COCOBOD. This aligns with Kongor (2017), who found that only 35% of cocoa farmers in Ghana managed to control capsids four times per season. According to the results presented in Table 5.3b, similar trends were observed with fungicide application, with 51.46% of farmers applying no fungicide, possibly due to cost or availability issues. 36.68% of cocoa farmers applied fungicides 6–9 times per season as recommended. This is in contrast to Kongor (2017), which found that only 14% of cocoa farmers in Ghana controlled black pod disease six times per season.

Only 20.17% of farmers applied organic pesticides (Table 5.3b), whilst only 16.50% of farmers practised hand pollination, indicating a relatively low adoption of these labour-intensive practices. Also, only 28.59% of farmers renovated cocoa trees that needed renovation on their plots. The practice of mulching was also less common (20.60% overall). Ahafo (28.34%) and Eastern (32.93%) had the highest rates of mulching adoption, while Bono East and Bono had the lowest rates. Likewise, the practice of deliberately harvesting water for work on cocoa plots was low, with 22.33% of farmers using it. Also, only 25.35% of farmers used personal protective equipment (PPEs), with Eastern (34.73%) and Ahafo

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(27.81%) reporting the highest adoption rates. On the other hand, a substantial majority (88.24%) of plots recorded the practice of intercropping cocoa trees with food crops.

Table 5.3b: Summary statistics of sustainable cocoa intensification practices

Practice	Pooled (N=927)	Ahafo (N=187)	Ashanti (N=165)	Bono (N=83)	Bono East (N=105)	Western North (N=220)	Eastern (N=167)
Inorganic fungicide application (Number of applications per season)							
None	51.46	39.04	57.58	54.22	62.86	58.18	41.92
1-3 times	3.13	1.60	0.61	3.61	4.76	4.55	4.19
4-5 times	8.74	8.02	5.45	6.02	7.62	9.09	14.37
6-9 times	36.68	51.34	36.36	36.14	24.76	28.18	39.52
Organic pesticides							
Yes	20.17	25.67	16.97	19.28	9.52	17.27	28.14
No	79.83	74.33	83.03	80.72	90.48	82.73	71.86
Hand pollination							
Yes	16.50	15.51	15.76	19.28	7.62	14.55	25.15
No	83.50	84.49	84.24	80.72	92.38	85.45	74.85
Renovation of cocoa trees							
Yes	28.59	31.55	28.48	22.89	20.00	25.91	37.13
No	71.41	68.45	71.52	77.11	80.00	74.09	62.87
Mulching							
Yes	20.60	28.34	16.36	15.66	7.62	15.91	32.93
No	79.40	71.66	83.64	84.34	92.38	84.09	67.07
Water harvesting							
Yes	22.33	27.27	16.36	19.28	12.38	19.55	34.13
No	77.67	72.73	83.64	80.72	87.62	80.45	65.87
Intercrop cocoa trees with food crops							
Yes	88.24	94.12	94.55	89.16	78.10	83.18	88.02
No	11.76	5.88	5.45	10.84	21.90	16.82	11.98
Use of personal protective equipment (PPEs)							
Yes	25.35	27.81	21.21	24.10	17.14	23.64	34.73
No	74.65	72.19	78.79	75.90	82.86	76.36	65.27

Source: Field data (2024)

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5.3 Analysis of the Level of Adoption of Sustainable Cocoa Intensification Practices by Cocoa Farmers in Ghana

The composite indices for intensification and sustainability offer a comprehensive view of the level of adoption of SCIPs at the plot level. These indices consolidated multiple indicators into singular measures, providing an overall assessment of the degree of intensification and sustainability across cocoa plots. Both indices were normalised within the bounds of 0 and 1, facilitating straightforward interpretation and comparison.

5.3.1 Composite index for cocoa intensification

Table 5.4 presents the summary statistics of the intensification indicators estimated for the plots in the study sample. The intensification indicators captured the intensity of adoption of various SCIPs aimed at enhancing cocoa productivity.

Table 5.4: Summary statistics of the cocoa intensification indicators

Indicator	Mean	Std. Dev.	Min	Max
Use of improved varieties	0.088	0.045	0	0.111
Planting density	0.014	0.023	0	0.111
Intensity of hand pollination	0.008	0.019	0	0.111
Intensity of fertiliser application	0.028	0.029	0	0.111
Intensity of insecticide application	0.0024	0.023	0	0.111
Intensity of fungicide application	0.040	0.022	0	0.111
Intensity of hired labour use	0.017	0.026	0	0.111
Intensity of family labour use	0.031	0.028	0	0.111
Intensity of communal labour use	0.025	0.033	0	0.111
Composite Intensification Index	0.284	0.167	0.001	0.870

Source: Field data (2024)

From Table 5.4, the use of improved varieties emerges as the major contributor to the cocoa intensification index, recording the highest mean value of 0.088, which reflects its relatively widespread adoption and central role in enhancing cocoa productivity within the study area. Conversely, the intensity of insecticide application, with a negligible mean of

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0.0024, contributes the least to the intensification index, indicating its minimal uptake or application intensity among cocoa farmers. This is consistent with the results of the level of adoption of SCIPs presented in section 5.1.3.

The intensification composite index had a mean score of 0.284, with a standard deviation of 0.167. This generally indicates low level of intensification in cocoa farming, with significant variation among plots. This implies that, on average, farmers demonstrate low levels of intensification in their cocoa farming practices. The minimum value of 0.001 indicates plots with almost no intensification practices, while the maximum value of 0.87 reflects plots adopting a wide range of SCIPs that enhance intensification. The distribution of the intensification index presented in Figure 5.1 shows that the distribution is moderately right-skewed, with most observations concentrated between 0.1 and 0.4.

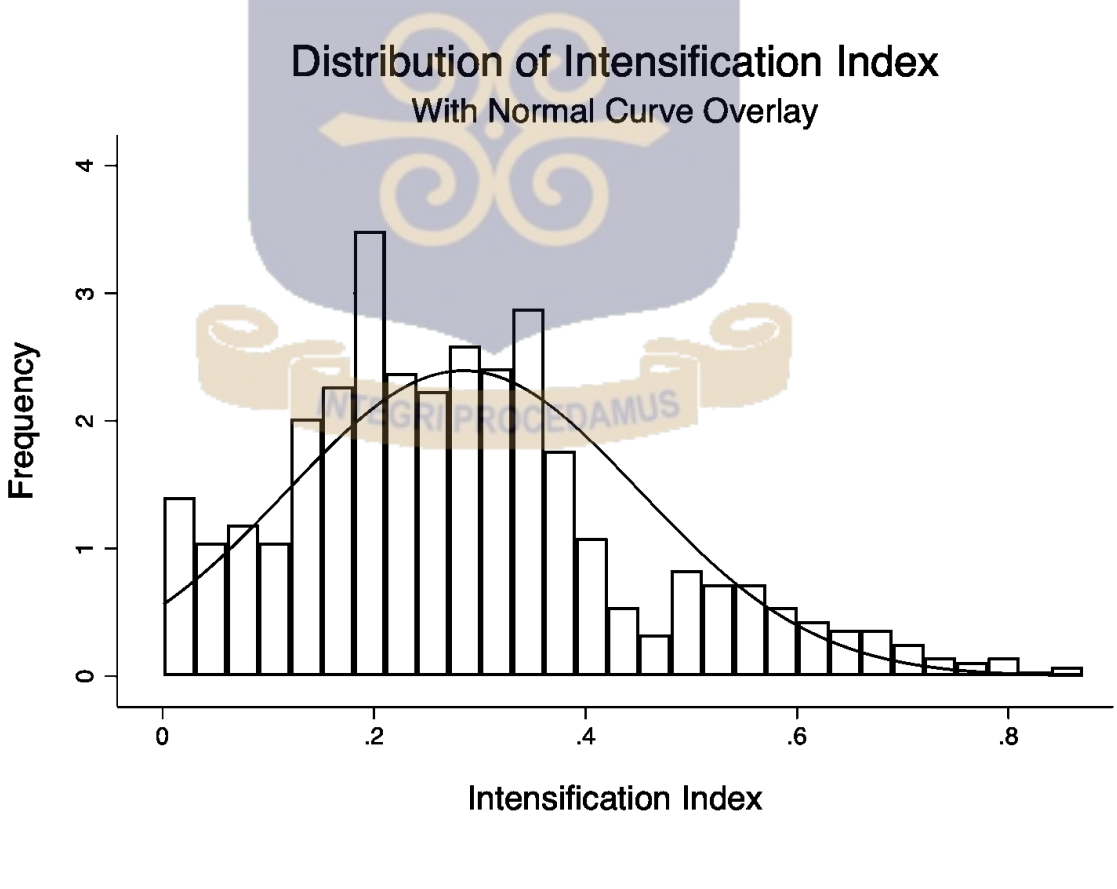


Figure 5.1: Distribution of the cocoa intensification index

Source: Constructed from field data (2024)

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The skewness implies that relatively few plots exhibit high levels of intensification. This distribution further implies that while intensification practices are adopted to some extent, highly intensive practices are relatively rare amongst the cocoa plots across the sampled regions.

5.3.2 Composite index for cocoa sustainability

The sustainability indicators that contributed to the composite index were grouped under the three main dimensions of agricultural sustainability as presented in Tables 5.5-5.7.

The economic dimension of sustainability provides insights into various aspects of cocoa farming that contribute to the economic viability of production systems. From the economic dimension, crop diversification stands out as the major contributor to the sustainability index with a mean value of 0.04, underscoring its significance in enhancing farmers' income security and production resilience. In contrast, labour productivity, with the lowest mean of 0.005, contributes the least, reflecting limited efficiency gains in labour use within cocoa production systems.

Table 5.5: Summary of indicators under the economic dimension of sustainability

Variable	Mean	Std. Dev.	Min	Max
Age of cocoa trees	0.026	0.005	0	0.04
Bean quality	0.016	0.016	0	0.04
Plot number per farm	0.009	0.005	0	0.04
Crop diversification	0.040	0.006	0	0.04
Labour productivity	0.005	0.006	0	0.04
Capital productivity	0.006	0.008	0	0.04
Intensity of rehabilitation	0.009	0.012	0	0.04

Source: Field data (2024)

The indicators under the social dimension of sustainability emphasise the human and community aspects of cocoa farming, including farmer demographics, social support

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systems, and labour conditions. Within the social dimension, isolation risk records the highest mean of 0.04, highlighting the role of living within a larger family structure in shaping farmers' social wellbeing and resilience. The use of personal protective equipment (PPEs), registering the lowest mean of 0.01, contributes the least to social sustainability, indicating minimal adherence to safe farming practices among cocoa farmers.

Table 5.6: Summary of indicators under the social dimension of sustainability

Variable	Mean	Std. Dev.	Min	Max
Age of farmer	0.026	0.005	0	0.04
Isolation risk	0.040	0.005	0	0.04
Farm continuity	0.022	0.014	0	0.04
Generational Renewal	0.024	0.013	0	0.04
Use of personal protective equipment (PPEs)	0.010	0.009	0	0.04
Workload exceeded	0.027	0.011	0	0.04

Source: Field data (2024)

The indicators under the environmental dimension of sustainability provide a comprehensive overview of practices aimed at maintaining ecological balance while supporting cocoa production. Under the environmental dimension, the intensity of inorganic weedicide application contributes most significantly to the sustainability index with a mean of 0.03. This implies that fewer farmers are applying inorganic weedicides, in line with the ban on their use in Ghana (Bandanaa et al., 2021). Conversely, the proper use of inorganic insecticides, with a mean of 0.004, contributes the least, suggesting limited compliance with recommended insecticide application standards. These results are consistent with the level of adoption of SCIPs presented in section 5.1.3.

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Table 5.7: Summary of indicators under the environmental dimension of sustainability

Variable	Mean	Std. Dev.	Min	Max
Excessive planting density	0.029	0.003	0	0.04
Use of organic fertilisers	0.007	0.011	0	0.04
Proper use of inorganic fertiliser	0.01	0.009	0	0.04
Proper use of inorganic insecticide	0.004	0.008	0	0.04
Proper use of inorganic fungicide	0.022	0.013	0	0.04
Intensity of inorganic weedicide application	0.03	0.006	0	0.04
Use of organic pesticides	0.009	0.014	0	0.04
Farm sanitation	0.021	0.009	0	0.04
Shade trees	0.014	0.014	0	0.04
Mulching	0.006	0.009	0	0.04
Water harvesting	0.014	0.015	0	0.04
Handling of agrochemicals	0.013	0.015	0	0.04

Source: Field data (2024)

The sustainability composite index, as presented in Table 5.8, indicates a mean of 0.451 and a standard deviation of 0.129. This suggests generally low levels of sustainability. However, comparatively, the mean index score of 0.451 suggests a relatively stronger performance in sustainability measures compared to the intensification measures (see Table 5.4).

Table 5.8: Descriptive statistics of composite index for cocoa sustainability

Sustainability Composite Index	Mean	Std. Dev.	Min	Max
	0.451	0.129	0.187	0.734

Source: Field data (2024)

The minimum value of 0.187 shows that even the least sustainable plots meet some basic criteria, while the maximum value of 0.734 points to plots adopting a wide range of SCIPs that enhance sustainability. The distribution of the sustainability index presented in Figure 5.2 shows a range that extends from approximately 0.2 to 0.8, with a noticeable concentration of observations between 0.3 and 0.6. The distribution appears roughly

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symmetric, centred around 0.4 to 0.5, suggesting that most observations cluster around these values. Also, the bimodal distribution suggests distinct variations in sustainability levels across different groups of farmers.

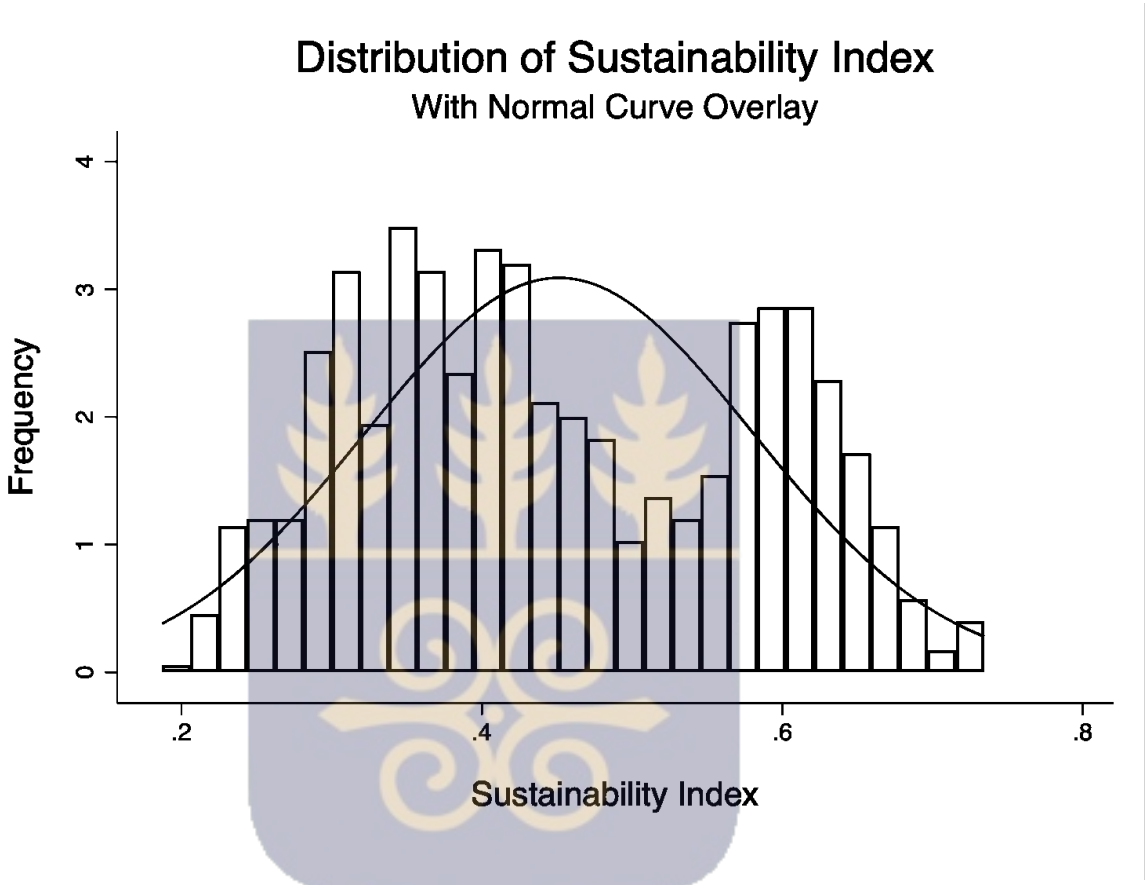


Figure 5.2: Distribution of the cocoa sustainability index

Source: Constructed from field data (2024)

5.3.3 Farm typologies based on intensification and sustainability indices

The cocoa plots within the data sample were categorised into four farm typologies using their intensification and sustainability scores, with an index threshold/ 'cut-off' of 0.5 as recommended by Uthes and Herrera (2019), Rigby et al. (2001), and Taylor et al. (1993). Thus, plots scoring below 0.5 on both indices were classified as conventional plots that are 'neither sustainable nor intensified' (NSNI), while those exceeding 0.5 on both indices were deemed both sustainable and intensified or simply 'sustainably intensified' (SI). Plots

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scoring above 0.5 on intensification but below 0.5 on sustainability were 'intensified but not sustainable' (INS), whereas those scoring above 0.5 on sustainability but below 0.5 on intensification were 'sustainable but not intensified' (SNI). This classification approach is in line with Helfenstein et al. (2020)'s conceptual framework that identified four distinct typologies of sustainable agricultural intensification pathways: (1) those that enhance only agricultural production (conventional intensification); (2) those that improve only sustainability (sustainable dis-intensification); (3) those that result in the decline of both; and (4) those that advance both simultaneously (sustainably intensified pathways). Table 5.9 presents a summary of farm typology categorised by levels of intensification and sustainability, with the values expressed as percentages.

Table 5.9: Farm typology based on the levels of intensification and sustainability

Classification	Percent
Neither Sustainable nor Intensified (NSNI)	58.25
Sustainable, Not Intensified (SNI)	29.45
Intensified, Not Sustainable (INS)	5.39
Sustainably Intensified (SI)	6.90

Source: Field data (2024)

The majority of cocoa plots within the study sample (58.25%) fell under the "Neither Sustainable nor Intensified" (NSNI) category. These are cocoa plots that score below 0.5 on both the intensification index and the sustainability index. They represent low-input, and low-management systems where neither modern intensification practices nor sustainable farming measures are actively pursued. These plots rely on traditional methods, minimal external inputs, and are characterised by ageing trees, low labour productivity, and exposure to environmental degradation. They are vulnerable to both productivity declines and environmental risks, contributing little to long-term farm resilience or ecosystem stability.

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Also, the "Sustainable, Not Intensified" (SNI) group accounted for 29.45% of cocoa plots within the study sample. Plots falling under this typology recorded a sustainability index above 0.5 but scored below 0.5 on the intensification index. These managers of these plots adopt various sustainability-enhancing practices, such as the maintenance of shade trees, farm sanitation, water harvesting, proper agrochemical handling, organic inputs, and efforts towards farm continuity and generational renewal. However, they make limited use of intensification measures like fertiliser application, hand pollination, and intensive chemical control of pests and diseases. Consequently, while these farms contribute positively to ecological health and social welfare, their productivity may remain suboptimal compared to intensified systems.

Meanwhile, 5.39% of cocoa plots were classified as "Intensified, Not Sustainable" (INS). These plots achieved a composite intensification index above 0.5, indicating a relatively high application of productivity-enhancing practices such as the use of improved cocoa varieties, high planting densities, increased fertiliser and pesticide use, and labour intensification. However, their sustainability index remains below 0.5, reflecting inadequate incorporation of economic, social, and environmental safeguards. These plots prioritise short-term yield gains over long-term resilience, risking soil nutrient depletion, chemical overuse, biodiversity loss, and social issues, including labour exploitation and farmer health risks due to poor handling of agrochemicals.

Finally, only 6.90% of the plots fell under the "Sustainably Intensified" (SI) classification. The sustainably intensified plots achieved scores above 0.5 on both the intensification and sustainability indices. These represent the ideal farm typology, effectively integrating productivity-enhancing innovations with practices that ensure long-term ecological, social, and economic viability. Such plots combine improved varieties, appropriate fertiliser and pesticide use, labour productivity measures, and other intensification practices with

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environmental management techniques, including shade trees, responsible agrochemical use, organic inputs, tree renovation, and attention to farmer health, generational renewal, and workload management. They are positioned to deliver high yields while safeguarding ecosystem services and promoting farmer well-being. Thus, only 6.90% of the plots achieved sustainable intensification.

The results indicate that the percentage of cocoa plots that attained sustainable intensification is low (6.90%), implying low levels of adoption of SCIPs. This implies that the majority of cocoa farmers have yet to fully integrate both sustainability- and intensification-enhancing measures into their farming systems. Thus, the potential for improving both yield and environmental sustainability in cocoa farming remains largely untapped.

5.4 Determinants of SCIPs Adoption

5.4.1 Multicollinearity test

The variance inflation factor (VIF) values and their reciprocals (1/VIF) for a range of explanatory variables included in the econometric estimations presented in this study (presented in Table 3 of Appendix 3) indicate that most of the variables fall within acceptable thresholds for multicollinearity. Amongst the variables, residential status and education exhibit the highest VIF values at 4.92 and 4.90, respectively, indicating a relatively stronger multicollinearity. The mean VIF is 2.16, suggesting that multicollinearity is generally low to moderate.

Clustered variance-covariance estimator

Since the analysis was done at the plot-level, robust standard errors were calculated using the clustered variance-covariance estimator, which accounts for potential correlation in the

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error terms amongst observations within the same household (MacKinnon, 2019; Cameron & Miller, 2015). Thus, the estimation employed robust standard errors clustered at the household level (using hh_id) to account for potential within-household correlation (MacKinnon, 2019; Cameron & Miller, 2015).

5.4.2 Factors that influence the adoption of individual and bundled SCIPs among cocoa farmers in Ghana

The factors that influence individual and bundled adoption of SCIPs amongst cocoa farmers in Ghana were analysed using a Multivariate Probit regression (MVP) model. The ten (10) most adopted SCIPs, which were identified through frequency analysis were used as the dependent variables. These included shade trees, improved varieties, farm sanitation, organic pesticides, inorganic fertiliser, organic fertiliser, hand pollination, inorganic insecticide, inorganic fungicide, renovation of cocoa trees.

5.4.2.1 Analysis of the interrelationships among related SCIPs

The symmetric variance–covariance matrix derived from the MVP regression is presented in Table 5.10. It provides valuable insights into the interrelationships amongst farmers' adoption decisions about various SCIPs. A Likelihood ratio test of the hypothesis that the adoption decisions for the 10 SCIPs are independent of one another was conducted. The chi-square value of 437.335 ($p < 0.000$) indicates that the correlations amongst the error terms (ρ) in the MVP model are significantly different from zero, implying a strong rejection of the null hypothesis of independence. This provides robust evidence that the adoption decisions were indeed interdependent. This rejection of the assumption of independence of multiple SCIPs adoption implies that the 10 SCIPs are adopted simultaneously as a bundle. Thus, unobservable factors influencing the adoption of one

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Table 5.10: Correlation coefficients from symmetric variance–covariance matrix

	ρ_{FS}	ρ_{ST}	ρ_{IV}	ρ_{OP}	ρ_{IF}	ρ_{OF}	ρ_{HP}	ρ_{INS}	ρ_{FUNG}	ρ_{REN}
ρ_{FS}	1									
ρ_{ST}	0.14**	1								
	(0.069)									
ρ_{IV}	0.072	-0.061	1							
	(0.085)	(-0.08)								
ρ_{OP}	0.22***	0.098	-0.02	1						
	(0.073)	(0.072)	(0.087)							
ρ_{IF}	-0.032	0.16**	-0.039	0.24***	1					
	(0.074)	(0.067)	(0.085)	(0.07)						
ρ_{OF}	0.217***	0.063	-0.152*	0.785***	0.33***	1				
	(0.075)	(0.072)	(0.082)	(0.04)	(0.08)					
ρ_{HP}	0.368***	0.054	0.116	0.21***	-0.012	0.17**	1			
	(0.066)	(0.072)	(.087)	(0.07)	(0.08)	(0.073)				
ρ_{INS}	0.118*	-0.023	-0.067	0.25***	0.13**	0.317***	0.092	1		
	(0.066)	(0.065)	(0.071)	(0.07)	(0.07)	(0.061)	(.068)			
ρ_{FUNG}	0.24***	0.13**	0.055	0.11*	0.11*	0.19***	0.134**	0.588***	1	
	(0.062)	(0.06)	(0.071)	(0.07)	(0.07)	(0.065)	(0.07)	(0.045)		
ρ_{REN}	0.18***	0.12**	0.129*	0.22***	0.13**	0.195***	0.407***	0.001	-0.026	1
	(0.061)	(0.059)	(0.067)	(0.06)	(0.07)	(0.062)	(0.058)	(0.061)	(0.06)	

Likelihood ratio test: $\rho BA = \rho CA = \rho DA = \rho EA = \rho FA = \rho GA = \rho HA = \rho IA = \rho JA = \rho CB = \rho DB = \rho EB = \rho FB = \rho GB = \rho HB = \rho IB = \rho JB = \rho DC = \rho EC = \rho FC = \rho GC = \rho HC = \rho IC = \rho JC = \rho ED = \rho FD = \rho GD = \rho HD = \rho ID = \rho JD = \rho FE = \rho GE = \rho HE = \rho IE = \rho JE = \rho GE = \rho HE = \rho IE = \rho JE = \rho HF = \rho IF = \rho JF = \rho IG = \rho JH = \rho JI = 0$

$(\chi^2)\ (45) = 437.335$; Prob > $(\chi^2) = 0.0000$

Source: Field data (2024) ***: Significant at 1%; **: Significant at 5%; *: Significant at 10%. (Robust clustered standard errors in bracket)

A=FS= Farm sanitation practices; B=ST=Shade trees; C=IV=Improved varieties; D=OP=Organic pesticides; E=IF=Inorganic fertiliser; F=OF=Organic fertiliser; G=HP=Hand pollination; H=INS=Inorganic insecticide; I=FUNG=Inorganic fungicide; J=REN= Renovation of trees

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practice also affect the likelihood of adopting others, underscoring the need for an integrated approach to promoting SCIPs. The correlation coefficients (ρ) serve as indicators of the degree to which adoption decisions for different practices are interdependent. These correlations reveal whether the practices are complementary or substitutive. Complementary practices are those that are positively correlated, suggesting that the adoption of one practice increases the likelihood of adopting the other. Conversely, practices that are negatively correlated are substitutes, where adopting one practice reduces the likelihood of adopting the other.

