Ghana's Fertilizer Subsidy Program (GFSP) and Complementarity of agricultural intensification technologies: any role to build household food security resilience?

By

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PREFACE

The research contained in this thesis was undertaken and completed by the candidate as a PhD thesis in the discipline of Agricultural Economics, School of Agricultural, Earth and Environmental Sciences, College of Agriculture, Engineering and Science, University of KwaZulu-Natal, Pietermaritzburg, South Africa. The research had no financial support from any individual or organization.

The contents of this research have not been submitted in any form to another university. Except where others' work is acknowledged in the text, the results reported are purely based on the candidate's investigations.

As the candidate's supervisor, I agree to the submission of this thesis:

Signed 

Date: 12-12-2024

Professor E.W. Zegeye (Supervisor)

DECLARATION 1: PLAGIARISM

I, Alhassan Nuhu Jinbaani, declare that:

(i) The research reported in this thesis, except where otherwise indicated or acknowledged, is my original work;

(ii) This thesis has not been submitted in full or in part for any degree or examination to any other university;

(iii) This thesis does not contain other person's data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons;

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(v) Where I have used material for which publication followed, I have indicated in detail my role in the work;

(vi) This thesis is primarily a collection of materials, prepared by myself, published as journal articles or presented as a poster and oral presentation at conferences. In some instances, additional material has been included;

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Signed 

Alhassan Nuhu Jinbaani

Date: 12/12/2024

DECLARATION 2: PUBLICATIONS AND CONFERENCE CONTRIBUTIONS

A. PUBLICATIONS

The following publications (published and submitted/under review) from the research presented in this thesis.

Chapter 3

1. **Jinbaani AN** and Wale E. 2023. How does participation in Ghana's fertilizer subsidy program (GFSP) affect the adoption of sustainable intensification practices (SIPs) and gross farm inputs? Development Studies Research, 10:1: 2180047. DOI: 10.1080/21665095.2023.2180047. https://doi.org/10.1080/21665095.2023.2180047

Chapter 4

2. **Jinbaani AN** and Wale E. Impacts of Participation in Ghana's Fertilizer Subsidy Program (GFSP) on multiple dimensions of food security. Cogent Food & Agriculture (Under review)

Chapter 5

3. **Jinbaani AN** and Wale E. Impacts of the complementarity of Integrated Soil Fertility Management (ISFM) technologies on multiple dimensions of food security: evidence from Ghana. Development in Practice (Under review)

B. CONFERENCE CONTRIBUTIONS:

1. **Jinbaani AN** and Wale E. 2024. Does Participation in Ghana's Fertilizer Subsidy Program (GFSP) Affect Multiple Dimensions of Food Security? Paper presented at the 32nd International Conference of Agricultural Economists (ICAE), New Delhi, India, 2 - 7 August 2024.

2. **Jinbaani AN** and Wale E. 2024. Does the Complementarity of Integrated Soil Fertility Management (ISFM) Technologies Affect Multiple Dimensions of Food Security? Evidence from Ghana. Paper presented at the 32nd International Conference of Agricultural Economists (ICAE), New Delhi, India, 2 -7 August 2024.

3. **Jinbaani AN** and Wale E. 2023. Impacts of Participation in Ghana's Fertilizer Subsidy Program (GFSP) on multiple dimensions of food security and resilience. Paper presented

at the Joint Conference of African Association of Agricultural Economists (AAAE) and Agricultural Economic Association of South Africa (AEASA), Durban, South Africa, 18 - 21 September 2023.

4. **Jinbaani AN** and Wale E. 2022. Impacts of the complementarity of Integrated Soil Fertility Management (ISFM) technologies on multiple dimensions of food (in)security and household resilience: evidence from Ghana. Paper presented at the 59th Agricultural Economic Association of South Africa (AEASA) Conference, Swakopmund, Namibia, 2 - 5 October 2022.