The results from the correlation matrix presented in Table 5.10 show that the adoption of SCIPs is not mutually exclusive in 29 of the 45 cases (see equation 4.9). The identification of complementary practices suggests potential synergies that can be leveraged in policy design, such as promoting a group of practices simultaneously to enhance adoption rates. For example, farm sanitation (FS) and hand pollination (HP) show a strong positive correlation (ρ=0.368, significant at 1%), suggesting that farmers who adopt farm sanitation practices such as consistent hand weeding, removal of base chupons, and pruning are more likely to adopt hand pollination as well. This is consistent with Wongnaa et al. (2021), which explained that farms are expected to be pruned two months before pollination to ensure proper flower development, and fertiliser application is necessary to support pod setting. The correlation between farm sanitation and organic pesticides ($\rho = 0.217$, $p = 0.003$) also reveals a positive and statistically significant relationship. This suggests that the same unobservable factors, such as farmer preferences or knowledge, may drive the adoption of both farm sanitation and organic pesticides. The relationship between inorganic fungicides and inorganic insecticides ($\rho = 0.588$, $p < 0.001$) further suggests that farmers who are motivated to control pests may simultaneously adopt both types of agrochemicals. Also, organic fertiliser (OF) application and the application of organic pesticides (OP)

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reported the highest correlation (ρ=0.785, significant at 1%), indicating a very strong complementary relationship.

On the other hand, organic fertiliser (OF) application and the planting of improved cocoa varieties (IV) exhibit a negative correlation (ρ = -0.152, significant at 10%), suggesting a substitutive relationship. Substitute practices highlight trade-offs, and understanding farmers' constraints and preferences can help tailor interventions to reduce the competing demands they face. For instance, farmers adopting improved varieties often rely on conventional fertilisation methods, diminishing the dependence on organic inputs. This pattern may stem from extension advice on the planting of improved cocoa varieties, which emphasise synthetic fertilisers, thereby reducing the perceived benefits of organic alternatives. Extension services promoting modern agronomic techniques typically advocate for improved varieties alongside synthetic fertilisers, reinforcing this substitution effect.

5.4.2.2 Analysis of the determinants of simultaneous adoption of SCIPs

The results from the MVP regression analysis presented in Table 5.11 (a&b) show a Wald (χ^2) test (2096.73, p-value = 0.0000) which indicates that the independent variables, as a group, significantly influence the simultaneous adoption of the 10 SCIPs. Thus, the null hypothesis that all regression coefficients are jointly not different from zero was strongly rejected. The results from Table 5.11(a) reveal that plot ownership was a critical determinant of SCIPs adoption behaviour, significantly encouraging the use of improved varieties, shade trees, organic pesticides, inorganic fertilisers, and organic fertilisers. Specifically, owning a cocoa plot enhances the likelihood of adopting improved varieties by 53.5%, shade trees by 25.1%, organic pesticides by 63.9%, inorganic fertilisers by 50.6%, and organic fertilisers by 56.5%. However, plot ownership decreased the likelihood

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Table 5.11a: Multivariate probit regression results for determinants of joint adoption of multiple SCIPs (Plot and institutional factors)

Variables	F.sanitat. M. effect	Shade tree M. effect	Impr. Var. M. effect	Org. Pest. M. effect	Inorg. Fert M. effect	Org. Fert M. effect	Hand Pollin. M. effect	Insecticide M. effect	Fungicide M. effect	Renovatio M. effect
Plot	0.020	0.251*	0.535***	0.639***	0.506***	0.565***	0.052	-0.224*	-0.093	0.184
ownership	(0.173)	(0.140)	(0.158)	(0.191)	(0.189)	(0.174)	(0.173)	(0.134)	(0.131)	(0.126)
Farm	-0.013***	-0.011***	-0.024***	-0.006	-0.011**	-0.004	0.003	-0.006	-0.010***	-0.010***
distance	(0.005)	(0.004)	(0.004)	(0.005)	(0.005)	(0.005)	(0.005)	(0.004)	(0.003)	(0.003)
Drought	0.354*	-0.312**	0.268	-0.227	0.054	-0.389*	0.336*	-0.030	0.017	-0.105
risk	(0.181)	(0.150)	(0.171)	(0.208)	(0.200)	(0.201)	(0.184)	(0.153)	(0.150)	(0.140)
Topograph	0.094***	0.142	0.492***	0.326	0.088	-0.271	0.165	0.121	0.242*	0.283**
y	(0.150)	(0.158)	(0.148)	(0.239)	(0.236)	(0.211))	(0.203)	(0.141)	(0.138)	(0.135)
Soil	0.032	0.030	0.619***	0.280	0.636**	0.196	-0.290	0.114	0.146	0.115
fertility	(0.214)	(0.156)	(0.144)	(0.256)	(0.292)	(0.225)	(0.190)	(0.145)	(0.140)	(0.134)
Fungicide	-0.145	-0.193	0.076	0.317**	0.123	0.361**	-0.354**	0.430***	0.156	-0.161
subsidy	(0.157)	(0.145)	(0.210)	(0.155)	(0.155)	(0.153)	(0.170)	(0.159)	(0.141)	(0.144)
Insecticide	0.412**	0.117	-0.018	0.444**	0.666***	0.324*	0.203	0.946***	0.702***	0.159
subsidy	(0.161)	(0.159)	(0.199)	(0.172)	(0.168)	(0.173)	(0.180)	(0.167)	(0.157)	(0.147)
Fertiliser	0.015	0.339**	-0.273	-0.309	0.510***	0.719***	0.503***	-0.268	-0.069	0.045
subsidy	(0.176)	(0.159)	(0.230)	(0.193)	(0.157)	(0.174)	(0.171)	(0.164)	(0.151)	(0.154)
Credit	0.154	-0.083	-0.312	0.271	0.251	0.550***	0.806***	0.343**	0.150	-0.157
	(0.179)	(0.162)	(0.207)	(0.188)	(0.183)	(0.179)	(0.178)	(0.166)	(0.159)	(0.154)
Usefulness of extension										
Useful	1.090***	0.435**	1.264***	0.243	0.566**	0.671***	1.018***	0.520***	0.385**	0.130
	(0.358)	(0.175)	(0.399)	(0.250)	(0.255)	(0.209)	(0.220)	(0.161)	(0.157)	(0.156)
Not Useful	1.510***	0.173	0.051	-0.364	0.404	-0.311	0.422	0.068	0.328*	-0.562***
	(0.318)	(0.222)	(0.188)	(0.362)	(0.319)	(0.344)	(0.301)	(0.200)	(0.194)	(0.206)
Number of	0.255***	0.237***	0.008	0.456***	0.236***	0.324***	0.455***	-0.103	0.008	0.232**
train atten.	(0.089)	(0.083)	(0.115)	(0.094)	(0.088)	(0.101)	(0.091)	(0.092)	(0.085)	(0.083)

Source: Field data (2024) ***: Significant at 1%; **: Significant at 5%; *: Significant at 10%.

(Robust clustered standard errors in bracket)

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Table 5.11b: Multivariate probit regression results for determinants of joint adoption of multiple SCIPs (Household characteristics)

Variables	F.sanitat. M. effect	Shade tree M. effect	Impr. Var. M. effect	Org. Pest. M. effect	Inorg. Fert M. effect	Org. Fert M. effect	Hand Pollin. M. effect	Insecticide M. effect	Fungicide M. effect	Renovtion M. effect
Education	0.022	0.040	-0.003	0.033	-0.024	0.025	0.020	0.023	-0.018	0.029
	(0.036)	(0.030)	(0.036)	(0.036))	(0.034)	(0.035)	(0.036)	(0.029)	(0.028)	(0.028)
Experienc	-0.017*	-0.020**	-0.010	-0.021**	-0.016*	-0.015*	0.011	-0.011	-0.003	-0.004
e	(0.009)	(0.008)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.008)	(0.008)	(0.007)
Household	0.041	0.036	0.073	0.162***	-0.006	0.162***	0.073*	0.033	0.034	0.067**
size	(0.038)	(0.035)	(0.047)	(0.041)	(0.038)	(0.043)	(0.040)	(0.037)	(0.035)	(0.034)
Gender	-0.045	-0.047	0.216	-0.036	-0.382*	0.293	0.168	0.129	0.019	-0.098
	(0.207)	(0.159)	(0.174)	(0.215)	(0.219)	(0.210)	(0.196)	(0.153)	(0.149)	(0.141)
Residentia	-0.050	0.065	0.033	-0.112	0.318	-0.329	-0.829***	0.189	0.667***	-0.004
l status	(0.265)	(0.215)	(0.256)	(0.288)	(0.257)	(0.267)	(0.280)	(0.203)	(0.195)	(0.200)
Religion	-0.305**	-0.280**	-0.380	-0.110	0.261*	-0.593***	-0.469***	-0.155	-0.070	-0.294**
	(0.144)	(0.140)	(0.238)	(0.149)	(0.142)	(0.169)	(0.150)	(0.151)	(0.144)	(0.142)
Land	-0.001	-0.022	0.172***	-0.014	-0.009	-0.043**	-0.030*	-0.006	0.004	0.049***
holding	(0.019)	(0.016)	(0.054)	(0.020)	(0.017)	(0.018)	(0.018)	(0.018)	(0.017)	(0.016)
Farm asset	0.091**	0.087**	-0.143***	0.133***	-0.052	0.144***	0.149***	0.161***	0.002	0.107**
	(0.044)	(0.042)	(0.072)	(0.046)	(0.040)	(0.056)	(0.047)	(0.059)	(0.046)	(0.048)
Livestock	-0.046	-0.046	0.119	-0.094	0.240***	-0.069	-0.126*	-0.026	0.065	-0.102*
holding	(0.063)	(0.060)	(0.099))	(0.066)	(0.064)	(0.072)	(0.066)	(0.067)	(0.063)	(0.062)
Transition	-0.490***	-0.266**	-0.673***	0.048	-0.185	0.315**	-0.153	0.133	-0.034	-0.081
zone	(0.136)	(00.116)	(0.141)	(0.141)	(0.136)	(0.145)	(0.134)	(0.116)	(0.111)	(0.108)
Number of obs	927									
Wald (χ^2) (353)	2096.73									
Log likelihood	-3326.6536									
Prob > (χ^2)	0.0000									

Source: Field data (2024) ***: Significant at 1%; **: Significant at 5%; *: Significant at 10%.

(Robust clustered standard errors in bracket)

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of inorganic insecticide application by 22.4%, suggesting that plot ownership may shift focus toward practices essential for long-term productivity. This pattern reinforces the notion that land tenure security, through plot ownership, encourages various adoption decisions that require long-term investment (Asamoah and Owusu-Ansah, 2017; Ertiro, 2006). When land tenure is uncertain, farmers are less likely to invest in long-term SCIPs, fearing that they may not fully reap the benefits. This is consistent with Nyarindo et al. (2024), Maré et al. (2022), Mutyasira et al. (2018), and Kassie et al. (2013), which emphasised that tenure security is crucial for achieving sustainable agricultural intensification amongst smallholder farmers.

Conversely, farm distance, measured as the walking distance from home to plot, exhibited a predominantly negative effect on the adoption of SCIPs. Specifically, the distance from a farmer's plot to their household reduces the likelihood of implementing cocoa tree renovation by 1% as well as farm sanitation practices such as regular weeding, pruning and removal of base chupons, mosses, and mistletoes 1.3%. Similarly, farm distance reduces the likelihood of planting shade trees by 1.1% and improved cocoa varieties by 2.4% as well as applying inorganic fertiliser by 1.1% and fungicides by 1%. This may be due to the increased time and labour costs associated with the physical access of remote plots. Greater distances typically mean higher transportation costs, more time spent travelling to and from the farm, and increased logistical challenges, which could deter farmers from adopting practices that require frequent monitoring or additional labour. Thus, improving transportation infrastructure could improve the likelihood of SCIPs adoption.

The findings further reveal that flat topography significantly enhanced the likelihood of adopting farm sanitation practices, improved varieties, fungicide, and cocoa tree renovation. For example, flatter terrains increased the probability of adopting farm sanitation practices by 9.4% and improved varieties by 49.2%. Flat lands are generally

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easier to manage and cultivate, reducing the cost and effort of adopting labour-intensive SCIPs such as farm sanitation practices, planting of improved varieties, fungicide application, and cocoa tree renovation. This is consistent with Rahn et al. (2018) and Kassie et al. (2015&2013), which highlighted topography as one of the factors influencing the adoption of SIPs. The results from Table 5.11(a) further reveal that perceiving the soil fertility of one's plot to be poor significantly increased the adoption of improved varieties and inorganic fertilisers. Farmers who perceived the soil fertility of their plots to be poor were more likely to adopt improved varieties by 61.9% and inorganic fertilisers by 63.6%. Also, the role of subsidies was particularly found to be an important factor that influenced the likelihood of adopting SCIPs. The value of fertiliser subsidy allocated to a plot increased the likelihood of adopting hand pollination and both organic and inorganic fertilisers. This finding aligns with the *a priori* expectation that subsidies reduce the cost of fertilisers, making them more accessible and encouraging their use. The positive effect of fertiliser subsidies on the adoption of organic fertilisers may be due to the fact that inorganic fertiliser subsidies can lower the costs of production and encourage the reallocation of resources to the complementary use of organic fertilisers, which last longer in the soil, and are often seen as more sustainable and environmentally friendly. The value of fertiliser subsidy allocated to a plot was also found to positively influence the adoption of practices such as hand pollination, which rely heavily on fertilisers. Thus, subsidies can reduce the financial barriers associated with purchasing fertilisers, making it more feasible for farmers to adopt practices that require them. Also, the value of insecticide subsidy allocated to a plot strongly influenced the adoption of insecticides, fungicides, inorganic fertilisers, and organic pesticides, with notable increases of 94.6%, 70.2%, 66.6%, and 44.4%, respectively. These results underscore the direct and spill-over effects of subsidies

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on both targeted and complementary practices. This finding is consistent with Kotu et al. (2017), which found access to capital as a positive factor influencing the adoption of SIPs. The number of attendances to training workshops relating to SCIPs showed a consistently positive influence across the likelihood of adopting multiple SCIPs. It significantly increased the likelihood of adopting farm sanitation practices, shade trees, organic pesticides, inorganic fertilisers, organic fertilisers, and hand pollination. Notably, the number of trainings attended increased the likelihood of engaging in cocoa tree renovation by 23.2%. Training attendance plays a crucial role in shaping farmers' adoption of various agricultural practices, particularly those that require technical knowledge, improved skills, or awareness of modern farming techniques. For instance, training highlights the importance of soil amendment and climate-regulating benefits of shade trees and the use of both organic and inorganic fertilisers, making them more inclined to adopt their use. Also, training sessions may highlight the importance of maintaining a clean and disease-free farming environment. Thus, farmers who have attended training sessions relating to SCIPs are more likely to engage in regular farm sanitation practices, such as timely weeding, pruning and removal of base chupons, mosses, and mistletoes, as well as removing diseased or decaying plant material. Furthermore, through training attendance, farmers may be educated on hand pollination techniques to improve yields in the face of low natural pollination. These findings are consistent with Wuepper et al. (2018), who underscored the pivotal role of training in facilitating the adoption of organic fertilisers within Ghana's pineapple industry. These findings also align with Tennhardt et al. (2024), Ehiakpor et al. (2021), Brown et al. (2021), Benitez-Altuna et al. (2021), and Kotu et al. (2017), who highlighted training as a positive factor influencing the adoption of SIPs.

The results from Table 5.11(a) further reveal that farmers who found extension services useful were significantly more likely to adopt farm sanitation practices, improved varieties,

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hand pollination, insecticides, shade trees, inorganic fertilisers, fungicides, and organic fertilisers. The effects were particularly pronounced for improved varieties, with an increase in adoption likelihood of 126.4%. This indicates that when farmers perceive extension services as useful, they are more likely to engage in practices that they believe will improve their productivity and farm sustainability. Since these practices are highly technical or require continuous support and guidance, extension services typically provide farmers with valuable information, advice, and support. Positive perception of these services directly influences their implementation, as farmers are more likely to adopt practices that are supported by trusted and effective extension services. This finding is consistent with Kassie et al. (2013), which identified the quality of extension services as a significant factor influencing the adoption of sustainable agricultural practices.

Access to credit positively influenced the adoption of organic fertilisers and hand pollination, with marginal effects of 0.550 and 0.806, respectively. These findings suggest that farmers with access to credit are more likely to adopt practices that require substantial investments, particularly those that are labour-intensive and costly. Access to credit may alleviate financial constraints, enabling farmers to purchase farm input and hire labour needed for the effective adoption of organic fertilisers and hand pollination. This finding is consistent with Jumpah et al. (2024), Maré et al. (2022), Ehiakpor et al. (2021) and Kassie et al. (2015) who identified credit access as a key determinant for the adoption of sustainable intensification technologies.

Experience in cocoa farming was negatively associated with the adoption of multiple SCIPs (Table 5.11b). The marginal effects indicated that more experienced farmers were less likely to adopt practices such as maintaining shade trees, farm sanitation, use of organic pesticides, and the application of both organic and inorganic fertilisers. For example, the marginal effect of shade tree was -0.02, indicating that each additional year of farming

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experience slightly decreases the probability of adoption by 2%. In particular, the negative and significant effects observed on practices such as shade tree planting and the use of organic pesticides and fertilisers suggest that experienced farmers, who have established their methods of cocoa cultivation over time, exhibit resistance to adopting unfamiliar or new practices that may be more labour-intensive, despite their potential benefits.

Also, household size showed a positive effect on the adoption of organic fertilisers, organic pesticides, hand pollination and cocoa tree renovation. This suggests that larger households have the requisite family labour input required for the implementation of these labour-intensive practices. This result is consistent with Tennhardt et al. (2024) and Asamoah (2015), which identified household size to influence the adoption of labour-intensive practices on cocoa farms. Also, the gender of the household head had a significant negative effect on the adoption of inorganic fertilisers, reducing its likelihood by 38.2%. This suggests that male-headed households may be less inclined to adopt inorganic fertilisers compared to female-headed households. Contrary to *a priori* expectations and the findings of Adams et al. (2024a) and Benitez-Altuna et al. (2021), this study identified a significant negative association between male-headed households and the adoption of inorganic fertilisers. This divergence may reflect context-specific factors, including variations in risk perception, targeted input support initiatives for women, and differences in fertiliser procurement practices. While earlier studies linked male farmers to higher adoption rates through improved access to extension services and inputs, recent decentralised interventions and gender-focused agricultural programmes may have narrowed this gap, affording female farmers better or more equitable access to inorganic fertilisers. Moreover, male-headed households may manage larger, more diversified holdings, including non-cocoa plots or competing cash crops, which could influence fertiliser allocation decisions.

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Farmers who were indigenes of the communities within which their farms were located were more likely to adopt inorganic fungicides, with a positive marginal effect of 0.667, while migrant farmers were more likely to adopt hand pollination, a practice that yields immediate rewards. These findings suggest that indigenes often have better access to critical inputs, enabling them to engage in sustainably intensified farming strategies.

Furthermore, household ownership of farm assets was found to significantly increase the likelihood of adopting organic pesticides and fertilisers, shade trees, hand pollination, insecticide application, cocoa tree renovation, and farm sanitation measures such as routine weeding, pruning, and the removal of basal chupons, mosses, and mistletoes. Ownership of critical farm assets, such as spraying equipment, pruning tools, and means of transportation, enhances operational efficiency, thereby facilitating the timely and effective implementation of these labour- and input-intensive practices.

Farmers' unwillingness to adopt innovative practices that conflict with their religious beliefs was also found to have significant negative effects on the likelihood of adopting farm sanitation, shade tree, hand pollination, and organic and inorganic fertilisers. In Ghana, as in many other Sub-Saharan African contexts, religious beliefs shape farmers' worldviews, decision-making processes, and perceptions of natural resources. Certain faith-based doctrines or traditional religious interpretations may discourage practices perceived to interfere with divine will or natural order. For instance, the deliberate modification of plants through hand pollination or the application of agrochemicals might be viewed by some as unnatural or spiritually inappropriate. Similarly, beliefs about the sanctity of the land and divine control over crop yields can deter farmers from adopting hand pollination and fertiliser use, which are seen as human attempts to manipulate outcomes ordained by higher powers. Additionally, religious practices that emphasise non-interference with nature or prohibit the cutting of specific tree species could restrict farm

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sanitation and shade tree management. These religious convictions often override economic incentives, reducing the likelihood of adopting practices perceived to conflict with religious or spiritual values.

Finally, being located in the Forest-Savannah transition zone of Ghana significantly affects adoption decisions, with farmers in the transition zone exhibiting a reduced likelihood of adopting practices such as farm sanitation, shade tree, and improved cocoa varieties. This reflects the unique challenges faced by farmers in these areas, such as climatic conditions, access to inputs, or other resource constraints, which may hinder the uptake of these SCIPs. Conversely, farmers in the transition zone are more likely to adopt organic fertilisers, which may reflect a necessity for alternative soil management practices in these areas.

5.4.3 Factors that influence the attainment of sustainable intensification of cocoa plots in Ghana

The marginal effects from the multinomial logit model, presented in Table 5.12, provide detailed insights into how various explanatory variables influence the likelihood of cocoa plots falling into four sustainable intensification farm typologies in Ghana: "Sustainable, Not Intensified (SNI)", "Intensified, Not Sustainable (INS)", "Sustainably Intensified (SI)" and "Neither Sustainable nor Intensified (NSNI)" which was used as the base category. The model produced a pseudo R-squared value of 0.592, indicating that approximately 59.2% of the variation in the likelihood of adopting different SCIP typologies is explained by the included covariates. This reflects a reasonably strong model fit, suggesting the selected variables exert considerable explanatory power over the typology outcomes. The model's overall significance is

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Table 5.12: Multinomial logit results for determinants of SCIPs adoption

	SNI	INS	SI	NSNI
Variables	Marginal effect	Marginal effect	Marginal effect	Marginal effect
Plot ownership	0.009 (0.032)	-0.034 (0.026)	0.041(0.034)	-0.085*** (0.026)
Farm distance	-0.001 (0.001)	0.000 (0.001)	-0.002* (0.001)	0.003*** (0.001)
Flat topography	0.001(0.04)	-0.045 (0.032)	0.112**(0.048)	-0.068***(0.026)
Access to credit	0.035 (0.035)	0.097** (0.039)	0.06* (0.032)	-0.134***(0.037)
Training	0.064 (0.015)	0.009 (0.016)	0.05***(0.016)	-0.054***(0.019)
Extension visits	0.053*** (0.017)	-0.039** (0.020)	0.07***(0.020)	-0.084***(0.017)
Experience	-0.003* (0.002)	0.004*** (0.001)	-0.002 (0.001)	0.001 (0.002)
Education	0.011 (0.005)	-0.005 (0.005)	0.003 (0.006)	0.003 (0.005)
Household size	0.013 (0.008)	-0.043*** (0.009)	0.023***(0.008)	0.007 (0.009)
Gender	0.036 (0.026)	-0.027 (0.028)	-0.003 (0.034)	-0.007 (0.024)
Residential status	0.135** (0.068)	0.092** (0.042)	0.157** (0.067)	-0.114***(0.042)
Farm asset	0.013 (0.01)	-0.002 (0.011)	0.007 (0.007)	-0.018 (0.018)
Land holding	-0.006 (0.007)	0.018*** (0.004)	0.01** (0.004)	-0.023*** (0.007)
Religion	-0.008 (0.036)	0.07** (0.031)	-0.092***(0.03)	0.031 (0.036)
Transitional zone	-0.019 (0.023)	0.093*** (0.022)	-0.052** (0.023)	0.023 (0.021)
Number of obs	927			
Pseudo r-squared	0.592			
Chi-square	5305.86			
Prob > (χ^2)	0.0000			

Source: Field data (2024) ***: Significant at 1%; **: Significant at 5%; *: Significant at 10%.
(Robust clustered standard errors in bracket)

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confirmed by a Wald chi-square statistic of 5305.86, with a p-value well below the conventional 1% level. This decisively rejects the null hypothesis that all coefficients are jointly insignificant, confirming that the explanatory variables collectively exert a statistically significant influence on SCIP typology adoption.

According to the findings, access to credit significantly influenced farmers' adoption of SCIPs by effectively integrating intensification practices with sustainability measures, leading to their classification into the "Sustainably Intensified (SI)" farm typology, rather than the base typology of "Neither Sustainable nor Intensified (NSNI)". Specifically, credit access enhanced the likelihood of sustainable intensification by 6.01% (p-value = 0.063). On the other hand, it increases the probability of adopting intensification practices leading to their classification into the “Intensified, Not Sustainable (INS)” typology by 9.72% (p-value = 0.012). Access to credit facilitates the acquisition of essential inputs required for the successful implementation of SCIPs. It alleviates financial constraints, enabling farmers to purchase farm input and hire labour needed for the effective adoption of SCIPs. The number of extension visits was also found to significantly influence the attainment of sustainable intensification of cocoa plots in Ghana. Each additional extension contact increased the likelihood of being classified as “Sustainably Intensified (SI)” by 7.01% (p-value = 0.000). It also increased the likelihood of cocoa farmers being “Sustainable, Not Intensified (SNI)” by 5.27% (p-value = 0.001), compared to being in the base typology of "Neither Sustainable nor Intensified (NSNI)". This is consistent with the findings of Jumpah et al. (2024), Maré et al. (2022), Rahn et al. (2018), Kassie et al. (2015&2013) who noted that access to extension service was one of the key determinants of the adoption of sustainable intensification technologies through enhancing farmer knowledge and support. Conversely, the number of extension contacts decreased the likelihood of intensification without sustainability (INS) by 3.93% (p-value = 0.045), emphasising the important role of

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extension services in dissuading practices that prioritise intensification alone with sustainability.

The results further indicate that the participation of cocoa farmers in training workshops relating to SCIPs plays a crucial role in fostering sustainable intensification. Each additional training session attended enhanced the probability of effectively integrating intensification practices with sustainability measures leading to the "Sustainably Intensified (SI)" classification by 5.04% (p-value = 0.001). This highlights the important role of capacity-building initiatives in equipping farmers with the requisite knowledge and technical proficiency to implement SCIPs effectively. Household size also fosters sustainable intensification. Each additional household member increased the likelihood of the cocoa plot being “Sustainably Intensified (SI)” by 2.29% (p-value = 0.003), indicating that labour availability may facilitate the implementation of labour-intensive SCIPs. In contrast, larger household size reduced the probability of being “Intensified, Not Sustainability (INS)”, compared to being in the base typology of "Neither Sustainable nor Intensified (NSNI)". Intensification involves high input utilisation per unit of land. Thus, while a larger household size can provide additional labour for farm operations, it may also strain household resources, limiting the ability to invest in high input.

Residential status, measured as being an indigene of the community in which one’s plot is situated, increased the likelihood of sustainable intensification (SI) by 15.68 percentage points (p = 0.019). It also significantly increases the probability of being in the “Intensified, Not Sustainable (INS)” typology by 9.16% (p-value = 0.030). However, it reduces the likelihood of being in the ‘Sustainable, Not intensified (SNI)’ typology by 13.48% (p-value = 0.048). Household heads who are native to the communities where their cocoa plots are situated are more likely to cultivate strong social ties within their local institutions, thereby facilitating enhanced access to essential agricultural inputs. In contrast, migrant farmers

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may encounter social exclusion or weaker land tenure security, which can diminish both their capacity and willingness to adopt SCIPs.

Farming experience slightly reduces the probability of being classified as “Sustainable, Not Intensified (SNI)’ by 0.3% (p-value = 0.052). However, each additional year of experience increases the likelihood of being classified into the ‘intensification without sustainability (INS)’ typology by 0.41% (p-value = 0.006), suggesting that more experienced farmers may prioritise on productivity-oriented intensification strategies that may yield immediate returns over long-term sustainability measures. Also, the distance between a farmer’s residence and their cocoa plot was found to negatively influence the likelihood of adopting SCIPs that combine intensification with sustainability measures, thereby reducing the probability of being classified as a "Sustainably Intensified (SI)" farm, rather than the base "Neither Sustainable nor Intensified (NSNI)" typology, by 2%. Extended walking distances can serve as a significant deterrent to frequent farm visits and routine monitoring, thereby diminishing the likelihood of adopting labour-intensive SCIPs. The physical and logistical challenges associated with managing distant farms may hinder timely intervention, reduce engagement with the best agronomic practices, and ultimately limit the effectiveness of sustainable intensification efforts.

When farmers are unwilling to adopt practices that conflict with their religious beliefs, it reduces their likelihood of being “Sustainably Intensified” by 9.25% (p-value = 0.003), suggesting that strict religious and value-based factors can profoundly shape farmers' decision-making processes and significantly hinder the adoption of SCIPs. Religious obligations in many African farming communities often impose restrictions on labour activities during specific sacred or taboo days. These customary observances may prevent farmers from accessing their cocoa plots at crucial periods, disrupting the consistent implementation of SCIPs which require continuous monitoring and timely interventions to

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be effective. Such constraints are especially consequential during labour-intensive and time-sensitive stages of cocoa production, including harvesting and post-harvest processing. For instance, activities such as pulp-conditioning and fermentation demand regular stirring at precise time intervals to ensure optimal bean quality. Interruptions caused by religious observances may lead to suboptimal fermentation outcomes, compromised bean quality, and ultimately diminished market value.

Finally, the geographical location of a cocoa plot within Ghana's transition agroecological zone was found to significantly reduce the likelihood of sustainable intensification by 5.17% ($p = 0.026$). This zone is characterised by distinct agroecological constraints, including lower rainfall, higher temperatures, and sparse tree cover. Compared to the more fertile and humid forest zones of the south, farmers in the transition zone contend with moderate soil fertility and elevated drought risk. It would therefore be expected that cocoa farmers in this zone would prioritise the adoption of SCIPs, particularly soil fertility enhancement and water conservation practices, to counter these vulnerabilities. Paradoxically, this result contradicts both the a priori expectation of this study and the findings of Maré et al. (2022), Mutyasira et al. (2018), and Kassie et al. (2015, 2013), who identified exposure to drought and climate risks as significant drivers of sustainable intensification uptake. Farmers within the transition zone may be constrained by limited financial resources, inadequate technical support, and a lack of institutional incentives to adopt SCIPs. Also, the heightened production risks posed by drought, soil degradation, and erratic rainfall patterns may be discouraging investment in unfamiliar, capital-intensive SCIPs, particularly where their short-term returns remain uncertain. Moreover, restricted access to targeted sustainable intensification programmes further diminishes the feasibility of SCIP adoption, despite the zone's pronounced environmental challenges. In addition, many farmers in the transition zone increasingly diversify their livelihoods into non-cocoa

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enterprises or alternative, less-risky crops, thereby reducing their incentive to intensify cocoa production systems.

5.5 The Effects of SCIPs Adoption on Yield, Farm Income and Food Security of Farming Households in Ghana

The MESR was used to estimate the effects of SCIPs adoption on yield, farm income and food security of farming households in Ghana.

5.5.1 Test for potential endogeneity

The selection model results presented in Table 5.13 indicate that farmers' perception of SCIPs was significantly correlated with all sustainable intensification (SI) typologies or treatment groups (i.e. SNI, INS, and SI), except for 'non-user' households managing conventional cocoa plots that were neither sustainable nor intensified (NSNI). Specifically, SCIPs perception was a significant determinant across all adoption categories, with negative effects observed for SNI (-0.012***), INS (-0.009*), and SI (-0.009***), underscoring the pivotal role of favourable perceptions in influencing adoption decisions. Conversely, its effect on NSNI is positive (0.007) but statistically insignificant. Thus, a favourable perception of SCIPs, captured by a lower perception index, increased the likelihood of adopting SCIPs. The consistent negative significance in the SNI, INS, and SI categories indicates that farmers with a favourable perception of SCIPs are more inclined to adopt them. The observed pattern provides supporting evidence for the relevance of the perception of SCIPs as an instrumental variable (IV) for SCIPs adoption decisions (Tesfaye and Tirivayi, 2018; Di Falco et al., 2011). Additionally, the observed pattern lends credibility to the exclusion restriction by showing no systematic effect on non-adopters (Ma and Abdulai, 2016; Di Falco and Veronesi, 2013).

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Table 5.13: Marginal effect estimates of adoption of SCIPs from the selection model

	SNI	INS	SI	NSNI
Variables	Marginal effect	Marginal effect	Marginal effect	Marginal effect
Plot ownership	0.011 (0.028)	0.028 (0.026)	0.036(0.031)	-0.075*** (0.022)
Farm distance	-0.001 (0.001)	0.000 (0.001)	-0.001* (0.001)	0.002*** (0.001)
Flat topography	-0.005(0.048)	-0.042 (0.035)	0.112**(0.048)	-0.065**(0.028)
Access to credit	0.001 (0.034)	0.060** (0.021)	0.061* (0.032)	-0.114***(0.032)
Training	-0.095(0.197)	0.007(0.223)	0.05***(0.016)	0.079 (0.497)
Extension visits	0.040 (0.067)	-0.046(0.070)	0.180**(0.085)	-0.173***(0.062)
Experience	-0.003* (0.002)	0.004** (0.002)	-0.002 (0.002)	0.001 (0.002)
Education	0.002(0.006)	-0.006 (0.006)	0.001 (0.007)	0.003 (0.006)
Household size	0.011 (0.008)	-0.043*** (0.010)	0.023***(0.008)	0.008 (0.010)
Gender	0.039 (0.035)	-0.022 (0.027)	-0.013 (0.037)	-0.004 (0.024)
Residential status	-0.105** (0.044)	0.070* (0.036)	0.122** (0.050)	-0.088***(0.034)
Farm asset	0.007 (0.012)	-0.001 (0.012)	0.007 (0.008)	-0.014 (0.022)
Land holding	-0.006 (0.009)	0.018*** (0.004)	0.01** (0.004)	-0.021*** (0.008)
Religion	-0.001 (0.052)	0.085 (0.248)	-0.092***(0.03)	0.012 (0.130)
Transitional zone	-0.022 (0.022)	0.086*** (0.023)	-0.043* (0.023)	0.021 (0.023)
SCIPs Perception	-0.012***(0.001)	-0.009*(0.005)	-0.009***(0.002)	0.007(0.013)
Resid_Extension	0.021(0.024)	0.023(0.016)	0.030(0.027)	0.027(0.019)
Resid_Credit	0.106 (0.136)	0.086(0.075)	0.056(0.043)	-0.136(0.122)
Resid_Training	0.037(0.026)	0.007(0.019)	0.032(0.034)	-0.011(0.023)

Source: Field data (2024) (Bootstrapped standard errors in parentheses)
***: Significant at 1%; **: Significant at 5%; *: Significant at 10%.

The control function approach was employed to correct for potential endogeneity in credit access, extension visits, and training attendance by including first-stage residuals (*Resid_Credit*, *Resid_Extension*, and *Resid_Training*) in the outcome equation. The estimated residuals were statistically insignificant across treatment regimes in the MESR model, suggesting no strong evidence of endogeneity in the outcome equation (Issahaku and Abdulai, 2020; Ma and Abdulai, 2016; Wooldridge, 2015). This indicates their exogeneity in the outcome model of the MESR estimation, ensuring that the estimated treatment effects stemmed from the modelled selection process rather than unobserved confounders or model misspecifications.

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5.5.2 Selectivity correction based on a multinomial logit model

The second-stage selectivity correction results from the MESR, presented in Tables 4–8 in Appendix 3, offer important insights into the observable and unobservable determinants of cocoa yield, farm income, and food security across treatment categories: SNI, INS, SI, and the base category, NSNI. The findings confirm that both observed and unobserved factors jointly influence farmers' decisions to adopt SCIPs, as well as the resulting yield, income, and food security outcomes within the SCIPs framework. The ρ (rho) coefficients (Table 4, Appendix 3) represent the correlation between the unobserved factors influencing farmers' selection into the treatment regimes in the multinomial logit model and the unobservable components of the outcome equations for cocoa yield, conditional on selectivity correction. In essence, they capture the covariance between the error terms in the selection equations (ε's in Equation 4.13) and the outcome equations (μ's in Equations 4.14a–4.14d), following Bourguignon et al. (2007). The presence of statistically significant ρ coefficients, such as ρ_{SNI}, ρ_{SI}, and ρ_{NSNI}, confirms the existence of selection bias arising from unobservable factors. The direction and significance of the ρ coefficients are particularly revealing. The alternating signs suggest both positive and negative selection bias across treatment categories. Notably, negative and statistically significant correlations are observed for the SNI ($\rho = -0.218$, $p < 0.10$) and SI ($\rho = -0.640$, $p < 0.01$) categories, implying that unobservable factors increasing the probability of selection into these regimes tend to systematically reduce yields. Conversely, positive and statistically significant correlations emerge for the SI ($\rho = 0.517$, $p < 0.10$) and NSNI ($\rho = 0.524$, $p < 0.05$) categories, indicating that unobserved characteristics associated with selection into these groups are positively correlated with higher yields. These patterns reinforce the hypothesis that farmers self-select into SCIPs based on their unobserved comparative yield advantage

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(or disadvantage), justifying the necessity of correcting for such selection effects to avoid biased estimates.

The λ (lambda) coefficients represent the inverse Mills ratios, which capture the influence of unobserved factors simultaneously affecting the decision to adopt SCIPs and the associated yield outcomes. Statistically significant λ values signal the presence of selectivity bias. Positive λ coefficients suggest that unobservable factors improve yield outcomes, whereas negative values indicate a reduction effect. For example, in the yield model, the λ coefficients are significant and negative for both the SNI ($\lambda = -334.804$, $p < 0.10$) and SI ($\lambda = -674.800$, $p < 0.10$) categories, implying that unobserved characteristics increasing the likelihood of selecting these regimes are associated with lower cocoa yields. Conversely, the NSNI category records a positive and statistically significant λ ($\lambda = 512.940$, $p < 0.01$), suggesting that unobservable factors favouring selection into this group are correlated with higher yields. The estimated error variances (σ^2) measure the extent of unobserved heterogeneity in yield outcomes within each treatment regime. Notably, the large variances, particularly in the SI ($\sigma^2 = 655.260$) and NSNI ($\sigma^2 = 511.440$, $p < 0.01$) regimes, indicate considerable variability in yield outcomes attributable to unobservable factors within these groups. Moreover, the statistically significant constant term in the NSNI category suggests that unobserved factors unrelated to SCIPs adoption remain an important determinant of cocoa yield in this group.

Similar trends are observed in the farm income and food security models. The ρ coefficients (Table 5, Appendix 3) indicate that unobservable factors influencing farm income are negatively associated with selection into the SNI and SI regimes, while NSNI shows evidence of positive selection bias. Likewise, the significant ρ values reported in Tables 6–8 (Appendix 3) confirms a strong correlation between unobserved determinants of adoption decisions and food security outcomes, as measured by the HFIAS, HFCS, and rCSI. These

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findings reiterate the importance of correcting for selectivity effects to obtain unbiased estimates of the true impacts of SCIPs adoption on food security outcomes. Furthermore, the relatively large error variances (σ^2) for the NSNI category in the food security models highlight greater unobserved heterogeneity in food security outcomes within this group. This heterogeneity reflects the influence of diverse, unmeasured factors not captured by the model's covariates.

The consistent presence of significant selectivity effects implies that reliance on OLS or unadjusted estimation techniques would have produced biased and inconsistent estimates. Through the MESR framework's selectivity correction mechanism, the study finds that SCIPs adopters consistently failed to outperform non-adopters, regardless of the specific treatment regime or SCIPs adoption decision (see Ma and Abdulai, 2016). Consequently, accounting for selectivity effects was essential for obtaining reliable and consistent estimates of treatment effects in this context. These results affirm the appropriateness of the MESR model over OLS or other selection-unadjusted models, as neglecting selectivity bias would have led to inaccurate and potentially misleading policy conclusions.

5.5.3 Effects of SCIP adoption on cocoa yield, cocoa farm income and household food security

The effects of adopting SCIPs on cocoa yield, farm income and household food security outcomes were estimated across four treatment categories: NSNI (Neither Sustainable nor Intensified), SNI (Sustainable, Not Intensified), INS (Intensified, Not Sustainable), and SI (Sustainably Intensified). The NSNI category served as the baseline for comparison. The analysis considered the observed outcomes for plots and households in each treatment group, counterfactual outcomes if they had remained in the base group (NSNI), and two key Average Treatment Effects: Average Treatment Effect on the Treated (ATT) and

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Average Treatment Effect on the Untreated (ATU). Results for the estimation of the ATT and ATU are presented in Tables 5.14 and 5.15 respectively.

5.5.3.1 Effects of SCIPs adoption on cocoa yield

The results from Table 5.15 indicate that the adoption of SCIPs had a significant and positive effect on cocoa yields across all typologies or treatment groups. In the SNI typology, households adopting SCIPs achieved an observed yield of 461.71 kg/ha, compared to a counterfactual yield of 440.13 kg/ha if they were in the NSNI typology. This yielded an ATT of 21.58 kg/ha, corresponding to a 4.9% increase. This implies that the adoption of sustainability-enhancing practices, such as the maintenance of shade trees, farm sanitation, water harvesting, proper agrochemical handling, organic inputs, contributes to improved yields. However, in the absence of complementary intensification measures, including fertiliser use, hand pollination, and intensive chemical control of pests and diseases, these gains remain modest. In the INS typology, where intensification is pursued without adequate sustainability measures, the observed yield was 448.82 kg/ha, while the counterfactual yield under NSNI conditions would have been 333.81 kg/ha. This resulted in an ATT of 115.01 kg/ha, representing a 33.95% increase. This implies that the implementation of high-input, productivity-enhancing practices, including the use of improved cocoa varieties, high planting densities, and increased fertiliser and pesticide application, improves cocoa yields in Ghana. This yield is substantial even when intensification is pursued without the complementary adoption of sustainability-enhancing practices such as shade tree maintenance, farm sanitation, water harvesting, proper agrochemical handling, and the use of organic inputs. It is consistent with Vanlauwe and Dobermann (2020), which highlighted the pivotal role of intensification measures in attaining high yields.

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Table 5.14: Average Treatment Effect on the Treated (ATT) of SCIPs adoption on cocoa yield, cocoa farm income and household food security

Outcome Indicators	Treatment	Observed Effect	Counterfactual Effect (if household were to be in the NSNI typology)	True Effect (ATT) [H0: mean(diff) = 0]	% Change
Yield					
	SNI	461.712(63.189)	440.132(6.474)	21.58***(5.649)	4.9
	INS	448.821(16.663)	333.812(11.308)	115.008***(15.716)	33.95
	SI	882.332(36.441)	658.475(19.637)	223.857***(34.108)	34.00
Cocoa Farm Income					
	SNI	3571.074 (231.32)	3264.2 (202.34)	306.87***(112.88)	9.40
	INS	1129.04 (67.45)	1521.663 (79.30)	-392.623**(162.722)	-25.80
	SI	5210.191 (346.82)	3884.704 (254.69)	1325.487***(261.329)	34.12
Food Security					
HFIAS	SNI	2.299(0.061)	3.135(0.039)	-0.836***(0.085)	-26.67
	INS	2.645(0.044)	3.186(0.049)	-0.541***(0.061)	-16.98
	SI	1.587(0.035)	3.361(0.027)	-1.774***(0.273)	-52.78
HFCS	SNI	32.407(1.563)	25.069(0.351)	7.338***(1.352)	29.27
	INS	25.514(0.5113)	22.204(0.599)	3.311***(0.795)	14.91
	SI	42.59(1.251)	28.327(0.333)	14.263***(1.082)	50.35
rCSI	SNI	3.284(0.202)	5.054(0.4)	-1.77***(0.313)	-35.02
	INS	7.301(0.256)	8.482(0.544)	-1.18***(0.517)	-13.92
	SI	1.196(0.114)	3.221(0.812)	-2.025***(.809)	-62.87

Source: Field data (2024) ***: Significant at 1%; **: Significant at 5%; *: Significant at 10%. (Bootstrapped standard errors in parentheses)

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Table 5.15: Average Treatment Effect on the Untreated (ATU) of SCIPs adoption on cocoa yield, cocoa farm income household food security

Outcome Indicators	Observed Score (household in the NSNI typology)	Counterfactual Score (if household were to be in the SNI, INS or SI typologies)			True Effect (ATU) [H0: mean(diff) = 0]	% Change
		SNI	INS	SI		
Yield	271.83(2.797)	364.729(4.10)			92.899***(3.895)	34.17
	271.83(2.797)		452.090(7.609)		180.26***(6.66)	66.31
	271.83(2.797)			676.479(4.497)	407.65***(26.55)	149.97
Cocoa Farm Income						
	2292.082 (102.26)	2912.291(109.99)			620.21***(72.058)	27.06
	2292.082 (102.26)		1550.259(84.76)		-741.823***(78.417)	-32.37
	2292.082 (102.26)			3625.024(224.01)	1332.942*** (55.21)	58.15
Food Security						
HFIAS	2.952(0.018)	1.514(0.188)			-1.438***(0.197)	-48.71
	2.952(0.018)		2.030(0.025)		-0.922***(0.03)	-31.23
	2.952(0.018)			4.635(0.323)	1.683***(0.312)	63.46
HFCS	23.219(0.113)	22.552(0.566)			-0.667***(0.549)	-2.87
	23.219(0.113)		22.059(0.232)		-1.16***(0.054)	-4.99
	23.219(0.113)			21.876(0.662)	-1.343***(0.052)	-5.78
rCSI	19.361(0.250)	19.345(0.385)			-0.016***(0.001)	-0.08
	19.361(0.250)		19.872(0.26)		0.512***(0.175)	2.64
	19.361(0.250)			21.542(0.155)	2.181***(0.217)	11.27

Source: Field data (2024) ***: Significant at 1%; **: Significant at 5%; *: Significant at 10%. (Bootstrapped standard errors in parentheses)

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It also aligns with the arguments of Sassen et al. (2022), Toledo-Hernandez et al. (2020), Vanlauwe and Dobermann (2020), Tothmihaly et al. (2019), and Gockowski and Sonwa (2011) that without strategies like adoption of improved varieties, hand pollination, and inorganic fertiliser, the potential yield gains of sustainable intensification cannot be realised. The SI typology, which effectively integrates both sustainability and intensification practices, delivered the highest yield gains. Households in this group achieved an observed yield of 882.33 kg/ha, compared to a counterfactual yield of 658.48 kg/ha under NSNI conditions. This translated into an ATT of 223.86 kg/ha, equivalent to a 34.0% increase. This implies that the adoption of SCIPs that resulted in the attainment of sustainable intensification resulted in the highest yield. These results highlight the synergistic benefits of effectively combining improved varieties, hand pollination, and other intensification practices with environmental management techniques like shade trees, responsible agrochemical use, organic inputs, tree renovation, and attention to farmer health, generational renewal, and workload management. This finding is consistent with Kotu et al. (2017), which demonstrated that integrating commercial inputs with cultural practices significantly enhanced farm productivity.

For households currently in the NSNI typology, the counterfactual analysis reveals substantial potential yield gains if they were to adopt SCIPs. Households classified under the NSNI typology could boost their average yield from 271.83 kg/ha to 364.73 kg/ha by transitioning to the SNI typology. This shift would result in an Average Treatment effect on the Untreated (ATU) of 92.90 kg/ha, reflecting a 34.17% increase in yield. If these households adopted the INS typology, their yield would rise to 452.09 kg/ha, with an ATU of 180.26 kg/ha, representing a significant 66.31% increase. Finally, transitioning to the SI typology would result in the greatest improvement, raising the average yield to 676.48

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kg/ha. This change would correspond to an ATU of 407.65 kg/ha, representing a 149.97% increase in yield.

These findings demonstrate the positive impact of the adoption of SCIPs on cocoa yields. While intensification alone provides substantial benefits, the integration of sustainability practices amplifies these gains, making the adoption of SCIPs that effectively integrate both sustainability and intensification practices the most effective strategy for enhancing cocoa productivity. This evidence underscores the critical importance of promoting SCIPs for long-term productivity improvements.