5. **Jinbaani AN** and Wale E. 2022 Impacts of Participation in Ghana's Fertilizer Subsidy Program (GFSP) on multiple dimensions of food security and resilience. Paper presented at the 15th Annual Interdisciplinary Conference, Institute for Interdisciplinary Research (IIR), University for Development Studies, Ghana, 7 - 8 September 2022.

6. **Jinbaani AN** and Wale E. 2021. How does participation in Ghana's Fertilizer Subsidy Program (GFSP) affect investment in Green Revolution Technologies and Gross Farm Expenses? Paper presented at the College of Agriculture, Engineering and Science online Postgraduate Research and Innovation Symposium, University of KwaZulu-Natal, South Africa, 9 - 10 December 2021.

7. **Jinbaani AN** and Wale E. 2021. Evolution of the Green Revolution and Input Subsidies: Comparative Analysis of Land Productivity for Maize in Asia and Africa. Paper presented at the 32nd Research Staff Association (RSA) Annual General Meeting and 3rd Scientific Conference, CSIR-Science and Policy Research Institute, Accra, Ghana, 19 - 21 October 2021

ABSTRACT

There is a decline in recent times of Ghana's agricultural sector's contribution to national GDP. In addition, the position of the crops sub-sector slipped from being the second largest economic activity in 2018 to being the third largest economic activity in 2019. Agriculture in Ghana remains largely subsistent, contributing almost 80% of the national food consumption. These declines have risen concerns among policy makers about meeting the country's food security needs and achieving SDGs 1 and 2. Food insecurity persists in Ghana. For instance, Ghana remains not self-sufficient in maize production. This situation is often blamed on poor yields from farmers' fields. Decline in soil fertility has been cited in the literature as the cause of low yields. Subsequently, increased use of mineral fertilizers is being promoted in Ghana since it is considered as the alternative to improving crop yields. Climate change/variability and other shocks including increased cost of mineral fertilizer have compelled the government of Ghana to implement the Ghana's Fertilizer Subsidy Program (GFSP).

Consequently, increasing application of mineral fertilizers has been reported in the literature of between six to ten times more since 2010 than it was in the 2000s. The number of farmers using mineral fertilizers has also increased due to Fertilizer Subsidy Programs (FSPs). In the long-run, crop yield tends to increase with the application of mineral fertilizers only when integrated with that of organic materials. This calls for implementation of sustainable production systems that enhance efficiency of mineral fertilizers and soil health. Without widespread adoption of sustainable intensification practices among smallholder farmers, declining soil fertility and food insecurity will persist in SSA.

This study is, therefore, aimed at addressing three identified empirical knowledge gaps in the literature regarding FSPs, farmers' own investments in promoting intensification practices, rural development, and food (in)security. Firstly, there was the dearth of assessment that is rigorous of the impact of FSPs on sustainable intensification practices. Earlier empirical assessments on FSPs centered on their evolution and concepts, advantages and disadvantages associated with their implementation. These disadvantages finally led to their halt. Evidence exists regarding the impacts of Fertilizer Subsidy Programs (FSPs) on household welfare and input market development. However, studies in the past have not looked at the contribution of FSPs to sustainable intensification practices and, farm inputs in general, among smallholder farmers. Addressing this gap could help policy makers in designing and implementing agricultural policies and programs that address environmental sustainability, climate change-related issues and rural development.

The second identified gap was the paucity of literature on the contribution of FSPs to all the four food security dimensions. Empirical evidence remains limited in explaining food security's complex

nature and its drivers to policy makers and development practitioners. The current approach does not offer a holistic pathway in addressing food insecurity since it results from multiple drivers such as availability, access, utilization and stability of food. Evaluating what policies, socio-economic characteristics and institutional factors positively impact on these multiple dimensions of food security could help government formulate policies that could reduce food insecurity in Ghana.

The third gap identified was limited attention given to the complementarity of ISFM practices in improving household food security. In addition, exit strategy has not been provided in the current literature for FSPs despite reported evidence of their unsustainability due to capture by people of influence, inefficiencies and poor targeting of program beneficiaries. Widespread adoption of ISFM practices could serve as exit strategies for FSPs, not only in Ghana but SSA as a whole. Empirical studies on the impact of ISFM practices in improving soil organic carbon has largely been limited to field experiments in Ghana. This makes it difficult to relate the impact of ISFM practices to household food security. With proper empirical evidence on the impact of complementarity of ISFM practices on households' food security using household survey data, policies could be designed to enhance adoption of the complete package of ISFM practices at the plot level.

Following the knowledge gaps identified, the specific objectives of the study were to: (i) assess the extent to which GFSP affected adoption of agricultural intensification technologies and gross farm inputs; (ii) investigate the impact of GFSP on multiple dimensions of household food security; and (iii) examine the impacts of the complementarity of Integrated Soil Fertility Management (ISFM) technologies on multiple dimensions of food security.

First, two-stage least squares with instrumental variables (2SLS-IV) and endogenous switching regression (ESR) were used to study the effect of participation in Ghana's Fertilizer Subsidy Program (GFSP) on the adoption intensity of Sustainable Intensification Practices (SIPs) and gross farm inputs. A nationally representative dataset of 4,365 maize-growing households for two survey periods (2012/13) and (2016/17) who purchased mineral fertilizers was used for the study.

The study finds that participation in the GFSP increased the adoption intensity in both SIPs and gross farm inputs. The implication is that investments into climate-smart technologies and gross farm inputs by beneficiaries of GFSP is attributable to participation in the program. This finding explains the crucial role of GFSP as a pro-rural development policy beyond just the provision of mineral fertilizers to smallholder maize farmers to achieve increased productivity. This is because of the forward and backward linkages between rural agricultural input markets and farmers' direct purchases of farm inputs. The study also found mutual aid schemes, farmer cooperatives, agricultural loans, household wealth, and connection of a farm household dwelling to the national electricity grid to positively and

significantly increased adoption intensity of SIPs and gross farm inputs. This finding highlights the fact that besides government policy such as GFSP towards improving adoption of SIPs and rural development, rural infrastructure and farmer institutions also have a critical role to play.

Secondly, the impact of participation in GFSP on multiple dimensions of food security was examined using propensity score matching without replacement, nearness neighbor matching, inverse probability weighting, and inverse probability weighted regression adjustment. The food availability dimension in terms of average yield of maize was 1.5 ton/Ha, still lower than the potential yield estimate of 5.5 tons/Ha by Ghana's Ministry of Food and Agriculture. It implies that complementary adoption of technologies is key to bridging this productivity gap. Food access and stability dimensions increased in 2017 compared to 2013. However, the utilization dimension of food security declined, implying that the diversity of food intake may not necessarily be explained by increases in the access dimension of food security in terms of food and total household expenditures. The empirical results indicate that the overall average treatment effect of the GFSP was positive and statistically significant for food availability and food access. The GFSP increased maize yield/Ha between 29 to 34 percent at $p < 0.01$ among program beneficiaries. For food access, the GFSP increased household consumption expenditure by 37 percent at $p < 0.01$. The effect of GFSP on the stability dimension of food security was also positive, though weaker statistically against robustness checks. There was, however, negative effect of GFSP on food utilization. The study could not find a straight forward relationship between participation in the GFSP and household food security, as food availability may not necessarily lead to better utilization or nutrition. The less impressive performance of GFSP on utilization and stability dimensions of food security implies that maize growing households who benefited from the program are still food insecure. The positive and significant relationship between the value of agricultural equipment owned and engagement in off-farm enterprise with participation in GFSP may imply that smallholder farmers who may have 2Ha or less of farmland under cultivation but can afford the full cost of fertilizer are benefitting from the subsidy program. The study also found significant and negative correlation between increasing farm size and participation in the subsidy program. It means that farmers with farm sizes greater than 2Ha have not benefitted from the program.