5.5.3.2 Effects of SCIPs adoption on cocoa farm income

The Average Treatment Effect on the Treated (ATT) quantifies the impact of SCIPs adoption on cocoa farm income by comparing the actual income of adopters to the counterfactual scenario in which they would have remained in the NSNI baseline typology. Amongst SNI farmers, the adoption of SCIPs led to a significant income increase of GHC 306.87 ($p<0.01$), representing a 9.40% rise relative to the counterfactual. This suggests that sustainability-oriented practices, even in the absence of intensive input use, produce moderate economic benefits. By contrast, INS farmers experienced a significant income loss of GHC 392.62 ($p<0.05$), equating to a 25.80% decline. This result suggests that pursuing intensification strategies in isolation, without integrating sustainability principles, may lead to inefficiencies that erode potential income gains. The observed decline could stem from higher input costs or suboptimal resource allocation, ultimately negating the expected financial benefits of intensification. The highest economic benefit was observed amongst SI farmers, for whom the adoption of SCIPs resulted in an income increase of GHC 1325.49 ($p<0.01$), translating to a 34.12% rise. This outcome highlights the advantages of integrating both sustainability and intensification, as the combined approach

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likely enhances resource efficiency. This is supported by Bandanaa et al. (2021), which found organic cocoa systems to be associated with efficient utilisation of environmental resources, particularly, withdrawal of water from the soil, land degradation, and emission of greenhouse gases. Practices such as mulching, organic fertilisation, and planting of shade trees enrich the soil structure and nutrient retention, reducing reliance on chemical inputs. Integrated pest management further reduces inorganic pesticide dependency, cutting production costs while preserving biodiversity. Though initial adoption costs may be higher, long-term savings on synthetic inputs translate into greater net returns. These findings highlight the crucial role of integrated strategies in cocoa farming, demonstrating that economic success is maximised when sustainability and intensification are pursued simultaneously. This finding is also consistent with Bandanaa et al. (2024), which found organic cocoa farming systems to be more profitable (by approximately 20%) than conventional cocoa farming systems. It is also consistent with Kotu et al. (2017), which demonstrated that integrating commercial inputs with cultural practices significantly enhanced household income of maize farmers in Ghana. Setsoafia et al. (2022) and Abdallah et al. (2021) also revealed that the simultaneous adoption of these practices resulted in greater improvements in farm income for maize and cassava farmers. This further suggests that intensification must aim to enhance the efficiency of resource use, ensuring that inputs are applied at levels optimally aligned with maximum yield potential. Exceeding these thresholds will lead to inefficiencies and resource wastage, disrupting the biophysical balance essential for environmental stability. As such, excessive input use should be discouraged on both environmental, economic and social sustainability grounds. The Average Treatment Effect on the Untreated (ATU) measures the hypothetical effects of the adoption of SCIPs on cocoa farm income for NSNI households, assuming they have transitioned to one of the three alternative SCIPs adoption typologies. If NSNI households

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had adopted SNI practices, their cocoa farm income would have increased by GHC 620.21 ($p<0.01$), reflecting a 27.06% rise. This suggests that incorporating sustainability-focused practices, even without intensification, can moderately improve farm income. However, had these households adopted INS practices, they would have experienced a substantial income decline of GHC 741.82 ($p<0.01$), representing a 32.37% reduction. This reinforces the notion that intensification without sustainability may lead to inefficiencies, elevated production costs, or decreased profitability.

In contrast, if NSNI households had adopted strategies that effectively integrated both sustainability and intensification practices, their cocoa farm income would have increased significantly by GHC 1332.94 ($p<0.01$), marking a 58.15% rise. This finding highlights the superior economic potential of combining sustainability and intensification, as it yields the most substantial income improvement. The results suggest that NSNI households would derive the greatest financial benefit from transitioning to the SI typology, which would nearly double their income relative to their current typology. Adopting SCIPs that facilitate a transition to the SNI typology yields moderate income gains; however, sustainability practices alone do not achieve the same financial improvements as when integrated with intensification. Conversely, adopting SCIPs that facilitate a transition to INS appears detrimental, further substantiating the argument that intensification without sustainability is counterproductive.

5.5.3.3 Effects of SCIPs adoption on household food security

5.5.3.3.1 Effects of SCIPs adoption on household food insecurity access scale (HFIAS)

The adoption of SCIPs leads to a significant reduction in food insecurity, as measured by the HFIAS, across all SCIPs adoption typologies or treatment groups. In the SNI typology, the observed HFIAS score was 2.30, while the counterfactual score was 3.14, resulting in

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a true effect (ATT) of -0.836 points, representing a 26.67% reduction in food insecurity. This indicates that the adoption of SCIPs that lead to SNI classification resulted in a significant decrease in food access, availability and stability, which are captured by the HFIAS (Dompreh et al., 2021). The INS typology, on the other hand, had an observed HFIAS score of 2.65 and a counterfactual score of 3.19, yielding an ATT of -0.541 points, or a 16.98% reduction in food insecurity. This finding suggests that while the INS typology contributes to reducing food insecurity, its effect is less pronounced than that of the SNI typology. This implies that intensification alone delivers only marginal improvements in household food access, availability and stability, as it lacks the complementary benefits of sustainability practices. The SNI typology integrates sustainable farming methods that enhance soil fertility and water retention, reducing reliance on chemical inputs and easing financial strain on households. In contrast, the limited effect of the INS typology may result from higher production costs driven by dependency on external inputs, placing greater financial pressure on farming households. The SI typology, which effectively integrates intensification and sustainability strategies, achieved the most substantial reduction in the HFIAS score. With an observed score of 1.59 compared to a counterfactual score of 3.36, it yielded a true effect (ATT) of -1.774 points, reflecting a 52.78% decline in food insecurity.

Furthermore, households in the NSNI typology, with an HFIAS score of 2.952, would experience a significant decline to 1.514 upon transitioning to the SNI typology. This shift represents a statistically significant reduction of 1.438 points, equating to a 48.71% enhancement in food security. A switch to the INS typology would result in a reduction of their HFIAS score to 2.030, which corresponds to a statistically significant 31.23% reduction in food access, availability and stability. Transitioning from the NSNI to the SI typology significantly compromises food security, as indicated by a 1.683-point increase

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in the HFIAS score, reflecting a 63.46% deterioration. This underscores the vulnerability of conventional cocoa farmers when adopting SCIPs, suggesting that the shift imposes economic strains that exacerbate household food insecurity. The decline in food security may stem from higher initial investment costs, labour reallocation, or temporary yield fluctuations during the transition period.

5.5.3.3.2 Effects of SCIPs adoption on household food consumption score (HFCS)

The adoption of SCIPs improves HFCS significantly across the different treatment typologies. In the SNI typology, the observed outcome was 32.41, compared to a counterfactual outcome of 25.07. This resulted in a true effect (ATT) of 7.34 points, which signified a 29.27% improvement in food security. In the INS typology, the observed outcome was 25.51 points, compared to the counterfactual outcome of 22.20 points. This yielded an ATT of 3.31 points, which corresponds to a 14.91% increase in food access, availability, and utilisation, which are captured by the HFCS. Thus, while the INS typology was associated with a positive effect on food consumption, it yielded the least improvement with an increase of 3.31 points or a 14.91% gain. In contrast, the SI typology shows the most substantial improvement in HFCS which captures food access, availability, and utilisation (Dompreh et al., 2021). It recorded an actual score of 42.59, compared to a counterfactual score of 28.33, yielding a true effect (ATT) of 14.26 points, or a 50.35% increase.

For households in the NSNI typology, with an average HFCS of 23.219, transitioning to the SNI typology would reduce their HFCS to 22.552. This shift represents a statistically significant decline of 2.87% in food security (ATU). Switching from the NSNI to the INS typology would further lower the HFCS to 22.059, with a significant ATU of -1.16, reflecting a 4.99% decline in household food access, availability, and utilisation. Similarly,

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transitioning from the NSNI typology to the SI typology would decrease the HFCS to 21.876, reflecting a significant ATU of -8.657, representing a 5.78% decline in food security. This result suggests that, if transitioning to the adoption of SCIPs leads to reduced household food access, availability, and utilisation across all treatment groups, the SI typology would experience the most severe decline. This confirms the vulnerability of conventional cocoa farmers transitioning to adopting SCIPs, highlighting that the shift imposes economic strains that exacerbate household food insecurity.

5.5.3.3.3 Effects of SCIPs adoption on reduced coping strategies index (rCSI)

The adoption of SCIPs significantly reduced reliance on coping strategies, as measured by the rCSI, across all treatment regimes. Under the SNI treatment regime, the observed rCSI score was 3.28, compared to a counterfactual rCSI score of 5.05, resulting in a true effect (ATT) of -1.77 points, or a 35.02% reduction in the reliance on coping strategies. This suggests that the adoption of SCIPs in the SNI typology leads to a significant reduction in the need for coping strategies. This further implies a significant improvement in household food access and stability (Dompreh et al., 2021). Households under the INS treatment regime recorded an observed rCSI score of 7.30, compared to a counterfactual score of 8.48, yielding a true effect (ATT) of -1.18 points, representing a 13.92% reduction in reliance on coping strategies. Also, the SI typology yielded the largest reduction in coping strategies, with an actual rCSI score of 1.20, compared to a counterfactual rCSI score of 3.22, resulting in a true effect (ATT) of -2.03 points, or a 62.87% decrease. This indicates that while the SI typology resulted in the biggest reduction in coping strategies, the INS typology resulted in the least reduction in these strategies.

Furthermore, households in the NSNI typology, with an observed rCSI score of 19.361, would experience a slight decrease in their rCSI by 0.016 points if they switched to the SNI

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typology, reflecting a modest reduction of 0.08% in the use of coping strategies. On the other hand, switching from the NSNI typology to the INS typology would increase the rCSI to 19.872, with a significant ATU of 0.512 points, corresponding to a 2.64% decline in household food access and stability. Similarly, switching from NSNI to the SI typology would increase the rCSI to 21.542, with a significant ATU of 2.181 points, reflecting an 11.27% increase in coping strategies. This implies that households transitioning from the NSNI typology to the SI typology would experience a substantial reduction in their food security, as measured by the increased reliance on coping strategies.

Transitioning from the NSNI typology to various SCIP regimes significantly alters household food security outcomes in Ghana, with shifts to SI typology consistently exacerbating food insecurity across all indicators. This underscores the economic and nutritional vulnerability conventional cocoa farmers face during the transition to sustainability practices. Thus, there is a clear and pressing need for well-targeted economic incentives to cushion households against the short- to medium-term economic strains associated with adopting sustainability practices. This argument is corroborated by past studies. Vanlauwe and Dobermann (2020) asserted that, for farmers to adopt SIPs in the short term, these interventions must deliver a discernible yield increase coupled with a minimum profit gain of USD 50 per hectare. In the absence of such immediate, tangible returns, alternative technologies are unlikely to succeed. Mahrizal et al. (2012) estimated that transitioning from conventional to organic cocoa production results in yield losses of approximately 28–30%, necessitating a commensurate price premium to offset these declines. Similarly, Tsiboe et al. (2018) reported a 20% yield reduction associated with environmentally friendly production systems, requiring an equivalent price adjustment to preserve profitability. Finally, Piñeiro et al. (2020) concluded that, irrespective of the type

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of incentive offered, programmes delivering short-term economic gains consistently achieve higher adoption rates.

5.6 Incentives that Promote the Adoption of Sustainable Cocoa Intensification Practices in Ghana

The TNA presented in Figure 5.3 illustrates incentives that can enhance the adoption of SCIPs in Ghana. These incentives are categorised into three organising themes: Market-Based/Economic, Technical Support, and Social or Cultural Incentives. Collectively, these three themes converged into the overarching global theme of incentives for SCIPs adoption (Figure 5.3).

5.6.1 Economic or market-based incentives that promote the adoption of sustainable cocoa intensification practices (SCIPs)

The 'Market-Based/Economic Incentives' organising theme in Figure 5.3 underscores the financial incentives that can promote SCIPs in Ghana. The introduction of annual payments for ecosystem services (PES), the direct payment of sustainability premiums at the farmgate, and the establishment of tenure security for shade trees to facilitate the commercial utilisation of their economic products are economic incentives identified by this study (Figure 5.3). These are market-based instruments which can serve as indirect regulatory tools to influence cocoa farmers' behaviour by altering their economic conditions (Mazaheri et al., 2022; Quarmine et al., 2012), in order to encourage farmers to adopt more sustainable production practices (Rosenow et al., 2019; Stiglitz & Rosengard, 2015).

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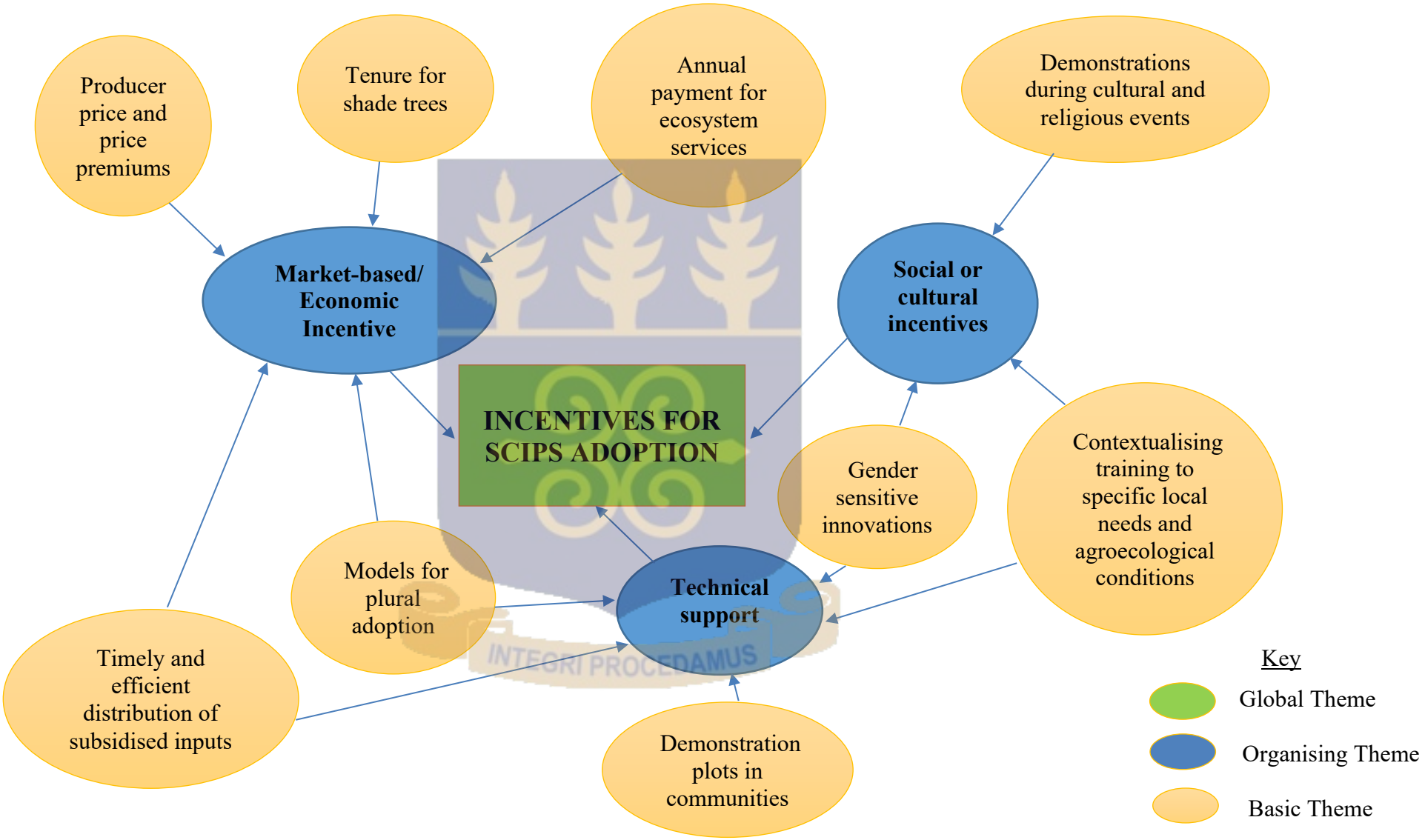


Figure 5.3: Thematic network analysis of the incentives that promote adoption of Sustainable Cocoa Intensification Practices (SCIPs)

Source: Constructed from field data (2024)

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5.6.1.1 Commensurate annual increase in cocoa producer prices

The cocoa producer price was stressed by both the farmers (100%[n=22]) and the experts (100%[n=18]) as the most significant economic incentive driving the adoption of SCIPs in Ghana (Figure 5.3). It was explained that the cocoa producer price regime of COCOBOD shields farmers from global market fluctuations, ensuring a degree of economic security. With better income, farmers can afford essential inputs for the adoption of SCIPs. A significant annual increase in the cocoa producer price that ensures that farmers receive a commensurate percentage of the free-on-board (f.o.b) price consistent with world market trends can greatly enhance the sustainability of cocoa farming in Ghana (Quarmine et al., 2012). This would also reduce the dependence on illegal activities such as smuggling or side-selling, ensuring that cocoa remains within the formal value chain, where sustainability standards and monitoring are enforced. A consistently rising and equitable cocoa price producer was suggested to strengthen this financial incentive. Comments made to buttress this point include:

A consistent and fair increase in the cocoa producer price remains the most effective incentive for SCIPs adoption. In fact, a well-structured and predictable increment could even mitigate the smuggling of cocoa beans out of Ghana [RO07(E)].

5.6.1.2 Sustainability premiums paid at the farm gate

Both the experts (56%[n=10]) and farmers (64%[n=14]) agreed that premium pricing for sustainably produced cocoa at the farmgate holds the potential of incentivising the adoption of SCIPs in Ghana (Figure 5.3). Farmers producing high-quality cocoa beans often receive higher

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prices in the market, especially if they are selling to specialty or fair-trade markets (Quarmine et al., 2012). These premiums can increase farm profitability and provide more stable incomes, allowing farmers to reinvest in sustainable farming practices. However, the absence of pay-for-quality pricing mechanisms undermines farmers' incentives to improve cocoa quality beyond existing standards (Quarmine et al., 2012). In recent years, certification programmes such as Fairtrade and Rainforest Alliance have played a crucial role in incentivising sustainable cocoa farming by ensuring that farmers who adhere to the sustainability standards receive a substantial premium at the end of the year, in addition to the farmgate price (Bandanaa et al., 2024; 2021). Some sustainability programmes further reinforce these incentives by providing farm inputs, specialised training opportunities, or community development projects to farmers who successfully implement these certification standards (Laven & Boomsma, 2012). Results from the TNA emphasised that expanding such premium-based systems at the community level, through a pay-for-quality pricing mechanism, would allow all cocoa farmers to directly access financial incentives at designated sale centres, provided they meet sustainability requirements. Comments made to buttress this point include:

In Asunafo North, farmers participate in certification cooperatives, which guarantee premium payments in addition to the farmgate price. Farmers who comply with the stipulated requirements receive substantial premiums at the end of the year. This model could be expanded at the community level, enabling all eligible farmers to access premiums at designated sales centres upon meeting sustainability standards [RO11 (E)]

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5.6.1.3 Timely and efficient distribution of subsidised inputs

COCOBOD's input subsidy programme emerged from the TNA as offering a major economic incentive to farmers in the adoption of SCIPs in Ghana. Both the farmers (100%[n=22]) and the experts (100%[n=18]) emphasised the need for COCOBOD and key stakeholders to ensure that appropriate logistical infrastructure is in place to prevent delays and shortages, particularly during peak application periods. COCOBOD supplies agrochemicals, motorised slashers and sprayers, and premixed fuel to cocoa farmers. These inputs from the COCOBOD subsidy programme, especially the agrochemicals, including fertilisers, insecticides and fungicides, are widely regarded as high quality and certified, yet their distribution is often inadequate and untimely. Farmers reported that distribution through the cooperative channels has become highly politicised, with inputs disproportionately allocated based on political affiliations. Consequently, some farmers, especially those who do not align with the ruling government, are excluded from accessing inputs. Comments made to buttress this point include:

Despite government subsidies, many approved agrochemicals fail to reach the intended farmers due to inefficiencies in the distribution system. Instead, these inputs often surface in input shops with labels such as "Government Property. Not for Sale" stuck on them. Additionally, while the cooperative distribution channels are well-intentioned, they have been heavily politicised, favouring farmers affiliated with the ruling party [RO09(F)].

Extension coordinators from COCOBOD attributed the delays in input distribution to an administrative requirement for real-time data to enhance traceability and mitigate input diversion. According to a district extension coordinator:

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COCOBOD now requires real-time data on input distribution and usage through the Kobo platform. Farmers' data, including details on recipients, application dates, and quantities applied, must be uploaded before distribution can commence. You have to wait for the KoBo App to be activated for you before you can commence the distribution of these inputs [RO19 (E)].

The timely and efficient distribution of subsidised inputs would remove financial barriers to adopting SCIPs by ensuring that farmers can access fertilisers, improved seedlings, and pesticides at affordable costs (Bakali et al., 2023; Piñeiro et al., 2020; Jacobi et al., 2017). It will also ensure the timely implementation of time-bound SCIPs that follow strict numerical recommendations. It was suggested that a return to the original cooperative approach, where inputs are pooled and applied collectively, would ensure fairness and efficiency. However, this should be matched with the de-politicisation of the cooperative distribution channels to establish transparent mechanisms to ensure equitable access. Also, there is a growing call for stricter regulation of agrochemical sales to eliminate the widespread availability of poor quality and uncertified inputs on the market. A reintroduction of certified input shops in cocoa-growing communities was suggested as a means to achieve this. Regulating the activities of these shops through efficient licencing, with products approved by CRIG, was also suggested. This approach would help mitigate the proliferation of counterfeit farm inputs, and ensure that only approved chemicals reach farmers, safeguarding both crop health and environmental sustainability. Comments made to buttress this point include:

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The government must regulate the sale of agrochemicals to ensure that only approved products are available on the market. Certified input shops, previously in existence, should be reinstated. These shops should obtain licences from COCOBOD, and their inputs should be sanctioned by CRIG [RO15(F)]

COCOBOD must depoliticise these cooperatives to ensure fair and equitable distribution of inputs [RO09(F)]

5.6.1.4 Annual payments for ecosystem services

Payments for ecosystem services (PES) also emerged from the TNA as a crucial financial intervention that can provide direct compensation to farmers who adopt SCIPs, particularly for maintaining shade trees (Figure 5.3). Cocoa farming, when coupled with shade trees, provides significant ecological benefits, including carbon sequestration. These ecosystem services, however, are often undervalued in conventional agricultural systems. PES programmes that align the financial interests of farmers with the broader goal of sustainability would ensure that farmers are compensated for the long-term stewardship of their land, which might otherwise go unrecognised in conventional agricultural systems. Comments made to buttress this point include:

Farmers are more likely to adopt sustainable practices when they recognise tangible economic benefits, whether in the short or long term. One promising avenue is the carbon credit market, which farmers should be supported to access at the individual level. Some organisations, including Proforest, REDD+, and World Cocoa Foundation*, are already working to facilitate farmers' entry into this market. Farmers retain full discretion over how to utilise the funds.*

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Last year, some of these funds were allocated to district assemblies, and we anticipate further disbursements this year [RO06(E)].

This aligns with Vanlauwe and Dobermann (2020), who argued that incentive schemes such as payments for environmental services (PES) can provide important supplementary benefits, particularly during the early stages of SCIP adoption. Similarly, Bakali et al. (2023) found that both PES and input subsidies had a significant and positive impact on the uptake of conservation agriculture practices.

5.6.1.5 Tree tenure security for cocoa farmers

The establishment of clear legal frameworks to guarantee farmers' rights over planted and natural shade trees emerged as a major incentive that can promote the adoption of SCIPs in Ghana (Figure 5.3). Traditionally, naturally occurring trees (e.g., timber trees) on cocoa farms in Ghana are owned by the state. The Forestry Commission manages these trees, and farmers do not have full rights over them. A farmer indicated that:

When timber companies harvest trees, compensation is often paid to the state, not the farmers, leading to a lack of incentives for farmers to protect or plant trees [RO23(F)]

Tree tenure security for cocoa farmers, particularly for the sale of diversified products from shade trees, can provide a significant economic incentive for farmers to plant and maintain shade trees, knowing that they can benefit from the sale of the products derived from them. An expert from academia explained that:

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Shade trees on cocoa farms often provide a wide range of products, such as fruits, nuts, timber, medicine, and even honey. These products can diversify farmers' income streams, reducing their dependency on cocoa alone and improving their financial stability. For tree tenureship to work effectively, clear legal frameworks must be established to guarantee farmers' rights over shade trees [RO17(E)]

Thus, when tree tenure security is properly implemented, cocoa farmers will not only improve the sustainability of their farming practices but also gain additional financial incentives, which can drive the long-term adoption of SCIPs. These frameworks should outline how farmers can access, use, and sell the products from their trees, while ensuring that land tenure is secure. Supportive policies, such as access to markets for tree products, training in agroforestry techniques, and a fair price for tree products, can further encourage farmers to invest in shade trees.

5.6.2 Technical support as incentive for the adoption of sustainable cocoa intensification practices (SCIPs)

Technical support plays a critical role in facilitating the adoption of SCIPs by equipping farmers with the knowledge, skills, and technological resources necessary for effective implementation. It can transform the adoption of SCIPs from a theoretical concept into a practical, scalable, and inclusive reality, ensuring that cocoa farmers are well-equipped to navigate the complexities of sustainable intensification. Tailoring training programmes to specific local needs and agroecological conditions, incorporating gender-sensitive considerations in the development of new SCIP innovations, strategically situating

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demonstration plots within communities, and adopting clustered models to facilitate the collective adoption of capital-intensive SCIPs emerged from the TNA (Figure 5.3).