Finally, the study examines the impacts of the complementarity of Integrated Soil Fertility Management (ISFM) technologies on multiple dimensions of food security using the Multinomial Endogenous Switching Regression (MESR). Regarding the complementarity of adoption of ISFM technologies, the results show very low adoption of complementary technologies among maize growing households in Ghana. The empirical results from the MESR showed that all the ISFM choices positively and significantly determined all the dimensions of food security. Joint adoption of

the complete ISFM package gives the highest gain in all the dimensions of food security, except the stability dimension. Joint adoption of mineral and organic fertilizers gave the highest gain for achieving household food stability. The implication is that the availability dimension of food security can be met whilst households' food utilization can still fall below acceptable threshold. Rural development interventions have to focus on the adoption of the complete ISFM package. Otherwise, the piecemeal adoption of any one or two components will not have the desired impact. Input subsidy programs should include organic fertilizers to optimize program benefits. The implication is that policy makers and farmers should see organic and mineral fertilizers as complementarities but never as substitutes as it is currently the case in Ghana. From the multinomial logit results, the study found that household characteristics (e.g., number of years a household spent in school, land ownership, and household head engagement in off-farm work) and institutional factors (such as presence of a mutual aid scheme, access to extension visits, and distance to agriculture office) positively and significantly increased the likelihood of joint adoption of all the ISFM technologies. This finding underscores the need for a dual approach in promoting the adoption of ISFM practices among smallholder farmers by policy makers. This approach should take into account the role of government in increasing the number of extension staff and provision of the necessary infrastructure and logistics and the role of pro-farmer institutions such as farmer credit schemes and cooperatives. Future studies could quantify the potential contribution of ISFM technologies, and broadly, SIPs to the national GDP. Such an effort could add empirical evidence on the pay-offs associated with these technologies for increased adoption by smallholder farmers. Examining these and other related questions employing panel data could result in better understanding of the temporal and spatial dimensions of ISFM practices and their food security impacts and environmental sustainability.

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DEDICATION

This thesis is dedicated to my late parents and all teachers of Sub-Sahara Africa (SSA) who work under difficult and challenging conditions.

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LIST OF ACRONYMS

AGRA	Alliance for Green Revolution in Africa
ATT	Average Treatment Effect on the Treated
CAADP	Comprehensive African Agricultural Development Programme
COVID-19	Coronavirus Disease
DDS	Dietary Diversity Score
ESR	Endogenous Switching Regression
FAO	Food and Agriculture Organization of the United Nations
FCS	Food Consumption Score
FFS	Food Frequency Score
FSPs	Fertilizer Subsidy Programs
FVS	Food Variety Score
GDP	Gross Domestic Product
GFSP	Ghana's Fertilizer Subsidy Program
GHS	Ghana Cedis
GLSS	Ghana Living Standard Survey
GoG	Government of Ghana
GSC	Ghana Seed Company
GSS	Ghana Statistical Service
HA	Hectare
HDDI	Household Dietary Diversity Index
HFIAS	Household Food Insecurity Access Scale
HHS	Household Hunger Scale
IFDC	International Fertilizer Development Center
IIA	Independence of Irrelevant Alternatives
IMR	Inverse Mills Ratio

ISFM	Integrated Soil Fertility Management
IV	Instrumental Variable
MERS	Multinomial Endogenous Switching Regression
MIHFP	Months of Inadequate Household Food Provisioning
MNL	Multinomial Logit
MoFA	Ministry of Food and Agriculture
NGOs	Non-Governmental Organizations
NPK	Nitrogen, Phosphorus, and Potassium
SAP	Structural Adjustment Program
SDGs	Sustainable Development Goals
SIPs	Sustainable Intensification Practices
SSA	Sub-Saharan Africa
TIP	Targeted Inputs Program
UN	United Nations

CHAPTER 1: INTRODUCTION

1.1 Background to the Study

Climate change and variability resulting in increasing floods and drought have caused decreasing food supply in many African countries (Nkwi et al., 2023; Bedeke, 2023). In addition, recent global phenomena, such as the 2008 global food crisis, and very recently, the COVID-19 pandemic have caused disruptions to food systems, livelihoods, and food security (Tadasse et al., 2016; Alabi and Ngwenyama, 2023; Kunyanga et al., 2023). Declining soil fertility and poor agricultural practices (Dimkpa et al., 2023) exacerbated by increasing population growth and demand for food are widening food insecurity in sub-Sahara Africa (FAO et al., 2019; Dimkpa et al., 2023). According to estimates from FAO et al. (2019), about 820 million people are undernourished worldwide and around 2 billion people suffer from moderate to severe food insecurity. The African continent is witnessing a surge in hunger (FAO et al., 2019). Another disruption to global food security is the Russia-Ukraine war. The war has caused prices of food and fertilizer to rise. Export of grains has also been restricted from these two countries which are both agricultural power houses (Ben Hassen and Bilali, 2022; Alexander et al., 2023).

Governments in Sub-Saharan Africa (SSA) have responded to these shocks with the reintroduction of fertilizer subsidies aimed at reducing their impacts on food systems, specifically the production component of food systems and cushioning consumers (Nhlengethwa et al., 2023). Subsequently Fertilizer Subsidy Programs (FSPs) have become important agricultural policy instruments in SSA as a measure against shocks to smallholder farming systems. FSPs are also considered as policy strategies to achieve a green revolution in Africa (Doward, 2009; Jayne and Rashid, 2013) as evidenced in their potential of increasing yield by 18% and household income by 16% in some SSA countries including Malawi, Nigeria, Zambia and Kenya (Nguyen et al., 2023). Therefore, FSPs once again have gained prominence within the agricultural policy framework of developing countries (Doward, 2009; Jayne and Rashid, 2013). Other macro-level benefits attributed to FSPs include increased consumption for staples, improved wages and increased employment for agricultural labour. Others include improved real incomes, decreased rates of poverty among smallholder farm households, as well as increased agricultural Gross Domestic Product (GDP) (Hemming et al., 2018).

The use of FSPs declined in the 1980s and 90s (Hemming et al., 2018) largely because of the private input markets (Morris et al., 2007). Their re-introduction by most African countries between 2007 and 2008 has failed to reverse the shortcomings associated with the past FSPs such as fertilizer overuse among smallholder farmers (Rashid et al., 2013), less impact on the development of input markets in the private sector, and corruption related procurement procedures (Druilhe and Barreiro-Hurlé, 2012).

A number of studies have assessed the positive impacts of fertilizer subsidies on various outcome variables such as increased national food supply and farmers' farm level output, at least in the short-term (Jayne et al., 2018), increased farm incomes (Wossen et al., 2017; Zinnabauer et al., 2018; Ricome et al., 2024), increased total food and non-food expenditures (Wossen et al., 2017) and both manure and total mineral fertilizer use (Ricome et al., 2024). The redesign and implementation of 'smart' subsidy programs has also led to investigations on the extent to which current subsidy programs are achieving the 'smart' objective. 'Smart' subsidy programs have the objective of developing the private retail agro-input markets through increased purchases of agro-inputs by smallholder farmers (Morris et al., 2007). Many studies have found mixed results in this regard (Mason and Ricker-Gilbert, 2012; Mason and Jayne, 2013; Ricker-Gilbert et al., 2013; Liverpool-Tasie, 2014; Obayelu, 2016; Mather and Jayne, 2018; Kaiyatsa et al., 2018). Some studies have found evidence of FSPs crowding out the private input markets (Mason and Ricker-Gilbert, 2012; Mason and Jayne, 2013; Ricker-Gilbert et al., 2013; Obayelu, 2016). Others have found evidence of subsidy programs crowding in private input markets (Liverpool-Tasie, 2014; Kaiyatsa et al., 2018). However, the relationship between fertilizer subsidy programs and commercial purchases of soil intensification practices on one hand, and that of fertilizer subsidy programs and food security on the other hand, remains less explored. This is despite input subsidies being used by governments to cushioning smallholder farmers against input price shocks due to external factors such as global food crisis, health pandemics and wars, and at the same time sustainably meeting their food security needs.