5.6.2.1 Contextualising training to specific local needs and agroecological conditions

Contextualised training programmes tailored to local agroecological conditions emerged from the TNA as holding the potential to enhance the relevance and applicability of SCIPs (Figure 5.3). Recognising the diverse environmental and socio-economic conditions across cocoa-producing regions, farmers (91%[n=20]) and experts (83%[n=15]) alike suggested that training initiatives should be tailored to address site-specific challenges. Comments made to buttress this point include:

All soils in Ghana are not the same. There are some places where certain practices will not be conducive. So, there is the need for site-specific research to determine which areas are appropriate for which practice so that recommendations will be based on such site-specific findings [RO31(F)]

Site-specific research is essential to tailor recommendations to the diverse agroecological conditions across Ghana's cocoa-growing regions. Current efforts from COCOBOD in this regard include distributing different insecticides to different communities to prevent pest resistance. More needs to be done. For instance, future research should assess the relative performance of the hybrid and the traditional varieties of cocoa in the various regions of Ghana to establish areas where the traditional varieties outperform the hybrid varieties. Establishing demonstration plots in each community would facilitate localised experimentation and knowledge dissemination [RO13(E)]

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Cocoa farming is highly influenced by local environmental factors such as soil type, climate, topography, and water availability. So, training programmes should be designed to address the particular agroecological context of the region, whether it's a high-rainfall area, a drought-prone zone, or a region with specific pest and disease pressures [RO26(E)].

By tailoring training programmes to address the unique challenges and opportunities in each region, farmers can receive relevant, practical advice that aligns with their specific farming conditions, which increases the likelihood of successful implementation. This is consistent with studies like Vanlauwe and Dobermann (2020), Piñeiro et al. (2020), and Jacobi et al. (2017) which emphasised the pivotal role of farmer training and tailored extension services as incentives for the adoption of agricultural innovation.

5.6.2.2 Demonstration plots in communities to serve as model farms to showcase best practices

One of the most effective technical support strategies that emerged from the analysis was the establishment of demonstration plots within farming communities (Figure 5.3). These plots could serve as practical learning sites where farmers can observe and engage with sustainable intensification techniques first-hand. By showcasing successful SCIP applications in real farming environments, demonstration plots would reinforce best practices and provide tangible validation of their benefits. A farmers indicated that:

Every district should have demonstration sites for clustered communities at central points that are easily accessible to these communities [RO04(F)].

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Farmers in this area observe that older cocoa varieties like Tetteh Quarshie and Amazonia outperform hybrid varieties, in terms of bean weight, establishment, and long-term yield stability. Hybrids struggle to establish, often producing flowers without setting pods, and even when successful, their yields decline significantly after four years. This suggests that hybrid performance is highly dependent on location, soil conditions, and management practices. Given Ghana's diverse soils, a site-specific research approach is necessary to determine the best-suited varieties, fertilisers, and farming practices for different regions. Establishing demonstration and experimental plots in each community would provide valuable insights into locally appropriate agrochemicals and inputs, ensuring that recommendations align with specific environmental conditions [RO29(F)].

For demonstration plots to be truly effective, they need to be well-managed, easily accessible, and adequately supported with follow-up training and resources. It's also important that farmers have the opportunity to be involved in the establishment and management of these plots, fostering a sense of ownership and commitment to the results. However, establishing demonstration plots in communities could be hindered by tenure complexities, as securing land for this initiative could be difficult.

5.6.2.3 Scalable plural adoption models that promote flexible cost-sharing implementation strategies

Recognising the financial constraints associated with adopting capital-intensive SCIPs, the development of scalable plural adoption models that promote flexible cost-sharing implementation strategies emerged as an important incentive to promote wide adoption (Figure

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5.3). Developing models for the plural adoption of labour- and capital-intensive practices, especially those that are expensive, would be a strategic way to increase the scalability and affordability of SCIPs amongst cocoa farmers. By leveraging collective efforts, farmers can share resources, reduce individual costs, and enhance their ability to adopt practices such as irrigation, precision farming, and other advanced agricultural technologies. Comments made to buttress this point include:

COCOBOD should find a way to group us into clusters and provide us with capital-intensive equipment like irrigation pipes, pumps, boreholes, sprayers, pruners, etc. COCOBOD can look for a convenient financial solution so that we can pay for the equipment from our producer price [RO22(F)].

Cocoa trees can bear fruits all year round. But they need water to produce pods. We can't afford the irrigation systems, the borehole or well, pipes, pumps etc. We saw the irrigation pilot of COCOBOD at Esaase. Their plot produces high yields all year round. We need COCOBOD to cluster us and connect us to financial institutions that can give affordable credit to purchase irrigation [RO12(F)].

This can be achieved by the clustering of close and continuous farms to allow farmers to collaborate and share labour- and capital-intensive resources. Another potentially promising approach would be leveraging cooperatives to develop group financing models for investments in costly agricultural technologies, such as irrigation systems or precision farming tools. Cooperatives can pool resources from individual farmers, providing them with access to financing that they may not be able to obtain individually.

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5.6.2.4 Gender-sensitive approaches that ensure inclusivity and equitable participation

Gender-sensitive approaches that ensure inclusivity and equitable participation in sustainable cocoa farming emerged as a major theme in the analysis (Figure 5.3). Many SCIPs are neither socially inclusive nor gender-sensitive. For example, critical tasks such as pruning, spraying, hand pollination, harvesting, and agrochemical application are largely performed by men due to their drudging nature. Similarly, pod breaking is predominantly a male-dominated activity. The preference for hiring male workers further reinforces gender disparities. Gender-sensitive innovations are crucial for ensuring that male and female cocoa farmers have equitable access to resources, opportunities, and decision-making processes and are both actively engaged in the adoption of SCIPs. To improve gender-sensitive approaches that ensure inclusivity and equitable participation, training programmes and technical assistance must be designed to be accessible and relevant to both men and women. Also, women farmers could be empowered through targeted training and support programmes. A respondent explained that:

A key innovation would be the provision of targeted training for women that builds their technical and leadership skills, specifically in practices that are often male-dominated, like pruning, spraying, and pod breaking. This can be achieved by providing separate women-only training sessions or by promoting gender-inclusive training that encourages both men and women to learn together, particularly in patriarchal communities where gender roles are tied to religious beliefs [RO32(E)].

Another key aspect is addressing workload imbalances and providing labour-saving technologies or practices that can help ease the burden on women, such as improved harvesting

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tools, efficient weeding methods, or mechanised spraying systems. Incorporating gender into the design of SCIPs should involve recognising that women often have different priorities and challenges compared to men, including their responsibilities in household management, child-care, and other non-farm tasks. A respondent indicated that:

Gender-sensitive innovations should include the creation of financing models that specifically target women farmers, such as microcredit programmes, group loans through cooperatives, or targeted grants for women-led farming initiatives. These financial support mechanisms can help women invest in the labour-intensive male-dominated activities that are essential for cocoa productivity and sustainability [RO10(E)].

5.6.4 Social and cultural incentives for the adoption of sustainable cocoa intensification practices (SCIPs)

Live demonstrations of SCIPs implementation and benefits during cultural and religious gatherings, along with targeted education and awareness campaigns, emerged from the TNA as pivotal socio-cultural incentives for driving the adoption of SCIPs in Ghana (Figure 5.3). This approach would foster acceptance, reduce resistance to change, and strengthen community buy-in. Religious ceremonies, local festivals, and cultural gatherings provide a platform to engage farmers within their social and cultural contexts. Demonstrating the application and benefits of specific SCIPs at these events through community-based learning and shared experiences can reinforce the perception that sustainable farming aligns with traditional agricultural practices rather than introducing foreign concepts. Comments made to buttress this point include:

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When sustainable cocoa practices are displayed at cultural and religious gatherings, they can become more than just agricultural techniques. They will transform into shared community values. By aligning SCIPs with deeply rooted traditions, we can create a natural pathway for acceptance, ensuring that sustainability is not seen as an external imposition but as an integral part of local identity and progress [RO17(E)].

Religious and cultural leaders, who often hold considerable influence, can play a pivotal role in endorsing SCIPs and reinforcing their importance through sermons, speeches, or symbolic rituals. A respondent explained that:

Cooperative leaders, chief farmers, rich farmers, MPs, and opinion leaders must be involved in training, since farmers listen to their local leaders, especially in the Muslim communities [RO38(F)]

One area where this information instrument can be helpful is in shaping farmers' perceptions and responses to challenges in cocoa farming, particularly in pest and disease management. It emerged from the discourse that religious and spiritual interpretations of disease outbreaks often influence farmers' decisions regarding the choice of treatment remedy. Farmers who perceive the incidence of pests and diseases to be caused by gods or enemies often seek spiritual interventions, believing that supernatural forces dictate the health of their farms, instead of relying on scientifically proven pest control and disease management techniques. Some district extension coordinators indicated that:

During a field visit to a cocoa farm located near an area severely affected by CSSVD, a striking observation was made. The farmer had placed posters of Adom Kyei Dua, a well-known

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spiritual leader, on several cocoa trees. This practice stemmed from the belief that the presence of these spiritual symbols could shield the farm from diseases, acting as a form of divine protection [RO01(E)].

Some farmers resort to sprinkling traditional herbal concoctions on trees, convinced that these practices would ward off pests and diseases. So, education is needed for farmers to understand the scientific causes and treatments of cocoa pests and disease, so they understand that libations and sacrifices are inadequate in effectively controlling pests and diseases [RO14(E)].

Education is needed to sensitise farmers about the real causes of disease and scientific solutions. Laws cannot work because these are people's belief systems. So, education is what can change minds [RO37 (F)].

Educational initiatives should not merely dismiss religious beliefs but rather work within cultural contexts to provide farmers with alternative, science-based solutions that align with their worldviews. This could involve collaborating with religious leaders to integrate messages about sustainable cocoa farming into sermons and community gatherings. By positioning scientific knowledge as complementary rather than antagonistic to spiritual beliefs, a gradual shift in perceptions can be fostered to encourage the adoption of effective disease control methods.

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CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

This chapter concludes the thesis report and is made up of five sections. Section 6.2 presents a summary of the entire study with regard to the problem statement, objectives and methods used for the study. A summary of the results for the four objectives of this study is also presented under this section. Section 6.3 presents the conclusions of the study. Section 6.4 presents a summary of the key policy recommendations arising from the study. The limitations of the study and suggestions for further research are presented in sections 6.5 and 6.6 respectively.

6.2 Summary of the Study

Ghana, the world's second-largest cocoa producer, continues to face persistently low productivity which perpetuates rural poverty, with nearly 30% of cocoa farmers living below the extreme poverty line. Efforts to boost productivity through intensification are hindered by high input costs, limiting farmers' ability to adhere to recommended agrochemical regimes. While government interventions such as COCOBOD's Productivity Enhancement Programmes provide subsidised inputs, inefficiencies in distribution force many farmers to depend on costly, often unapproved market alternatives, inflating production costs, eroding incomes, and discouraging reinvestment. As a result, extensification, which is expanding area under cocoa cultivation into forest reserves, has emerged as a coping strategy, intensifying deforestation and attracting international concern. In response, a shift towards sustainable intensification, aimed at optimising resource efficiency, has been widely advocated. However, adoption of SCIPs in Ghana remains fragmented. Existing studies largely focus on isolated

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practices, overlooking the synergistic benefits of adopting multiple SCIPs concurrently. Moreover, the socio-economic, institutional, and agroecological drivers of SCIPs adoption are insufficiently understood, resulting in fragmented, poorly coordinated interventions. Evidence is also lacking on the design of effective incentive structures to support widespread adoption. Finally, the broader welfare implications of SCIPs, particularly for food security, remain underexplored. This study addresses these critical gaps by assessing the level of adoption of multiple SCIPs among cocoa farmers in Ghana, identifying key determinants of adoption, estimating their effects on productivity, farm income, and food security, and analysing potential incentive mechanisms to facilitate widespread uptake.

A four-stage sampling approach was used to select 739 cocoa farming households across 20 communities in six major cocoa-producing regions of Ghana. Data for the 2022/2023 production season was collected using a structured questionnaire. To assess the level of SCIPs adoption, a five-step estimation procedure was employed to construct separate composite indices for intensification and sustainability for each plot in the study sample. These steps included the normalisation, weighting and aggregation of estimated indicators that were selected based on the SAFA and SIAF frameworks as well as insights from previous studies. The resulting indices enabled the classification of cocoa plots into four farm typologies: (1) Conventional cocoa plots that were neither sustainable nor intensified (NSNI), (2) Plots that were sustainable but not intensified (SNI), (3) Plot that were intensified but not sustainable (INS), and (4) Plot that were sustainably intensified (SI). Determinants of the bundled adoption of multiple SCIPs were analysed using a Multivariate Probit (MVP) model, which accounts for interdependencies amongst adoption decisions. The Multinomial Logit (MNL) model was further applied to examine the drivers of sustainable intensification, with the NSNI typology

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serving as the reference category. The effects of SCIPs adoption on cocoa yield, cocoa farm income and household food security were estimated using the MESR model, which compared outcomes across different adoption statuses (i.e. NSNI, SNI, INS, and SI). Cocoa yield was measured as the output of dried beans sold per plot in tonnes per hectare (t/ha). Cocoa income was calculated as cocoa revenue plus the value of subsidies received, minus the total variable cost of production, with all estimates normalised by plot size (hectares). Household food security was measured using three validated indices: HFIAS, HFCS, and rCSI. Finally, TNA was employed to analyse incentive mechanisms for scaling the adoption of SCIPs, drawing on multi-stakeholder consultations with cocoa farmers, extension officers, agricultural researchers, and industry representatives.

6.2.1 Sustainable intensification practices adopted by cocoa farmers in Ghana

The adoption of SCIPs among cocoa farmers varied considerably across regions. Improved cocoa varieties were widely adopted, particularly in Western North and Eastern regions, while Bono and Bono East recorded the lowest uptake. Hand weeding, together with the removal of chupons, mosses, and mistletoes, were widely practised, often multiple times per season. Intercropping stood out as a widely adopted practice, with nearly 90% of farmers integrating food crops into their cocoa farms. Approximately, 40% of farmers maintained the recommended shade tree density, with Western North and Eastern regions leading in this practice.

In contrast, several SCIPs remained underutilised. Pruning adoption remained low, with Ahafo and Western North reporting the highest rates and Bono East recording the largest share of non-adopters. Inorganic fertiliser use was modest, with higher adoption in Eastern and Ahafo

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and limited uptake in Bono and Bono East. Organic fertiliser application was even less prevalent, though relatively more common in Eastern and Ahafo. More than half of farmers did not apply insecticides or fungicides, with Western North and Eastern regions recording the highest usage and Ahafo the lowest. Adoption of organic pesticides and hand pollination was minimal, likely due to their labour-intensive nature. Cocoa tree renovation was practised by fewer than a third of farmers, and mulching remained uncommon, aside from relatively higher adoption in Eastern and Ahafo. Similarly, water harvesting was scarcely implemented, while the use of personal protective equipment (PPE) was limited, with Eastern and Ahafo recording the highest uptake.

6.2.2 Objective one: The level of adoption of sustainable cocoa intensification practices in Ghana

The intensification index recorded a mean value of 0.284, indicating generally low levels of intensification, while the sustainability index had a mean of 0.451, also reflecting low sustainability levels. Plot-level classification showed that 58.25% of plots were neither sustainable nor intensified (NSNI), 29.45% were sustainable but not intensified (SNI), 5.39% were intensified but not sustainable (INS), and 6.90% were sustainably intensified (SI). These results demonstrate that the overall extent of SCIP adoption on cocoa plots in Ghana remains low, with relatively few plots achieving a balance between intensification and sustainability.

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6.2.3 Objective two: Factors that influence the adoption of sustainable cocoa intensification practices by farmers in Ghana

The results presented under Objective Two provide strong evidence that household, farm-level, and institutional characteristics significantly influence the adoption of multiple SCIPs in Ghana. Specifically, the Multivariate Probit regression revealed significant complementarities among SCIPs, with the adoption of one practice often increasing the likelihood of adopting another. Strong associations were observed between hand pollination and farm sanitation ($\rho = 0.347$, $p < 0.001$), between inorganic and organic fertilisers ($\rho = 0.781$, $p < 0.001$), and between inorganic fungicides and insecticides ($\rho = 0.592$, $p < 0.001$). Plot ownership significantly increased the likelihood of adopting improved varieties (53.5%), organic pesticides (63.9%), and inorganic fertilisers (50.6%). Flat topography was positively associated with the adoption of improved varieties and sanitation practices, whereas longer walking distances to farms reduced the uptake of fertilisers, insecticides, fungicides, cocoa tree renovation, and sanitation practices. Farmers exposed to drought risk were more likely to adopt hand pollination and sanitation practices but less likely to adopt organic fertilisers and shade tree planting. Poor perceptions of soil fertility increased the likelihood of adopting improved varieties and inorganic fertilisers. Participation in training significantly enhanced adoption across a wide range of practices, while positive perceptions of extension services increased the uptake of improved varieties, shade trees, and both inorganic and organic inputs. Access to credit facilitated the adoption of organic fertilisers and hand pollination, whereas input subsidies strongly influenced adoption patterns, with fertiliser subsidies promoting shade tree planting, hand pollination, and fertiliser use, and insecticide subsidies increasing the uptake of insecticides, fungicides, sanitation, and fertilisers. Household asset holdings significantly

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enhanced the adoption of sanitation practices, shade trees, organic pesticides, organic fertilisers, hand pollination, insecticides, and cocoa tree renovation. In contrast, farming experience was negatively associated with the adoption of shade tree planting, sanitation practices, and hand pollination.

Likewise, extension services significantly influenced sustainable intensification, with each additional contact with an extension agent increasing the probability of a plot being sustainably intensified by 7.01 percentage points. Residential status also played an important role, as being a native of the community where the cocoa plot is located was associated with a 15.68 percentage point increase in the likelihood of achieving sustainable intensification. Access to credit, participation in training programmes, and household size further enhanced the probability of sustainable intensification. In contrast, farmers who reported religious constraints on agricultural decision-making were 9.25 percentage points less likely to achieve sustainable intensification, while farmers operating in the agroecological transition zone were 5.17 percentage points less likely to sustainably intensify their cocoa plots ($p = 0.026$).

These findings directly contradict the null hypothesis (H_0), which posited that household, farm-level, and institutional characteristics have no effect on the adoption of multiple SCIPs. On the contrary, the findings of this study reveal that these characteristics exert substantial effects on adoption patterns, both individually and interactively. Consequently, the null hypothesis is rejected in favour of the alternative, which asserts that household, farm-level, and institutional factors significantly affect adoption behaviour.

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6.2.4 Objective three: Effects of sustainable cocoa intensification practice (SCIPs) adoption on cocoa yield, farm income, and household food security in Ghanaian cocoa farming households

The results under Objective Three provide strong evidence that the adoption of SCIPs significantly affects cocoa yield, farm income, and household food security.

6.2.4.1 Effects of SCIPs adoption on cocoa yield

The adoption of SCIPs significantly improved cocoa yields across all plot typologies. Plots categorised as Sustainable but Not Intensified (SNI) and Intensified but Not Sustainable (INS) recorded Average Treatment Effects on the Treated (ATT) of 21.58 kg/ha (4.9%) and 115.01 kg/ha (33.95%), respectively. Sustainably Intensified (SI) plots achieved the highest yield improvement, with an ATT of 223.86 kg/ha, representing a 34.0% increase. Counterfactual analysis indicated that transitioning plots from the Neither Sustainable nor Intensified (NSNI) category to SNI, INS, and SI would increase yields by 92.90 kg/ha (34.17%), 180.26 kg/ha (66.31%), and 407.65 kg/ha (149.97%), respectively.

6.2.4.2 Effects of SCIPs adoption on cocoa farm income

The effect of adopting SCIPs on farm income varied across typologies. Farmers in the Sustainable but Not Intensified (SNI) category gained GHS 306.87 (9.40%), while those in the Intensified but Not Sustainable (INS) group incurred a loss of GHS 392.62 (25.80%). The Sustainably Intensified (SI) typology recorded the highest gains, with an increase of GHS 1,325.49 (34.12%). Counterfactual analysis showed that transitioning households from the Neither Sustainable nor Intensified (NSNI) group to SNI, INS, and SI would have changed

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incomes by GHS 620.21 (27.06%), –GHS 741.82 (32.37%), and GHS 1,332.94 (58.15%), respectively.

6.4.2.3 Effects of SCIPs adoption on household food security

The adoption of SCIPs significantly influenced household food security across typologies. Based on the HFIAS, food insecurity declined by 26.67% for Sustainable but Not Intensified (SNI) households, 16.98% for Intensified but Not Sustainable (INS), and 52.78% for Sustainably Intensified (SI) farmers. A transition from the Neither Sustainable nor Intensified (NSNI) category to SI, however, increased food insecurity by 63.46%. The HFCS improved by 29.27% for SNI, 14.91% for INS, and 50.35% for SI adopters, while transitions from NSNI reduced HFCS by 2.87%, 4.99%, and 5.78% for SNI, INS, and SI, respectively. The rCSI indicated a decline in reliance on food-related coping mechanisms by 35.02% for SNI, 13.92% for INS, and 62.87% for SI adopters. In contrast, transitions from NSNI to SNI reduced rCSI by only 0.08%, whereas transitions to INS and SI increased it by 2.64% and 11.27%, respectively.

These findings directly contradict the null hypothesis (H_0), which posited that the adoption of multiple SCIPs has no effect on yield, income, or food security outcomes. On the contrary, the results demonstrate that SCIP adoption exerts significant and differentiated effects on farmer livelihoods. Accordingly, the null hypothesis is rejected, supporting the conclusion that SIPs play a critical role in enhancing both the productivity and welfare of cocoa-farming households in Ghana.

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6.2.5 Objective four: Incentives for motivating cocoa farmers to adopt sustainable cocoa intensification practices (SCIPs)

The TNA identified three categories of incentives influencing the adoption of SCIPs in Ghana: Market-Based/Economic, Technical Support, and Social/Cultural.

Economic incentives included commensurate increases in the cocoa producer price, expansion of premium pricing for sustainably produced cocoa at the community level, timely and efficient distribution of subsidised inputs through depoliticised cooperative channels, reinstatement of certified input shops with regulated sales, and annual payments for ecosystem services (PES) to incentivise shade tree management.

Technical support incentives included contextualised training programmes tailored to specific agroecological conditions, strategically located and well-managed demonstration plots with follow-up training, and scalable pluralistic adoption models incorporating flexible cost-sharing strategies for labour- and capital-intensive SCIPs.

The findings demonstrate that current SCIPs are not gender-sensitive, as labour-intensive and technically demanding activities remain male-dominated. This exclusion perpetuates gender disparities in access to resources, decision-making, and participation, thereby constraining the equitable adoption and benefits of SCIPs.

Social and cultural incentives included live demonstrations of SCIP benefits during cultural and religious gatherings, culturally sensitive SCIP education and awareness campaigns, and the involvement of respected community leaders such as religious leaders, chief farmers, cooperative heads, and opinion leaders.

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6.3 Conclusions of the Study

Firstly, the study identified the SCIPs adopted by farmers in Ghana and analysed the level of adoption of these practices on cocoa plots examined the adoption of SCIPs among farmers in Ghana and found marked variation across practices and regions. Adoption of improved varieties, intercropping, and shade tree maintenance is relatively widespread, whereas labour- and input-intensive practices—including pruning, fertiliser application, hand pollination, mulching, use of organic pesticides, PPE, and cocoa tree renovation—remain very limited. Regional disparities further compound this unevenness, with Bono and Bono East recording the lowest adoption rates across several core practices. These findings underscore the need for targeted, context-specific interventions to promote broader uptake of sustainable intensification strategies. The level of adoption of SCIPs on cocoa plots in Ghana is low, with the majority of cocoa farm plots classified as neither intensified nor sustainable. This underscores the need for stronger and more coordinated efforts to promote balanced integration of both intensification and sustainability strategies.

Secondly, the study examined the factors influencing the adoption of SCIPs in Ghana and found that adoption patterns are highly interdependent, with practices such as hand pollination, farm sanitation, fertiliser application, and pest control reinforcing one another. This implies that, for instance, promoting the adoption of hand pollination can drive the adoption of farm sanitation practices, fertiliser application, and pest control measures. Adoption was positively associated with plot ownership, favourable topography, perceived soil fertility, training participation, access to extension services, credit, input subsidies, and household farm assets. In contrast, long walking distances to farms, exposure to drought risk, and greater farming experience reduced adoption likelihood. The attainment of sustainable intensification was

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further facilitated by access to extension and training services, credit, household labour availability, and being a native resident of the community, while restrictive religious beliefs and farming in the agroecological transition zone constrained adoption.

Thirdly, the study examined the effects of adopting SCIPs on cocoa yield, farm income, and household food security in Ghana. The findings demonstrate that while intensification alone improves yields, its integration with sustainability practices delivers the greatest gains, reinforcing the importance of promoting sustainable intensification for sectoral productivity. In terms of income, sustainable intensification offers the most effective pathway to financial improvement, whereas intensification without sustainability leads to income losses. This underscores the necessity of policies and interventions that prioritise a holistic approach. Household food security also improves most significantly when sustainability and intensification are combined; however, transitions from non-adoption to adoption can initially reduce food security, highlighting notable short-term adaptation burdens, and the need for targeted incentive mechanisms to mitigate initial food security disruptions and ensure a smoother pathway to long-term adoption. This underscores the need for economic incentives that must outweigh the adoption costs, or at least cover the opportunity costs associated with changing production methods for farmers to smoothly transition to the desired practice.

Finally, the study examined potential incentives for scaling the adoption of SCIPs in Ghana and found that adoption is shaped by interconnected economic, technical, and sociocultural drivers. Tangible economic incentives—including producer price adjustments, premium payments at the farm gate, tree tenure security, and payments for ecosystem services—are critical to supporting uptake, particularly during the transition phase. Technical incentives, such as locally tailored training and strategically located demonstration plots, play a pivotal

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role in strengthening adoption capacity. At the same time, social and cultural incentives, including aligning SCIPs with traditional values and the involvement of respected community leaders, enhance community acceptance and legitimacy, thereby facilitating widespread adoption. Mainstreaming gender considerations into SCIP design and implementation by promoting inclusive training programmes, labour-saving technologies, and targeted financial mechanisms for women farmers would enhance equitable participation, strengthen women's technical and leadership capacity, and ensure that the productivity and sustainability benefits of SCIPs are shared across genders.

6.4 Recommendations

1. COCOBOD, in collaboration with MoFA, research institutions, and development partners, should implement region-specific interventions to promote underutilised SCIPs. Policy efforts must prioritise balanced adoption of both intensification and sustainability strategies, with particular attention to Bono and Bono East, where uptake remains notably low.
2. MoFA and COCOBOD, through CHED, must enhance agricultural extension services and input support systems, particularly for experienced farmers and those in the transition zone. This effort must focus on improving farmers' perceptions of extension services and demonstrating their practical value.
3. Given the demonstrated benefits of SCIPs in improving cocoa yield, farm income, and household food security, COCOBOD, MoFA, and their partners must prioritise widespread promotion and support of these practices as a proven pathway to sectoral productivity and household welfare enhancement.

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4. Since the shift from non-adoption to SCIPs is associated with short-term declines in household food security, the Government of Ghana, through MoFA and COCOBOD, must design cocoa-specific incentive mechanisms to support farmer in the transition phase of adoption. These may include sustainability-based farmgate price premiums, payments for ecosystem services, and secure tree tenure rights enabling farmers to legally benefit from shade tree products. Revising tree tenure laws to explicitly grant farmers ownership rights over shade trees they plant or maintain is essential to providing supplementary income during the transition phase.
5. COCOBOD must work with stakeholders to maintain fair producer pricing and encourage the strategic clustering of contiguous farms to enable collaborative arrangements. Such clustering would facilitate the shared use of labour- and capital-intensive inputs, while farmer cooperatives could be leveraged to develop group-based financing mechanisms to improve access to high-cost technologies.
6. The findings demonstrate that SCIPs are not gender-sensitive, as labour-intensive and technically demanding activities remain male-dominated. This exclusion perpetuates gender disparities in access to resources, decision-making, and participation, thereby constraining the equitable adoption and benefits of SCIPs. Policymakers and development partners should mainstream gender considerations into SCIP design and implementation by promoting inclusive training programmes, labour-saving technologies, and targeted financial mechanisms for women farmers.

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6.5 Limitations of the Study

This study employed cross-sectional data, which is inherently limited in its ability to capture the dynamic and temporal evolution of cocoa farming practices and the adoption trajectory of SCIPs over time. As a result, the analysis cannot robustly infer causality or assess the long-term impacts of the adoption of SCIPs on agronomic performance and household welfare outcomes. Moreover, while the food security indicators utilised, namely the HFIAS, HFCS, and rCSI, are widely recognised and empirically validated, they do not fully encompass the six comprehensive dimensions of food security. In particular, dimensions such as stability, agency, and sustainability are only partially captured. Consequently, the findings may not wholly reflect the complex and evolving food security experiences of cocoa-growing households, particularly in relation to the long-term implications of the adoption of SCIPs.

6.6 Suggestions for Future Research

- Future research should utilise longitudinal studies to assess the long-term effects of SCIPs on cocoa yield, farm profitability, and household food security under varying incentive structures.
- Future research should examine the role of digital innovations in facilitating the adoption of SCIPs, with particular focus on the potential of precision agriculture and mobile-based advisory services to enhance decision-making and efficiency.
- Future research could employ choice experiments to empirically assess the interaction effects amongst economic, technical, regulatory, and socio-cultural incentives, with a

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view to identifying optimal combinations that capture farmers' preferences and trade-offs, thereby guiding strategies for the widespread adoption of SCIPs.

- Future research could explore how cooperative-led financing, public–private partnerships, and concessional loan schemes can be leveraged to create cost-sharing models for capital-intensive SCIPs, such as irrigation and precision agriculture, to reduce financial barriers for farmers.



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APPENDICES

APPENDIX 1: QUESTIONNAIRE FOR HOUSEHOLD SURVEY

EFFECTS OF THE ADOPTION OF SUSTAINABLE INTENSIFICATION PRACTICES ON THE YIELD AND FOOD SECURITY OF COCOA FARMING HOUSEHOLDS IN GHANA

Consent Form

My name is _____. I am from the Department of Agricultural Economics and Agribusiness at the University of Ghana. I am collecting data for a research study to see how the sustainable cocoa intensification practices are adopted and the impact of adoption on productivity, farm income and food security. You have been chosen randomly as one of the participants for this study. It is expected that the results from this survey will help the Ghanaian government and other stakeholders in the cocoa sector to fashion out policies, strategies and programmes that improve the lives of cocoa farmers. If you agree to participate in this study, I will ask you many detailed questions about your household and farming activities.

You are free to refuse to answer any of the questions that may make you uncomfortable and you also have the option to end the interview at any time. You can stop me at any time to clarify the questions or ask me to repeat something if you don't understand. I would like you to know that your participation is greatly appreciated. Your participation in this study will not affect you in anyway as the study is solely for research purposes. Your name and any other identifying information will be accessible only to the researchers and will never appear in any sort of report that might be published.

Do you agree to participate in the study? Yes_____ No _____

Signature (or thumbprint) _____ Date: _____

Signature of the Enumerator: _____ Date: _____

Date of interview: _____ Code: _____ Region: _____

District: _____. Community: _____

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Section A: Household Socioeconomic Characteristics

A1. Detailed household membership information (***members living together and eating from the same pot regularly, including those temporarily absent***)

Member code	Name of Household member	Relation of (Name) to household head **(Code A)**	Sex **(0= female, 1= male)**	Age **(years)**	Residential status (1=indigene, 2=migrant)	Literacy level in English **(Code B)**	Highest education completed **(in years of schooling)**	Do you have any disability* ? **(1=Yes, 0=No)**	Type of disability **(Code C)**	Membership of farmer-based group **(1=Yes, 0=No)** ***If NO, skip to next column***	Type of farmer-based group **(Code D)**
1	Programmer and enumerator: ***[start with household head]***										
2	Programmer and enumerator: First ask for number of people living in household. If 1, skip to B1			***Skip to next column.***							
3											

****A person with disability (PWD) is someone who has a physical, mental, intellectual or sensory impairment, which in interaction with various barriers, may hinder their full and effective participation in society on an equal basis with others (UN, 2006).***

Code A: 0= Self, 1= Husband/wife, 2= Son/daughter/adopted child, 3= Father/mother, 4= Sister/brother, 5=Grandchild, 6=Grandparent, 7=Mother/father-in-law, 8=Daughter/son-in-law, 9=Sister/brother-in-law, 10=Other relative, 11=Not related, 12=Other, specify_____

Code B: 0=Do not read and write, 1=Read only, 2=Read and write

Code C (Select all the applied): 1=Sight, 2=Hearing, 3=Speech, 4=Physical, 5=Mental, 6= Other, specify _____

Codes D (Select all the applied): 0= Cocoa farmer association, 1= Women's Association, 2= Youth Association, 3=Savings and credit group (including VSLAs and merry-go-rounds), 4= Mutual help and insurance groups/Funeral association, 6= Other, specify _____

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Functions of group **Code E**	Role in the group **(Code F)**	Do you have a religious affiliation? (**1=Yes, 0=No)**	Type of religious affiliation (**Code G)**	Have you ever sought guidance from religious leaders on decisions relating to cocoa production? (**1=Yes, 0=No)**	If a new technology was introduced that conflicted with your religious beliefs, would you adopt it? (**1=Yes, 0=No)**

Codes E (Select all the applied): 1=Sale of cocoa beans, 2=Input supply, 3=Savings and credit, 4=Sharing of information on good agronomic practices, 5=Cocoa insurance, 6=Cocoa farmer pension, 7=Cocoa intensification and sustainability, 8=Social welfare, 9= Other, specify _____
Codes F: 0= Executive member, 1=X-official, 2=Active member, 3=Passive member
Code G: 1=Christian, 2=Muslim, 3=Traditional, 4=Other, specify

SECTION B: FARM CHARACTERISTICS

B1. Household plot roster and adoption of sustainable intensification practices

Instruction: Kindly provide the following information for **cocoa plot this household manages, starting with the largest plot.**
Programmer: Design questionnaire for <u>TWO MAJOR</u> cocoa plots belonging to each household

A	B	C	D	E	F	G
What was the total number of cocoa plots managed by this household during the 2022/2023 season (**Number**)	Plot No.	Plot name (**Enumerator: Use name of location. If same location, distinguish name with _1, _2, etc**)	Who in the household is the main decisionmaker for this [plot]? **(Programmer: Populate answers using Member names Enumerator: ask to interview this person)**	How many years has [household member] been involved in cocoa farming? (**Number**)	What is the average number of days [household member] worked on [plot name]? (**Number**)	What is the average number of hours per day worked by [household member] on [plot name]? (**Number**)

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»»»»»»»»Continuation of household plot roster and adoption of sustainable intensification practices

H	I	J	K	L	M	N
What is the size of [plot name]? (**Number**)	Unit **(Code A)**	What is the walking distance from home to [plot name] in minutes? (**Number**)	What is the quality of the soil fertility on [plot name]? **(Code B)**	What is the topography of [plot name]? **(Code C)**	How prone to drought is [plot name]? **Code D**	How prone to flood is [plot name]? **Code D**

Code A: 0= acres, 1= hectares, 2= poles, 3=Square meters (25X25), 4= Square meters (36X36), 5=Small ropes, 6=Big ropes, 7= Other, specify__
Code B: 0=Very poor, 1=Poor, 2=Fair, 3=Good, 4=Very good
Code C: 0=On a hill, 1=part hill, part sloped, 2= On a slope, 3=part sloped, part flat, 4=Flat
Code D: 0= Extremely, 1= Very, 2=Average, 3= Somewhat, 4= Not at all

»»»»»»»»Continuation of household plot roster and adoption of sustainable intensification practices

	OWNED	**SHARECROPPED**			
O	P	Q	R	S	T
What was the household land right status of [plot] during the 2022/2023 season? **(Code E)** If 0 or 1, go to P If 3 go to Q ***If 2,4, or 5, skip to R***	What is the legal status of [Plot]? (**Code F**)	For the 2022/2023 season, what was the percentage of sales of dried cocoa beans that you paid the landowner as part of the share cropping agreement? **(Code G)**	What was the approximate number of cocoa trees on [Plot Name] during the agricultural season 2022/2023? (**Code I**)	What is the average age of cocoa trees on [Plot Name] in years? **Enumerator: Use the average age that represents majority of the trees** (**Age in years**)	Please list all the cocoa tree varieties on [plot] during the agricultural season 2022/2023? **(Code H)**

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Code E: 0= Freehold/ purchased, 1= Inheritance/gifted, 2= rented for cash or in kind from other households, 3= Sharecropping, 4= Trusteeship/family/ used free of charge, 5=Squatting, 6=Others, specify_____
Code F: 1=Complete legal documentation, 2=Partial legal documentation, 3=Now processing, 4=No documentation
Code G: 0=50% (Abunu), 1=33.3% (Abusa), 2=25% (Abunan), 3=Other, specify
Code H (Select all the applied): 1= Amelonado (Tetteh Quarshie), 2=Amazonia, 3=Criollo, 4=Trinitario (Violet pod), 5=Amazonian hybrid (Akokora bedi), 6=non-Amazonian hybrid (Abrewa bedi), 7= Other, specify
Code I: 1=Less than 500 trees, 2=500-1000 trees, 3=1001-1500 trees, 4=1501-2000 trees, 5=2001-2500 trees, 6=2501-3000 trees, 7=More than 3000 trees, 8= Other, specify

»»»»»»»»»Continuation of household plot roster and adoption of sustainable intensification practices

U	V	W	X	Y	Z
Did you or your household prune cocoa trees on [Plot Name] during the agricultural season 2022/2023? **(1=Yes, 2=No)** **If NO, skip to W**	What was the approximate number of times cocoa trees on [Plot Name] were pruned during the agricultural season 2022/2023? (**Number**)	Did you or your household practice hand weeding on [Plot Name] during the agricultural season 2022/2023? **(1=Yes, 2=No)** **If NO, skip to Y**	What was the approximate number of times hand weeding was done on [Plot Name] during the agricultural season 2022/2023? (**Number**)	Did you or your household remove chupons, mosses and mistletoes on [Plot Name] during the agricultural season 2022/2023? **(1=Yes, 2=No)** **If NO, skip to U_A**	What was the approximate number of times chupons, mosses and mistletoes were removed on [Plot Name] during the agricultural season 2022/2023? (**Number**)

»»»»»»»»»Continuation of household plot roster and adoption of sustainable intensification practices

U_A	V_A	W_A	X_A	Y_A	Z_A

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Did [Plot Name] have any shade tree during the agricultural season 2022/2023? **(1=Yes, 2=No)** **If NO, skip to X_A**	What was the approximate number of shade trees on [Plot Name] during the agricultural season 2022/2023? (**Number**)	Please list all the shade trees on [plot] during the agricultural season 2022/2023? **(Code A)**	Did you or your household practice mulching (*proka*) on [Plot Name] during the agricultural season 2022/2023? **(1=Yes, 2=No)** **If NO, skip to AA**	Please list all the mulching materials used on [plot] during the agricultural season 2022/2023? **(Code B)**	What was the approximate number of cocoa trees mulched on [Plot Name] during the agricultural season 2022/2023? (**Number**)

Code A (Select all the applied): 1=*Milicia excelsa* (African teak or Iroko or Odum), 2=*Terminalia ivorensis* (Black Afara or Emeri), 3=*Terminalia superba* (African limba wood or Ofram), 4=*Triplochiton scleroxylon* (African White wood or Wawa), 5=*Musanga cecropioides* (Corkwood or Odwuma or Oduma), 6=*Ficus exasperata* (Sandpaper tree or Nyankyerene), 7=*Spathodea campanulata* (African Tulip tree or Kokonsu), 8=*Ricinodendron heudelotii* (Cocoa's friend or Wama), 9=*Mangifera indica* (Mango), 10=*Newbouldia laevis* (Sesemasa), 11=*Inga edulis* (ice-cream bean), 12=*Gliricidia sp.* (mother of cocoa or madre), 13=*Alstonia boonei* (Cheese wood or Nyame dua), 14=*Cedrela odorata* (Cedar tree), 15=*Cola nitida* (Kola tree or Bisi dua), 16=*Khaya ivorensis* (African mahogany or Odupon), 17=Other, specify ___

Code B (Select all the applied): 1=Cocoa pod husk, 2=Cocoa pulp, 3=Other crop residue, 4=Sawdust, 5=Polythene, 6=Stones, 7= Other, specify _

»»»»»»»»Continuation of household roster and adoption of sustainable intensification practices

AA		AA_COST	BB	CC	CC_COST
Did you or your household practice hand pollination on [Plot Name] during the agricultural season 2022/2023? **(1=Yes, 2=No)** **If NO, skip to BB**	What approximate number of cocoa trees were hand pollinated on [Plot Name] during the agricultural season 2022/2023? (**Number**)	What was the associated cost in GHC (if any)? **(Programmer: this question is optional**) **(Amount in GHC)**	Did you or your household harvest water for work on [Plot Name] during the agricultural season 2022/2023? (**1=Yes, 2=No**) If **NO**, skip to **DD**	How did you or your household harvest water for work on [Plot Name] during the agricultural season 2022/2023? **(Code A)**	What was the associated cost in GHC (if any)? **(Amount in GHC)** **(*Optional response*)**

Code A (Select all the applied): 1=Used a Poly tank, 2=Used a storage drum, 3=Built a concrete tank, 4= Constructed an underground tank, 5=rooftop rain harvesting, 6=diverted a stream, 7=Channelled a river, 8=Other, specify_____

»»»»»»»»Continuation of household plot roster and adoption of sustainable intensification practices

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DD	EE	FF	FF_COST	GG
Was [Plot Name] irrigated anytime during the agricultural season 2022/2023? (**1=Yes, 2=No**) If **NO**, skip to **GG**	How did you or your household irrigate [Plot Name] during the agricultural season 2022/2023? **(Code A)**	Approximately, what percent of [Plot Name] was irrigated during the agricultural season 2022/2023? **(Code B)**	What was the associated cost in GHC (if any)? **(Amount in GHC)** (***Optional response***)	Did you or your household drain [Plot Name] during the agricultural season 2022/2023? (**1=Yes, 2=No**) If **NO**, skip to **II**

Code A (Select all the applied): 1=Use of Voltic bottle/gallon, 2= Use of bucket and cup, 3=diverted a stream, 4=Use of hand pump, 5=Use of treadle pump, 6=Use of motor pump, 7=Use of sprinkler, 8=Use of solar pump, 9=Other, specify_____
Code B: 1= Entire Plot (100%), 2= Three Quarters (75%), 3= Two Thirds (66%), 4=Half (50%), 5= One Third (33%), 6= One Quarter (25%), 7=Other, specify

»»»»»»»»»Continuation of household plot roster and adoption of sustainable intensification practices

HH	HH_COST	II	JJ	KK	LL	MM
How did you or your household drain [Plot Name] during the agricultural season 2022/2023? (**Code A**)	What was the associated cost in GHC (if any)? **(Amount in GHC)** (***Optional response***)	Was there a need to rehabilitate [Plot Name] during the agricultural season 2022/2023 because it was old or moribund? (**1=Yes, 2=No**) If **NO**, skip to **MM**	Did you or your household rehabilitate [Plot Name] during the agricultural season 2022/2023 because it was old or moribund? (**1=Yes, 2=No**) If **NO**, skip to **MM**	Did you or your household receive compensation for cutting down old and moribund cocoa farm? (**1=Yes, 2=No**) If **NO**, skip to **MM**	How much did you or your household receive as compensation in GHC? (**Amount in GHC**)	Did you or your household renovate old cocoa trees on [Plot Name] during the agricultural season 2022/2023? (**1=Yes, 2=No**) If **NO**, skip to **OO**

Code A: (Select all the applied): 1=Used suction pump, 2=Construction of shallow surface trenches/gutters, 3=Underground clay pipes, 4=Construction of deep drainage dykes/ditches, 5=Other, specify_____

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»»»»»»»»Continuation of plot household roster and adoption of sustainable intensification practices

NN		NN_COST	OO	PP	QQ	RR
What was the approximate number of cocoa trees renovated on [Plot Name] during the agricultural season 2022/2023? (**Number**)	How were old cocoa trees on [Plot Name] renovated during the agricultural season 2022/2023? **(Code A)**	What was the associated cost in GHC (if any)? **(Amount in GHC)** (***Optional response***)	Did you or your household intercrop cocoa trees on [Plot Name] with food crops during the agricultural season 2022/2023? (**1=Yes, 2=No**) If **NO**, skip to **QQ**	Please list all the food crops planted on [Plot Name] during the agricultural season 2022/2023? **(Code B)**	Did you or your household integrate [Plot Name] with farm animals during the agricultural season 2022/2023? **(1=Yes, 2=No)** If **NO**, skip to **B2**	Please list all the farm animals reared on [Plot Name] during the agricultural season 2022/2023? **(Code C)**

Code A (Select all the applied): 1=Planting of seeds of same variety (Atodwe), 2= Planting of seeds of improved variety (Atodwe), 3= Planting seedlings from same variety, 4= Planting seedlings from improved variety, 5=Side grafting with same variety, 6= Side grafting with improved variety, 7=Other, specify_____

Code B (Select all the applied): 1=Plantain, 2=Cassava, 3=Banana, 4=Cocoyam, 5=Yam, 6=Maize, 7=Other, specify_____

Code C **(Select all the applied)**: 1=Sheep, 2=Goat, 3=Cattle, 4=Poultry, 5=Other, specify_____

B2. Farm input utilization

Instruction: Kindly provide the following information about farm inputs utilization during the 2023/23 cropping season for the **TWO MAJOR cocoa plots belonging to this household. (Programmer: Populate answers using same plot order as in B1**.
Enumerator: Ask questions using the same plot order as in B1)

Farm input	Did your household apply [input] on [plot] during the 2022/23 cropping season? **(1=Yes, 2=No)** **(Yes = Next column**	Which type of [input] did your household use on [plot] during the 2022/23 cropping season? **(Select all the applied)**	What quantity of [input] did you or your household apply on [plot] during the 2022/23 cropping season??	Unit **(Code B)**	What quantity of [input] did you or your household receive as subsidy for [plot] during the 2022/23 cropping season?	Unit **(Code B)**

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	No – next row/ farm input)					
Inorganic fertilizer		(**Code A**)				
Organic fertilizer		**(CODE C)**	**(*Optional response*)**		If 2,3,4,5,6,7 or 8, skip this question	
Inorganic insecticide		(**Code D**)				
Inorganic fungicide		(**Code E**)				
Inorganic herbicide		(**Code F**)				
Bio/organic pesticide		**(CODE G)**				

Code A (Select all the applied): Asasewura=1, Dua pa=2, Cocofeed=3, Ferta Agra=4, Adom Cocoa Fertiliser=5, Adehye Cocoa Fertliser=6, So Aba Pa=7, Cocoset=8, Lithovit=9, Lifet A+=10, Sidalco=11, NPK 15:15:15=12, Cocoamaster=13, 14=Other, specify___

Code B (Select all the applied): 1= kilograms (kg), 2=grams (g), 3=sack/bag(10kg), 4=sack/bag(25kg), 5=sack/bag(50kg), 6=sack/bag(100kg), 7=litre, 8=mililitre, 9= sachet, 10=Other, specify___

Code C (Select all the applied): 1= COCOBOD supplied organic fertilizer, 2= Animal manure, 3=Green manure, 4=Compost, 5= cocoa pod husks, 6= other crop residue, 7=Biochar, 8= Other, specify___

Code D (Select all the applied): Akate master=1, Acati Power=2, Acetastar=3, Akate Star=4, Confidence=5, D Lion Akate Global=6, Confidor=7, Actara=8, Miricon=9, LUFU=10, Nomax=11, Buffalo Super=12, Thodan Super=13, 14=Other, specify_____

Code E (Select all the applied): Kocide=1, Funguran=2, Champion=3, Fungikill=4, Ridomil=5, Copper Nordox= 6, Metalm=7, Sidalco Defender=8, Agro Comment=9, Fantic= 10, Forum=11, Vamos=12, Banjo Forte=13, Delco=14, Royal Cop =15, 16=Other, specify_____

Code F (Select all the applied): Nwura wura=1, Round Up=2, Glyphagon glyphosphate=3, 4=Other, specify_____

Code G (Select all the applied): 1=Aqueous neem extract, 2=Garlic oil extract, 3= Spread of the predatory African Weaver ants (or Nhowhoa), 4= Use of pheromone sex traps, 5=Other, specify_____

»»»»»»»»Continuation of farm input utilization

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Input	When did you or your household receive [input] subsidy for [plot]? (**Code A**)	Which institution provided [input] subsidy (**Code B**)	What quantity of [input] did you or your household buy for [plot]?	Unit (**Code C**)	What was the total cost (in GHC) of [input] bought for [plot]?	What was the source of [input] bought for [plot]? (**Code D**)	How many times did you apply [input] on [plot] (**Number**)	When did you or your household apply [input] on [plot] (**Code A**)
Inorganic fertilizer								
Organic fertilizer	If 2,3,4,5,6,7 or 8, skip this question		(***Optional responses***)					
Inorganic insecticide								
Inorganic fungicide								
Inorganic herbicide								
Bio/organic pesticide			(***Optional responses***)					

Code A (Select all those that apply): 1=January, 2=February, 3=March, 4=April, 5=May, 6=June, 7=July, 8=August, 9=September, 10=October, 11=November, 12=December

Code B (Select all those that apply): 1=Government agricultural extension service, 2= Input Supplier, 3= Farmer Based Organization, 4= NGOs/ Projects/Programmes providing Extension services, 5= LBC, 6=Formal credit institution, 7=Family and friends, 8=Private extension agents, 9=Other, specify_____

Code C: 1= kilograms (kg), 2=grams (g), 3=sack/bag(10kg), 4=sack/bag(25kg), 5=sack/bag(50kg), 6=sack/bag(100kg), 7=litre, 8=millilitre, 9= sachet, 10=Other, specify___

Code D (Select all the applied): 1=Self-made, 2=Purchased from a dealer outside this community, 3=Purchased from a dealer within this community, 4=Exchanged, 5=Borrowed (loaned), 6=Gift, 7=Leftover from previous season, 8= Input Supplier, 9=Other, specify_____

B3. Labour utilization

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Instruction: Kindly provide the following information about labour utilization on **the TWO MAJOR cocoa plots belonging to this household during the cropping season 2022/23**

Type of cocoa farming activity	**Hired Labour**			**Family Labour**			**Communal/Exchange Labour/Ndoboa** (*Hint: anyone other than those in the household who worked on [plot] as unpaid labour*)		
	What is the average number of hired labour used to perform [activity] on [plot] during both the major and minor seasons in 2022/23?	How many days did hired labour perform [activity] on [plot] during both the major and minor seasons in 2022/23?	What was the total labour cost per day in GHC? (**Enumerator: include value in GHC of all payments in kind)**	What is the average number of family labour used to perform [activity] on [plot] during both the major and minor seasons in 2022/23?	How many days did family labour perform [activity] on [plot] during both the major and minor seasons in 2022/23?	What was the total labour cost per day in GHC? (**includes value in GHC of all payments in kind)**	What is the average number of exchange labour used to perform [activity] on [plot] during both the major and minor seasons in 2022/23?	How many days did exchange labour perform [activity] on [plot] during both the major and minor seasons in 2022/23?	What was the total labour cost per day in GHC? (**includes value in GHC of all payments in kind)**
Hand weeding									
Male									
Female									
Children (<15 years)									
Pruning									
Male									
Female									
Children (<15 years)									
Removal of chupons, mosses and mistletoes									
Male									
Female									

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Children (<15 years)									
Mulching									
Male									
Female									
Children (<15 years)									
Inorganic fertilizer application									
Male									
Female									
Children (<15 years)									
Inorganic insecticide application									
Male									
Female									
Children (<15 years)									
Fungicide application									
Male									
Female									
Children (<15 years)									
Herbicide/weedicide application									
Male									
Female									
Children (<15 years)									
Harvesting of cocoa pods									
Male									
Female									
Children (<15 years)									
Breaking of cocoa pods									

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Male									
Female									
Children (<15 years)									
Fermentation of cocoa pulp and beans									
Male									
Female									
Children (<15 years)									
Transportation of cocoa beans/pods									
Male									
Female									
Children (<15 years)									
Drying of cocoa beans									
Male									
Female									
Children (<15 years)									

B4. Safe use of agrochemicals

Instruction: Kindly provide the following information for **the <u>TWO MAJOR</u> cocoa plots belonging to this household during the cropping season 2022/23**.

A	B	C	D	E	F

INTEGRI PROCEDAMUS

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Did you or any household member use any personal protective equipment (PPEs) for work on [Plot Name] in the past season (2022/23)? **(1=Yes, 2=No)** ***If NO, skip to C***	Outline the personal protective equipment (PPEs) used on [Plot Name] during the agricultural season 2022/2023? (**Code A**)	Did you take any special precaution in storing agrochemicals on [Plot Name] during the agricultural season 2022/2023? **(1=Yes, 2=No)** **If NO, skip to E**	How did you or household member store agrochemicals on [Plot Name] in the past season (2022/23)? (**Code B**)	Did you or your household take any special precaution in disposing off the containers of agrochemicals on [Plot Name] during the agricultural season 2022/2023? (**1=Yes, 2=No**) If **NO**, skip to **B5**	How did you or household member dispose the containers of agrochemicals in the past season (2022/23)? (**Code C**)

Code A (Select all the applied):1=Protective clothes (Coat or overall), 2=Ventilation or Face mask, 3=Hand gloves, 4=Eye goggles, 5=safety boots, 6=Cap, 7=Other, specify_____

Code B (Select all the applied):1=Stored leftover pesticide in same bottle on farm, 2= Stored leftover pesticide in same bottle in the house, 3=transferred leftover pesticides into other containers, 4= assigned a designated area for storing pesticide, 5=kept pesticide out of the reach of children, 6=did not expose pesticides to sunlight, 7= kept pesticide away from food and water, 8= diluted leftover pesticide and sprayed at the edges of farm, 9= Other, specify_____

Code C (Select all the applied):1= punctured container to dissuade reuse, 2=dumped containers on the farm, 3= dumped containers on a designated site, 4=buried containers on farm, 5= burned containers on farm, 6= triple rinsing into knapsack sprayer, 7= reused containers, 8=Other, specify_____

B5: Harvest and postharvest processing

Instruction: Kindly provide the following information for **the TOW MAJOR cocoa plots belonging to this household during the cropping season 2022/23**.

A	B	C	D	E	F	G	H

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What was the approximate number of cocoa pods per tree on [Plot Name] in the 2022/2023 season? (**Number**) (***Optional responses***)	Did you and household member harvest cocoa pods in a timely manner on [Plot Name] in the 2022/2023 season? **(1=Yes, 2=No)**	How long after complete ripening did you or household member harvest cocoa pods on [Plot Name] in the 2022/2023 season? **(Code A)**	What was the average harvesting interval on [plot] in the 2022/2023 major season? **(Code B)**	What was the average harvesting interval on [plot] in the 2022/2023 minor season? **(Code B)**	Were there any losses of cocoa pods/beans on [Plot Name] before the harvest was completed in the 2022/23 season? **(1=Yes, 2=No)** **If NO, skip to H**	What were the main causes of the losses? **Code C**	After harvesting, what is the approximate percentage of diseased and defective cocoa pods removed from [Plot Name] in the 2022/2023 season? (**Number percent**) (***Optional responses***)

Code A: 1=Less than 3 days, 2=3-5 days, 3=6-7 days, 4=More than 7 days, 5= Other(specify) _____
Code B: 1=1=Less than 3 days, 2=3-5 days, 3=6-7 days, 4=8-10 days, 5= 11-14 days, 6=More than 14 days, 7= Other(specify) _____
Code C: 1=Drought, 2=Delayed rain, 3=Too much rain, 4=Fire/burnt farm, 5=Capsids incidence, 6=Blackpod disease, 7=Other diseases, 8= Theft of cocoa, 9=Late harvesting, 10=Inadequate labour, 11=Other(specify) _____

»»»»»»»»Continuation of harvest and postharvest processing

I		J	K	L
What quantity of dried cocoa beans did you or your household sell from [Plot Name] in the **2022/2023** season?		Price per 64kg bag at the end of the 2022/23 cropping season?	Do you or household member anticipate any shocks, such as bad weather including drought, delayed rainfall, flood, diseases or pests, to significantly reduce cocoa production on this plot in the next 5 years? **(1=Yes, 2=No)** **If NO, skip to O**	How do you or household member intend to resolve such an anticipated reduction in cocoa production in this community in the next 5 years? **(Code C)**
Quantity	**Unit (Code A)**			

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Code A: 1= kilograms (kg), 2=grams (g), 3=sack/bag(10kg), 4=sack/bag(25kg), 5=sack/bag(50kg), 6=sack/bag(64kg), 7=Other(specify) _____
Code C:1=Completely abandon cocoa farming, 2= Neglect cocoa farm for a while, 3= Reduce area of plot allocated to cocoa, 4= Increase area of plot allocated to cocoa, 5=Change planting date, 6=Increase planting density, 7=reduce planting density, 8=Use more fertilizer, 9=Use more insecticides, 10=Use more fungicide, 11=Plant improved varieties, 12=Practice irrigation, 13=Practice hand pollination, 14=Plant more shade trees, 15=Insure cocoa plot, 16=Rely on available early warning signs, 17=crop diversification, 18=off-farm income diversification, 20= Don't Know, 21=Other (Specify)

»»»»»»»»Continuation of harvest and postharvest processing

O	P	Q	R	S
Which method was used by you and your household in pre-conditioning your pods before breaking them in the 2022/2023 season? (**Code A**) **If 2,3, or 4, skip to Q**	What was the approximate number of days cocoa pods from [Plot Name] were stored before pod breaking during the agricultural season 2022/2023? (**Code B**)	Which method did you or household member use in breaking cocoa pods on [Plot Name] during the agricultural season 2022/2023? **(Code C)**	What method did you use in fermenting cocoa beans on [Plot Name] during the agricultural season 2022/2023? (**Code D**)	What was the approximate number of days cocoa beans were fermented on [Plot Name] during the agricultural season 2022/2023? (**Code E**)

Code A: 1=Pod storage, 2=mechanical depulping, 3=enzymatic depulping, 4=Draining cocoa beans, 5= Other(specify) _____
Code B: 1=Less than 3 days, 2=3–5 days, 3=6-7 days, 4=8-10 days, 5=11-14 days, 6=More than 14, 7= Other(specify) _____
Code C: 1=Used blunt cutlass for pod breaking, 2= Used wooden bar to hit the pod, 3=Hit two pods against each other, 4=Used stone for breaking pod, 5=Used sharp cutlass to split the pod open, 6=Used pod splitting machine, 7= Other(specify) _____
Code D:1= Traditional heap method with banana leaves, 2= Traditional heap method with polythene sheet, 3= Sweatbox method, 4=Tray method, 5= Other(specify) _____
Code E: 1=1-3 days, 2=4-5 days, 3=6-7 days, 4= more than 7 days, 5= Other(specify) _____

»»»»»»»»Continuation of harvest and postharvest processing

T	U	V
What was the approximate number of turnings of ferments during the fermentation process on [Plot Name] during the agricultural season 2022/2023? (**Code A**)	What was the approximate turning interval of ferments during the fermentation process on [Plot Name] during the agricultural season 2022/2023? (**Code B**)	What method did you use in drying cocoa beans on [Plot Name] **(Code C)**

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Code A: 1=none, 2=once, 3=twice, 4=thrice, 5=More than thrice
Code B: 1= Once every 24 hours, 2=Once every 48 hours, 3=Once every 72 hours, 4=After third day, 5=After fourth day, 6=After fifth day, 7= Other(specify) _____
Code C: 1= Sun drying on raised platforms, 2=Oven drying, 3=Use of solar dryer, 4=Use of hybrid dryer, 5= Other(specify) _____

»»»»»»»»Continuation of harvest and postharvest processing

W		X	Y		Z
What was the approximate number of days fermented cocoa beans were dried on [Plot Name] during the agricultural season 2022/2023 during the major season? (**Code D**)	What was the approximate number of days fermented cocoa beans were dried on [Plot Name] during the agricultural season 2022/2023 during the minor season? (**Code D**)	What was the approximate number of stirring and polishing per day of cocoa beans during drying on [Plot Name] in the major season? (**Code E**)	What was the approximate number of stirring and polishing per day of cocoa beans during drying on [Plot Name] in the minor season? (**Code E**)	What was the approximate stirring interval of cocoa beans during the drying process on [Plot Name] during the agricultural season 2022/2023? (**Code F**)	What precautions did you take against dew and rainfall during drying of cocoa beans on [Plot Name] during the agricultural season 2022/2023? (**Code G**)

Code D: 1=none, 2= 1-3 days, 3=4-5 days, 4=6-7 days, 5=8-10 days, 6=11-14 days, 7=More than 14 days
Code E: 1=None, 2=Once, 3=Twice, 4=thrice, 5=More than three times
Code F: 1= Once every 30 minutes, 2=Once every 1 hour, 3=2- 3 hours, 4=4-6 hours, 5=7-12 hours, 6= Other(specify) _____
Code G: 1= Covered the drying beans with a black polythene sheet, 2=Covered the drying beans with palm mats, 3= Covered the drying beans with tarpaulin, 4=Other(specify) _____

Section C: Farmers' perception about the adoption of sustainable cocoa intensification practices

INSTRUCTIONS: In this section, I would like to ask you whether you agree or disagree with these ideas about sustainable cocoa intensification practices. Sustainable cocoa intensification practices are various management techniques and practices, to increase the quantity and quality of cocoa beans produced per unit of land in a cost-effective way to increase profitability and improve the livelihood of the farmers, protect the environment, conserve biodiversity and other agro-ecological services, and to ensure that future generations can cultivate cocoa

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No.	Attribute of SCIPs	Strongly disagree 1	Disagree 2	Neutral 3	Agree 4	Strongly agree 5
1	***Sustainable cocoa intensification practices*** contribute to low cocoa yield in the first few years of implementation					
2	***Sustainable cocoa intensification practices*** contribute to low cocoa yield in the long term					
3	***Sustainable cocoa intensification practices*** cannot extend the productive years/age of my cocoa trees					
4	***Sustainable cocoa intensification practices*** do not sequester carbon, and do not reduce carbon emissions from my farm					
5	***Sustainable cocoa intensification practices*** do not conserve soil moisture and fertility on my cocoa farm					
6	***Sustainable cocoa intensification practices*** increase the quantity of agrochemicals used on cocoa farm in the long term					
7	Implementation of ***sustainable cocoa intensification practices*** require a lot of labour that I cannot afford					
9	Implementation of ***sustainable cocoa intensification practices*** require high expertise that is inaccessible to me					

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12	Implementation of ***sustainable cocoa intensification practices*** require long term land ownership that I do not have					

SECTION D: HOUSEHOLD ACCESS TO EXTENSION AND SUPPORT SERVICES

INSTRUCTIONS: Kindly provide the following information for **the TWO MAJOR cocoa plots belonging to this household during the cropping season 2022/23**.

A	B	C	D	E	F	G
Did you or any household member receive an extension service about cocoa production in the past season (2022/23)? **(1=Yes, 2=No)** **If NO, skip to F**	Type of service received (**Code A**)	Source of the service (**Code B**)	Number of times service was received (**Number**)	On average, how useful was the service received? (**Code C**)	Did you or any household member attend an agricultural training workshop/seminar about cocoa production in the past season (2022/23)? **[1=Yes, 2=No]** **If NO, skip to H.**	What is the approximate number of agricultural training workshops/seminars about cocoa production attended by household members in the past season (2022/23) (**Number**)

Code A (**Select all those that apply**): 0= Extension advisory on GAPs, 1= Delivery of fertilizer, 2=Delivery of insecticides, 3=Delivery of fungicide, 4=Supply of new cocoa varieties/seedlings, 5=Hand pollination services, 6=Weeding services, 7= Pruning services, 8= Chupons and mistletoes removal services, 9= Irrigation services, 10= Advice on shade trees, 11= Formation of farmer-based group, 12= Weather information services, 13=Crop insurance services, 14=Pension services, 15= Facilitate access to credit, 16=Harvesting services, 17=Extension support for farm rehabilitation (grafting, good planting, etc), 18= Other, specify, 19=None

Code B (Select all those that apply): 1=Government agricultural extension service, 2=Private agricultural extension agents, 3= NGOs/ Projects/Programmes providing extension services, 4= Input Supplier, 5= Farmer Based Organization, 6= LBC, 6=Formal credit institution, 7=Family and friends, 8=Electronic media (TV, Radio, etc), 9=Paper media (magazine, pamphlet, handout, flyers, etc), 10=Social media platform, 11=Artificial intelligence, 12=Other, specify

Code C: 1=Very useful, 2=Somewhat useful, 3=Not very useful, 4=Not useful, 5=Don't know

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»»»»»»»»Continuation of household access to support services

H	I	J	K	L	M
Did you or any household member secure cocoa crop insurance in the past season (2022/23)? [**1=Yes, 2=No**]. ***If NO, skip to K*** (***Optional response***)	How much did you or your household member pay as cocoa crop insurance premium in the past season (2022/23) in GHC? **(Amount in GHC)** (***Optional response***)	Give the name of the insurance provider **Code A** (***Optional response***)	Did you or any household member participate in cocoa farmer pension scheme in the past season (2022/23)? **[1=Yes, 2=No]** **If NO, skip to** (***Optional response***)	How much did you or your household member pay as monthly contribution to pension scheme in GHC? **(Amount in GHC)** (***Optional response***)	Give the name of provider of the pension **Code A** (***Optional response***)

Code A: 1=COCOBOD, 2=Solidaridad Cocolife, 3=Other(specify) _____

»»»»»»»»Continuation of household access to support services

N	O	P	Q	R	S
Did you or any household member have a farm succession plan in place during the past season (2022/23)? **[1=Yes, 2=No]** **If NO, skip to Q**	What is your relationship with the identified successor? **Code A**	Is the person identified in the succession plan being mentored to take over? **[1=Yes, 2=No]**	Did you or any member of your household need credit for a cocoa production related activity in the past 12 months? **[1=Yes, 2=No]** **If NO, skip to D4**	Did you or any member of your household request for credit to carry out these activities? **[1=Yes, 2=No]** **If NO, skip to D4**	Did you or any member of your household receive part or the full amount of the credit requested? **[1=Yes, 2=No]**

Code A: 0= Self, 1= Husband/wife, 2= Son/daughter/adopted child, 3= Father/mother, 4= Sister/brother, 5=Grandchild, 6=Grandparent, 7=Mother/father-in-law, 8=Daughter/son-in-law, 9=Sister/brother-in-law, 10=Other relative, 11=Not related, 12=Other, specify_____

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D1. Household livestock holding

INSTRUCTIONS: Kindly provide the following information about the livestock **belonging to this household (*Optional responses*)**

No.	Type of animal	Total Number	If your household would sell one of the [ANIMAL] today, how much would your household receive from the sale?
1	Cattle		
2	Goats		
3	Sheep		
4	Chicken		
5	Pigs		
6	Other poultry		
7	Grasscutter		
8	Rabbit		
9	Donkey		
10	Other(specify) _____		

D2. Farm assets holding

INSTRUCTIONS: Kindly provide the following information about the farm assets **belonging to this household (*Optional responses*)**

No	Land/farm asset	Total number	No	Land/farm asset	Total number
1	Cutlasses		2	Water pumps	
3	Rakes		4	Irrigation pipes	
5	Shovels		6	Trailers / carts/ aboboyaa	

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7	sickle/reaping hooks		8	Knapsack sprayer	
9	Mist blower		10	Farm house	
11	Hand dug well		12	Tractor	
13	Borehole		14	Prunner	

D6. Household land holding

INSTRUCTIONS: Kindly provide the following information about the land **belonging to this household (*Optional responses*)**

No	Land holding	Total size	Unit (Code A)
1	Non-cocoa agricultural farmland		**Code A**
2	Residential land		**Code A**
3	Other non- agricultural land		**Code A**

Code A: 0= acres, 1= hectares, 2= poles, 3=Square meters, 4=Small ropes, 5=Big ropes

Section E: Food Security Indicators

E1. Household Food Insecurity Access Scale (HFIAS)

INSTRUCTIONS: In this section, I would like to ask you about food availability in the household in the **past 4 weeks (30 days)**.

No.	Occurrence questions	Response:1=Yes; 2=No (Skip to next question)	If yes, how often did this happen in the past [4 weeks/30 days]? **(Code A)**
HIFAS1	In the past four weeks, did you worry that your household would not have enough food to eat?		
HIFAS2	In the past four weeks, were you or any household member not able to eat the kinds of foods you preferred because of lack of resources?		

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HIFAS3	In the past four weeks, did you or any household member have to eat a limited variety of foods due to a lack of resources?		
HIFAS4	In the past four weeks, did you or any household member have to eat some foods that you really did not want to eat because of a lack of resources to obtain other types of food?		
HIFAS5	In the past four weeks, did you or any household member have to eat a smaller meal than you felt you needed because there was not enough food?		
HIFAS6	In the past four weeks, did you or any household member have to eat fewer meals in a day because there was not enough food?		
HIFAS7	In the past four weeks, was there ever no food to eat of any kind in your household because of lack of resources to get food?		
HIFAS8	In the past four weeks, did you or any household member go to sleep at night hungry because there was not enough food?		
HIFAS9	In the past four weeks, did you or any household member go a whole day and night without eating anything because there was not enough food?		

Code A: 1= Rarely (once or twice), 2=Sometimes (three to ten times), 3= Often (more than ten times)

E2. Household Food Consumption Scale (HFCS)

How many days over the **last 7 days**, did **most** members of your household **(50% +)** eat the following food items, inside or outside the home? And what was their source?

Group	Extended food group	Extended list examples	Did you or anyone in your household consume any of these foods	Number of days eaten in the past 7 days	How was this food acquired? Write the main source of these foods

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			in the last 7 days? **1=Yes; 2 =No**	**If 0 days, do not specify the main source**	consumed over the past 7 days **(Codes A)**
1	Cereals, grains, roots and tubers	Rice, pasta, bread, sorghum, millet, maize, potato, yam, cassava, white sweet potato, plantain			
2	Pulses/legumes, nuts and seeds	beans, cowpeas, lentils, soy, pigeon pea, peanuts, or other nuts			
3	Milk and other dairy products	milk, yoghurt, cheese, and other dairy products [Exclude margarine/butter or small amounts of milk for tea/coffee]			
4	Meat, fish and eggs	goat, beef, chicken, pork, fish, including canned tuna, insects, escargot, and/or other seafood, eggs (meat and fish consumed in large quantities and not as a condiment			
5	Vegetables and leaves	, such as: spinach, onion, tomatoes, carrots, peppers, green beans, lettuce, etc			
6	Fruits	bananas, apples, lemon, mango, papaya, apricot, peach, etc			
7	Oil/fat/butter	vegetable oil, palm oil, shea butter, margarine, and other fats/oil			
8	Sugar, or sweet	sugar, honey, jam, candy, cookies, pastries, cakes and other sweet (sugary drinks)			

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9	Condiments / Spices	tea, coffee, cocoa powder, salt, garlic, spices, yeast/baking powder, tomato paste or sauce, and small amounts of meat, fish, milk or other food items consumed as a condiment			

Code A: 1 = Own production; 2 = Bought (purchase with cash or on credit); 3 = Free (gift, gathered, or exchanged); 4 = Begged; 5= Food aid from civil society, NGOs, government; 6= Other, specify

E3. Reduced Coping Strategies (rCSI)

INSTRUCTION: Now I will ask you about the number of days, in the **last 7 days**, that your household may have done some of the following actions to cope with lack of food or money to buy food

1. During the last 7 days, were there days (and, if so, how many) when your household had to rely on less preferred and less expensive food to cope with a lack of food or money to buy it? _____
2. During the last 7 days, were there days (and, if so, how many) when your household had to borrow food or rely on help from a relative or friend to cope with a lack of food or money to buy it? _____
3. During the last 7 days, were there days (and, if so, how many) when your household had to limit portion size of meals at meal times to cope with a lack of food or money to buy it? _____
4. During the last 7 days, were there days (and, if so, how many) when your household had to restrict consumption by adults in order for small children to eat to cope with a lack of food or money to buy it? _____
5. During the last 7 days, were there days (and, if so, how many) when your household had to reduce number of meals eaten in a day to cope with a lack of food or money to buy it? _____

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APPENDIX 2: GUIDE FOR KEY INFORMANT INTERVIEW

Identification of the incentives that could shift cocoa farmers towards the adoption of sustainable intensification practices in Ghana

Consent Form

My name is _____. I am from the Department of Agricultural Economics and Agribusiness at the University of Ghana. I am collecting data for a research study to identify the incentives that could shift cocoa farmers towards the adoption of sustainable intensification practices in Ghana. You have been chosen purposively as one of the participants for this study. It is expected that the results from this survey will help the Ghanaian government and other stakeholders in the cocoa sector to fashion out policies, strategies and programmes that improve the lives of cocoa farmers. If you agree to participate in this study, I will ask you detailed questions about cocoa production and the incentives that could shift cocoa farmers towards the adoption of sustainable intensification practices. You are free to refuse to answer any of the questions that may make you uncomfortable and you also have the option to end the interview at any time. You can stop me at any time to clarify the questions or ask me to repeat something if you don't understand. I would like you to know that your participation is greatly appreciated. Your participation in this study will not affect you in anyway as the study is solely for research purposes. Your name and any other identifying information will be accessible only to the researchers and will never appear in any sort of report that might be published.

Do you agree to participate in the study? Yes_____ No _____

Signature (or thumbprint) _____ Date: _____

Signature of the Enumerator: _____ Date: _____

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Background and Context

1. a. For how long now have you been involved with the cocoa sector in Ghana?

b. Can you describe your role and experience in the cocoa sector? (Code: 1=Extension officer, 2=District Director of COCOBOD, 3=Researcher at COCOBOD, 4=Researcher with other state institution or academia, 5=NGO, 6=Other, specify)

2.

a. What are some of the challenges you have identified that hinder the sustainability of cocoa production in Ghana? (Code: 1= Poor soil fertility, 2= Capsid/Mirid incidence, 3=Blackpod Disease infestation, 4=Cocoa Swollen Shoot Disease infestation, 5=Untimely access to subsidized agrochemicals, 6=High cost of agrochemicals, 7=Poor access to improved cocoa varieties, 8=High labour cost for agrochemical application, 9=High labour cost for weeding, pruning, and removal of chupons and mistletoes, 10=High labour for harvesting, pod breaking, fermentation, and drying, 11=Poor access to extension advisory services, 12=Low access to credit, 13=Aged cocoa trees, 14=Aging farmer, 15=Unregulated mining activities, 16=Low profit due to unfavorable land tenure arrangements, 17=Low farm reinvestment due to unfavorable land tenure arrangement, 18=Transportation, 19=Low technical skills, 20=Climate shocks (Drought), 21=Climate shocks (Frequent bushfires), 22=Climate shocks (Flooding), 23=Climate shocks (Excessive and unpredictable rainfall), 24=Other, specify)

b. Can you share some views on what the future holds for cocoa production in Ghana if these problems linger? (Code: 1=Lower yields (Quantity of cocoa beans), 2= Lower yields (reduced quality of cocoa beans), 3=reduced profit and household income, 3=deforestation and environmental degradation, 4=increased vulnerability to climate change, 5=farmers will exit cocoa farming, 6=Poor health and wellbeing of farmers, 7=Other, specify___)

c. In your view, what would be some of the implications of the EU proposal to ban cocoa and cocoa derived products procured from deforested areas, on the future of cocoa production in Ghana?

(Code: (Non-compliance could lead to) 1=damage Ghana's reputation, 1=market access restrictions, 1=reduce export revenue, 2= negative impact on livelihood of farming households, 3=incentivize the adoption of sustainable practices, 4=promote the implementation of robust traceability system, 5=promote the implementation of robust certification system, 6=increase investment in reafforestation efforts)

3. a. How familiar are you with sustainable intensification practices in cocoa production?

Sustainable cocoa intensification practices are various management techniques and practices, to increase the quantity and quality of cocoa beans produced per unit of land in a cost-effective way to increase profitability and improve the livelihood of the farmers, protect the environment, conserve biodiversity and other agro-ecological services, and to ensure that future generations can cultivate cocoa (Code: 1=Not at all, 2=A little familiar, 3=Somehow familiar, 4=Very familiar)

Enumerator: End interview if expert is not familiar with the concept of sustainable intensification or sustainable intensification practices

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8. In what ways (if any) can the adoption of sustainable intensification practices help in reducing the effects of the challenges you've highlighted? [Code: (SCIPs can) 1= increase the quantity of cocoa yield, 2= enhance the quality attributes of cocoa beans, 3= reduce the use of inorganic fertilizer, 4= reduce the use of inorganic pesticide, 5= improve water use efficiency, 6= control diseases, 7= reduce the effect of drought, 8= mitigate climate change, 9=control flood, 10=improve biodiversity, 11= reduce postharvest loses, 12=promote the health of farmer and farm workers, 13=provide retirement security, 14= reduce family conflict, 15=Other, specify]

4. Why do you think the adoption of these practices is low in Ghana? [Code: 1=Limited knowledge and training, 2= (Perception) No yield advantage in the short term, 3= (Perception) No yield advantage in the long term, 4=Potential risk of profit loss, 5=Inadequate income to reinvest in farm , 6=Fear of not being able to pay associated cost in time, 7=High labour cost, 8=High cost of inputs, 9= Inputs are not locally available, 10=technically difficult to implement, 11=Time consuming, 12=Poor access to subsidised input, 13= Poor access to credit, 14= poor access to land for long-term investment, 15=Peers not implementing, 16= Physical disability, 17=religious constraints, 18=Gender restrictions, 2=Inadequate trust and confidence in practices, 19= Some of the practices promote the spread of blackpod disease, 20= Some of the practices enhance activities of capsids, 21=Other specify]

Incentives to motivate the adoption of sustainable cocoa intensification practices

INSTRUCTIONS: In this section, I would like to ask you about incentives that can motivate farmers to adopt sustainable cocoa intensification practices in Ghana

5. a. What could be improved about the attributes of SCIPs to encourage cocoa farmers to adopt them on their farms? (Code: 1=Practices should be yield enhancing, 2=Practices should be quality enhancing, 3=Practices should be less labour intensive, 4=Practices should be less capital intensive, 5=Input should be made affordable, 6=Inputs should be available in my community, 7= Practices should be gender sensitive, 8=Practices should be easy to be implemented even by the physically disabled, 9=Practices should break cultural and religious barriers, 10=Other, specify)

6. a. In your opinion, which existing economic incentives are able to promote the adoption of sustainable intensification practices by cocoa farmers in Ghana? (Code: 1=COCOBOD input subsidies, 2=NGO/Solidaridad Cocolife input facility, 3= NGO/Solidaridad Cocolife credit facility,4= VSLA, 5=certification, 6=Other, specify)

b. How could economic incentives be improved or expanded to motivate cocoa farmers to (continue to) adopt sustainable intensification practices on their farms? (Code: 1=Timely access to subsidised inputs, 2=1-10% annual increase in the cocoa producer price, 3=11-20% annual increase in the cocoa producer price, 4= 21-30% annual increase in the cocoa producer price, 5=More than 30% annual increase in the cocoa producer price, 6=Cocobod disbanding the input supply system and pay farmers a higher price, 6=Farmers selling cocoa at spot prices, 6=Payment of special sustainable intensification premium (1-10% of the cocoa producer prices), 7=Payment of special sustainable intensification premium (more than 10% of the cocoa producer prices),

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8=Annual payment for ecosystem services, 9= Sale of diversified products from shade trees and intercropped food products, 10=Other, specify)

7. a. What types of training or technical support have been the most effective in encouraging cocoa farmers to adopt sustainable intensification practices on their farms? (Code: 1=Extension farm visits, 2=Farmer Field Schools, 3=Demonstration plots, 4=Farmer-to-farmer training, 5=Workshops and seminars, 6=On farm trials, 7=Coaching and mentoring, 8=Digital extension services, 9=Other, specify)

b. How could technical assistance and training be improved or expanded to make it easier for cocoa farmers to implement sustainable intensification practices on their farms? (Code: 1=Biweekly extension farm visits, 2=Monthly extension farm visits, 3= Monthly Farmer Field Schools, 4=Demonstration plots in my community, 5=Farmer-to-farmer training, coaching, and mentoring on specific SCIPS, 6=Monthly workshops and seminars, 7=Annual on farm trials, 8=Contextualizing training to specific local needs and agroecological zones, 9=Use of participatory and interactive approaches, 10=Use of both indigenous and expert knowledge in the coproduction of new technologies/information, 11=Development of user-friendly and affordable practices/technologies, 12=Involvement local farmers as trainers and facilitators, 13=Development of socially inclusive and gender sensitive packages, 14=Provision of continuous support and follow up visits, 15=Use of digital tools, 16=Foster partnership among farmers, local institutions, NGOs and researchers, 17=Support access to quality seedlings, inputs, and equipment, 18=Other, specify)

c. Which other institutional support services could be improved or expanded to make it easier for YOU to implement sustainable intensification practices on your farm? (Code: 1= Strict imposition of sustainability obligations at the farm level, 2=ban on sale of cocoa that is not deforestation free at the local/community level, 3=Intense monitoring to check smuggling of cocoa, 4=Ease in land acquisition and documentation, 5=regulation of existing sharecropping arrangements, 6=Public education and campaigns on the benefits of SCIPs, 7=creation of knowledge and awareness of a traceability system, 8=Facilitate access to affordable credit, 9=Provision of tree tenure for shade trees, 10=models for plural adoption and endogenous learning, 11=Strengthening of cocoa farmer-based organisations, 12=Other, specify)

8. a. In your view, are there any social or cultural incentives that could be leveraged to promote the adoption of sustainable intensification practices among farmers? (Code: 1=Community recognition and prestige, 2=religion and spiritual beliefs, 3= peer influences, 4=gender roles and expectations, 5= perceived risks and uncertainty of adopting practices, 6=ethnic and tribal affiliation, 7=age and generational differences, 8=other, specify)

b. How could social and cultural incentives be integrated into existing initiatives or programs? (Code: 1=Education and awareness campaigns through farmer organisations, 2=demonstrations during cultural and religious events, 3= Public celebration of successes/social status recognition for successful adoption, 4=Integration of indigenous knowledge in the development of SCIPs to improve trust, 5=Improving partnership with local leaders, extension agents, farmers and

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researcher in developing SCIPs, 6=development of techniques that respect and aligns with local beliefs and values, 7=Gender sensitive extension and innovation development, 8=Youth engagement, 9=Use of local language as instructional tool on digital extension platforms, 10=Other, specify)

9. Who do you recommend to take the lead in the provision of these incentives? [Code: 1= Farmer-led initiatives, 2= Public sector (Ghanaian government, Cocobod and its subsidiaries), 3=Private sector (Cocoa industry, input providers, banks, LBCs), 4=Public-private partnership (partnerships between public and private actors (in- and outside Ghana), including civil society), 5=Other, specify]

7. Do you have any question or concluding remarks as we bring this interesting discussion to a close?



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APPENDIX 3: MISCELLANEOUS RESLULTS

Table 1: WFP's HFCS food group weighting framework

Food Group	Weight
Cereals, roots, and tubers	2
Pulses (e.g., beans, lentils, peas)	3
Vegetables	1
Fruits	1
Meat, fish, and eggs	4
Milk and dairy products	4
Sugar and sweets	0.5
Oils and fats	0.5
Condiments (e.g., spices, tea, coffee)	0

Table 2: Weighting framework for rCSI

Coping strategy	Weight
Eating less preferred and less expensive food	1
Borrowing food or relying on help from a relative or friend	2
Limiting portion sizes at mealtimes	1
Restricting consumption by adults in order for small children to eat	3
Reducing the number of meals eaten in a day	1

Table 3: Results from multicollinearity test

Variable	VIF	1/VIF	Variable	VIF	1/VIF
Farm distance	1.90	0.524966	Residential status	4.92	0.203061
Number of extension visits	3.18	0.314567	Drought risk	1.19	0.837773
Number of train atten.	2.93	0.340762	Flood risk	1.13	0.887755
Experience	1.22	0.818647	Topography	1.42	0.705008
Household size	1.24	0.806377	Plot ownership	1.85	0.540304
Dependency ratio	1.71	0.583892	Soil fertility	1.48	0.674485
Land holding	1.24	0.808109	Usefulness of extension		
Farm asset	1.92	0.520337	Useful	1.88	0.532960
Livestock holding	1.69	0.593457	Not useful	4.69	0.213207
Credit	2.89	0.346536	Religion	1.26	0.795095
Education	4.90	0.203994	Gender	1.59	0.629125
Mean	2.16				

Source: Field data (2024)

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Table 4: Second-stage parameter estimates of yield using selectivity correction based on multinomial logit

Variables	SNI Estimate	INS Estimate	SI Estimate	NSNI Estimate
Plot ownership	31.653(30.598)	-35.294(36.459)	87.97*(48.77)	-12.312 (10.154)
Farm distance	-2.941***(1.115)	-1.030 (1.183)	-3.43**(1.46)	-1.463***(0.526)
Flat topography	61.724(43.942)	15.024 (14.421)	48.48(110.07)	19.386(14.087)
Access to credit	3.964***(1.148)	-5.927(5.506)	26.376(53.316)	39.946(34.139)
Training	4.461(4.360)	78.15**(32.71)	54.58**(27.73)	4.646(16.667)
Extension visits	32.399**(13.409)	66.737(42.703)	23.576(19.749)	28.366**(11.355)
Experience	-0.257(0.658)	-0.591(1.141)	-0.435(1.905)	1.059 (0.999)
Education	-4.104(3.171)	-6.536 (5.939)	4.776 (6.353)	-2.567(3.946)
Household size	10.098(9.786)	12.583(12.535)	-13.068(9.420)	11.684**(4.839)
Gender	-20.747(20.344)	21.225(21.105)	-13.509(53.182)	-10.908(12.934)
Residential status	-22.555(20.929)	130.71**(62.68)	-33.3(124.3)	86.876**(35.037)
Farm asset	19.326(16.243)	3.977(3.778)	20.07***(7.07)	-12.015(18.238)
Land holding	14.471(12.459)	3.402(4.114)	19.04***(7.01)	-13.586*(7.833)
Religion	-22.853(22.064)	-49.588(48.506)	69.714*(39.16)	16.847(33.224)
Transitional zone	36.777(34.136)	38.657(38.072)	-15.102(30.713)	-7.865(16.249)
λ_{SNI}	-334.804*(193.62)	-101.361(100.38)	-674.8*(317.7)	141.02**(58.980)
λ_{INS}	24.881(23.393)	36.061(30.222)	97.074(265.446)	-180.25(121.2)
λ_{SI}	-34.146(24.919)	334.35*(200.48)	71.45(177.61)	344.6**(140.08)
λ_{NSNI}	-312.02(206.896)	106.055 (109.75)	-129.92(129.32)	512.94***(156.8)
Constant	64.40(19.42)	123.633(141.797)	274.59(284.19)	250.93***(52.62)
$\sigma 2$	227.78 (184.52)	167.92(166.97)	655.26(449.37)	511.44***(179.79)
ρ_{SNI}	-0.218* (0.113)	-0.782 (1.123)	-0.64***(0.04)	0.624**(0.287)
ρ_{INS}	0.165 (0.301)	0.278 (1.188)	0.379 (0.916)	-0.797(0.699)
ρ_{SI}	-0.226(1.188)	0.517* (0.311)	0.279 (0.697)	0.524**(0.213)
ρ_{NSNI}	-0.067(1.267)	0.818(1.198)	-0.508(0.443)	0.268***(0.055)

Source: Field data (2024)

***: Significant at 1%; **: Significant at 5%; *: Significant at 10%. (Bootstrapped standard errors in parentheses)

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Table 5: Second-stage parameter estimates of cocoa farm income using selectivity correction based on multinomial logit

Variables	SNI Estimate	INS Estimate	SI Estimate	NSNI Estimate
Plot ownership	839.33* (495.01)	-157.07 (794.41)	548.3 (883.30)	-98.41(84.09)
Farm distance	-18.05 (20.79)	-33.23 (23.58)	-52.15**(22.36)	-20.53***(7.788)
Flat topography	1500.29** (764.12)	182.71 (873.67)	-545.49 (2021.31)	290.57 (201.07)
Access to credit	57.83 (84.81)	58.77 (110.14)	115.91 (86.03)	929.56*(494.84)
Training	548.86 (597.54)	1286.19*(676.54)	914.28**(432.01)	328.23 (257.839)
Extension visits	-323.99 (302.13)	-1687.26* (973.04)	392.62 (373.20)	131.68 (326.33)
Experience	3.06 (5.50)	95.52* (50.10)	-8.98 (32.57)	14.54 (14.31)
Education	87.24 (127.22)	-16.0 (21.09)	122.95 (107.8)	-81.40 (57.68)
Household size	175.40 (254.10)	-609.69 (408.26)	50.76 (158.21)	-75.67 (92.103)
Gender	-229.28 (579.78)	-39.98 (786.30)	-922.13 (706.41)	-279.92 (186.27)
Residential status	94.53 (136.58)	1734.59 (1358.7)	2230.10(1750.8)	1359.15*** (490.65)
Farm asset	138.98 (159.47)	-160.7 (522.47)	35.139** (15.85)	311.76 (265.19)
Land holding	209.769 (194.284)	171.5** (82.073)	76.035 (76.385)	300.96*** (107.94)
Religion	-897.90 (674.75)	-64.11 (122.20)	-41.433 (50.05)	145.52 (472.99)
Transitional zone	103.11 (555.42)	1866.4** (791.09)	-261.76(518.03)	123.98 (231.81)
λ_{SNI}	-2967.98***(306.8)	-4591.54 (3132.36)	-1105.38***(337.99)	2759.12** (1197.92)
λ_{INS}	-236.54 (852.74)	-9161.39* (4563.27)	-2572.4 (3266.12)	-130.81 (2165.46)
λ_{SI}	-329.22*** (34.66)	1392.02 (1001.82)	3448.99* (1996.17)	6801.10*** (2243.708)
λ_{NSNI}	-582.55* (346.56)	-2622.47 (3931.20)	1686.91 (1831.21)	10608.62***(2765.08)
Constant	333.39*** (38.18)	-495.61*** (47.34)	-17.44*** (4.72)	3756.807***(793.508)
σ 2	34.09*** (5.09)	2.12 (1.30)	99.44 (61.82)	174***(64.15)
ρ_{SNI}	-0.607*** (0.097)	-0.998 (0.822)	-0.351** (0.145)	0.66**(0.31)
ρ_{INS}	-0.128 (0.331)	-0.99** (0.49)	-0.816 (0.819)	-0.03 (0.71)
ρ_{SI}	-0.178* (0.097)	0.30 (0.24)	0.894* (0.454)	0.63***(0.06)
ρ_{NSNI}	-0.316 (1.440)	-0.57 (0.97)	0.535 (0.453)	0.54***(0.02)

Source: Field data (2024)

***: Significant at 1%; **: Significant at 5%; *: Significant at 10%. (Bootstrapped standard errors in parentheses)

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Table 6: Parameter estimates from selectivity correction based on multinomial logit for household food security using the household food insecurity access scale

Variables	SNI Estimate	INS Estimate	SI Estimate	NSNI Estimate
Plot ownership	0.029(0.048)	-0.119(0.234)	-0.286(0.245)	-0.228(0.169)
Farm distance	0.002(0.010)	0.004(0.007)	0.001(0.005)	0.007*(0.004)
Flat topography	-0.281(0.273)	-0.076(0.300)	-0.535(0.599)	-0.087(0.122)
Access to credit	0.003(0.003)	-0.496(0.373)	-0.274(0.262)	-0.324(0.314)
Training	-0.231(0.230)	-0.216(0.235)	-0.210*(0.122)	-0.018 (0.146)
Extension visits	-0.159(0.100)	-0.056(0.304)	0.295***(0.096)	-0.136 (0.195)
Experience	-0.002(0.024)	0.012(0.016)	0.008(0.009)	0.001(0.009)
Education	-0.015(0.053)	-0.037(0.056)	-0.014(0.031)	-0.055*(0.032)
Household size	-0.086(0.100)	-0.098(0.128)	-0.067*(0.040)	0.002(0.056)
Gender	-0.170(0.116)	-0.023(0.253)	-0.228(0.242)	0.009(0.115)
Residential status	0.552(0.582)	-0.174(0.462)	0.538(0.617)	-0.67**(0.308)
Farm asset	-0.299***(0.094)	-0.135(0.196)	-0.055**(0.027)	-0.206***(0.07)
Land holding	0.024(0.092)	-0.004(0.026)	-0.011(0.017)	0.008(0.064)
Religion	0.261(0.278)	0.353(0.614)	0.196(0.139)	-0.409*(0.216)
Transitional zone	-0.012(0.018)	-0.124(0.277)	-0.255**(0.128)	-0.024(0.146)
λ_{SNI}	1.882(1.403)	-0.603(1.146)	-0.837(1.685)	0.126(0.546)
λ_{INS}	0.156(0.146)	1.332(1.453)	-0.358(1.042)	1.351(1.040)
λ_{SI}	1.329(1.360)	-0.307(0.296)	-2.157(0.980)	-0.706(1.225)
λ_{NSNI}	2.874**(1.432)	-2.013(1.388)	-0.135(0.669)	-2.823*(1.589)
Constant	4.756***(1.282)	3.058***(1.392)	2.314(1.295)	3.552***(0.382)
σ 2	1.367(1.205)	1.379(0.847)	0.998(0.776)	1.452**(0.708)
ρ_{SNI}	0.609(1.163)	-0.513(1.052)	-0.838(1.339)	0.104(0.426)
ρ_{INS}	0.133(0.126)	0.134(0.175)	-0.358(0.826)	0.921(0.766)
ρ_{SI}	0.137(0.127)	-0.262(0.256)	-0.159(0.172)	-0.586(0.899)
ρ_{NSNI}	0.458**(0.187)	-0.715(1.090)	-0.135(0.533)	-0.342**(0.139)

Source: Field data (2024)

***: Significant at 1%; **: Significant at 5%; *: Significant at 10%. (Bootstrapped standard errors in parentheses)

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Table 7: Parameter estimates from selectivity correction based on multinomial logit for household food security using the household food consumption score

Variables	SNI Estimate	INS Estimate	SI Estimate	NSNI Estimate
Plot ownership	6.406(5.342)	2.863(1.825)	7.232(7.364)	1.042(1.315)
Farm distance	-0.037(0.232)	-0.042(0.057)	-0.376**(0.188)	0.003(0.034)
Flat topography	1.702(7.855)	-2.221(2.203)	-12.4(17.74)	0.388(0.912)
Access to credit	12.451(8.328)	-1.612(2.471)	-12.89*(7.52)	5.300*(2.959)
Training	5.010(4.955)	4.716***(1.771)	10.381**(5.012)	-0.279(1.142)
Extension visits	-1.039(6.877)	-0.651(2.365)	-7.827**(3.758)	2.192*(1.205)
Experience	0.078(0.562)	-0.002(0.130)	-0.161(0.369)	0.009(0.064)
Education	2.541*(1.461)	0.182(0.495)	0.105(1.377)	0.187(0.223)
Household size	3.006(2.953)	-0.178(1.040)	-0.439(1.582)	0.345(0.423)
Gender	26.685**(10.67)	0.911(1.923)	6.698(8.078)	0.013(0.876)
Residential status	-15.881(12.662)	0.998(3.057)	9.985(19.018)	1.437(2.196)
Farm asset	1.930(2.832)	7.964**(3.697)	1.650(1.238)	1.849(1.280)
Land holding	0.803(2.134)	0.009(0.232)	1.246(0.813)	-0.566(0.612)
Religion	4.588(8.684)	-35.366*(20.483)	-9.896*(5.856)	0.364(1.787)
Transitional zone	9.326(6.895)	0.431(2.010)	-2.714(5.555)	-0.920(1.052)
λ_{SNI}	-31.298(34.049)	8.733(8.415)	-13.381(42.128)	13.874*(7.398)
λ_{INS}	-2.003(9.835)	-5.971(10.903)	53.260(39.868)	-2.139(7.245)
λ_{SI}	31.635(37.989)	1.011(2.633)	46.027(28.838)	35.490***(12.12)
λ_{NSNI}	-89.387*(45.841)	9.416(11.700)	-4.290(17.917)	15.286(9.733)
Constant	148.74**(75.23)	41.680**(17.39)	83.4**(42.14)	22.067***(3.13)
σ 2	561.290(619.756)	59.433(45.733)	1458.14(1056.2)	207.449*(117.13)
ρ_{SNI}	-0.321(0.225)	0.133(1.012)	-0.350(0.998)	0.963**(0.433)
ρ_{INS}	-0.695*(0.369)	-0.775(1.125)	0.395***(0.044)	-0.255(0.811)
ρ_{SI}	0.335(0.122)	0.131(0.319)	0.205*** (0.05)	0.464***(0.021)
ρ_{NSNI}	-0.941**(0.430)	0.221(0.224)	-0.112(0.400)	0.825*(0.406)

Source: Field data (2024)

***: Significant at 1%; **: Significant at 5%; *: Significant at 10%. (Bootstrapped standard errors in parentheses)

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Table 8: Parameter estimates from selectivity correction based on multinomial logit for household food security using the reduced coping strategies index

Variables	SNI Estimate	INS Estimate	SI Estimate	NSNI Estimate
Plot ownership	-1.838(1.740)	-2.916(1.924)	-4.109**(2.014)	-2.079**(1.029)
Farm distance	0.193**(0.077)	0.158**(0.065)	0.067*(0.039)	0.100**(0.045)
Flat topography	-4.367(2.767)	1.879(2.457)	-0.037(2.363)	-0.724(1.239)
Access to credit	-0.457(2.310)	-0.258(2.705)	-2.800(1.793)	3.260(3.109)
Training	0.869(1.638)	0.001(1.647)	-2.161**(1.016)	1.368(1.415)
Extension visits	-0.024(1.727)	-0.351(2.514)	0.822(0.591)	1.329(1.931)
Experience	0.119(0.172)	0.077(0.107)	0.049(0.068)	0.121(0.083)
Education	0.215(0.360)	0.271(0.404)	-0.034(0.217)	-0.305(0.291)
Household size	-0.769(0.767)	-1.116(1.027)	-0.319(0.273)	-0.945*(0.535)
Gender	2.057(2.097)	-0.129(2.103)	0.965(1.302)	1.160(0.997)
Residential status	4.800(3.932)	-0.196(3.159)	-3.073(3.964)	-1.460(3.041)
Farm asset	-2.043***(0.741)	-1.957*(1.122)	-0.53***(0.182)	-3.486*(2.105)
Land holding	-0.619(0.588)	-0.062(0.185)	-0.171(0.127)	-0.168(0.670)
Religion	2.373**(1.056)	4.574(4.914)	2.458**(1.007)	-2.049(2.199)
Transitional zone	-2.013(1.696)	-0.210(2.081)	-0.576 (0.863)	1.737(1.398)
λ_{SNI}	14.114*(7.677)	-5.458(8.303)	9.306(10.286)	-7.333*(4.437)
λ_{INS}	2.328(2.699)	4.796(10.804)	2.889(7.727)	20.662**(10.046)
λ_{SI}	-0.922(10.152)	2.852(2.526)	-6.925(6.102)	2.139(14.101)
λ_{NSNI}	22.882**(9.952)	3.247(10.589)	-0.679(3.972)	-24.260*(13.233)
Constant	14.401(8.847)	2.117(10.319)	14.599*(8.566)	19.779***(4.06)
σ 2	60.781(46.821)	39.687(45.333)	33.242(32.951)	148.372*(78.512)
ρ_{SNI}	0.999**(0.520)	-0.866(1.115)	0.614(1.204)	-0.602*(0.359)
ρ_{INS}	0.299(0.343)	0.761(1.153)	0.501(0.904)	0.696**(0.287)
ρ_{SI}	-0.118(1.148)	0.453(0.289)	-0.496*(0.245)	0.176(1.063)
ρ_{NSNI}	0.935**(0.397)	0.515(1.179)	-0.118 (0.492)	-0.992***(0.017)

Source: Field data (2024)

***: Significant at 1%; **: Significant at 5%; *: Significant at 10%. (Bootstrapped standard errors in parentheses)

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APPENDIX 4: PLAGIARISM RESULTS

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