Existing fertilizer subsidy programs may implicitly assume that they result in outcomes such as sustainable land management practices (Vondolia et al., 2012) and improved food security. This is because sustainable land management practices are complementary technologies and adoption of fertilizer may lead to their investments by farmers. Fertilizer adoption also requires complementary inputs such as suitable soil and water conditions for optimum nutrient uptake by plants (Vondolia et al., 2012). Empirically investigating such relationships may help in the design and implementation of on-going and future FSPs for improved outcomes. Beyond FSPs, the study also explores the relationship between the complementarity of soil fertility management practices and multiple dimensions of food security. Given that the concept of food security is about an individual's ability to meet its fundamental nutritional and health needs (Tadasse, 2016), it is important that strategies are developed that enable individuals and households to empower themselves, so that they can operate sustainably and profitably without fertilizer subsidies or when the fertilizer subsidy program is phased out. However, Vanlauwe et al. (2023), Pergner and Lippert (2023) and Bossolani et al. (2023) argue that the use of mineral fertilizer is still crucial in improving agricultural land productivity even under soil health management and sustainable agricultural farming systems. As climate risks increase with

increasing erratic rainfall and temperature, meeting the food security needs of the increasing population through the application of mineral fertilizers becomes less reliable (Heisse and Morimoto, 2023). This is because as Heisse and Morimoto (2023) found out, the adoption decision of mineral fertilizers among smallholder farmers is highly responsive to climate variability. This means that promoting mainly the use of mineral fertilizers by agricultural policies may defeat the objective of achieving sustainable agricultural intensification.

Adopting agricultural intensification technologies, for example, could complement subsidies to arrest deteriorating soil fertility due to population pressure, reduced fallow periods, and poor soil and water conservation practices. The claim that low fertilizer rates applied by farmers in Africa is due to farm budget constraints and poor access to inputs (Morris et al., 2007; Vanlauwe et al., 2023), which can be resolved with the introduction of fertilizer subsidies, might not be entirely true. It overlooks important agronomic constraints such as inherently poor soil fertility, exacerbated by years of unsustainable agricultural practices (Morris et al., 2007) that also limit fertilizer demand (Jayne et al., 2018). Application of fertilizer is only effective in the short-run in increasing crop yield. In the long-run, however, crop yield tends to decrease with the application of chemical fertilizer without manure or organic matter (Hui et al., 2017). Improving agronomic systems in the short-term with the aim of building resilient food systems in the long-term thus becomes paramount for improved food security for smallholder farmers and overall poverty reduction in Africa.

Following the adoption of the Comprehensive African Agriculture Development Programme (CAADP), under the New Partnership for Africa Development, and the subsequent Malabo Declaration in 2014, African Union (AU) member countries made commitment to increase food security and eradicate hunger among Africa's smallholder farmers by 2025. This is to be achieved by doubling current agricultural productivity levels to attain accelerated agricultural growth by 2025. Member countries are expected to develop policies and put in place support services that lead to access to quality and affordable inputs. Such policies and support services must also facilitate reliable and sustainable production services (AUC, 2014). This explains why most African countries now have in place input subsidies. It is believed that reducing hunger calls for investments that are linked to production and supported by safety net programs, such as FSPs, that are also targeted at poor farmers who have vulnerability to the negative impacts of climate change (AUC, 2003; AUC, 2014) and other disruptions to food systems such as COVID-19. But the question that still remains unanswered is: “Are these FSPs contributing to sustainable production practices and food security?” These poor farmers mostly live in rural areas. They are in the majority of the most extreme poor in the world, living on or less than US$1.25 a day (Barrett and Bevis, 2015).

Complementing the use of synthetic fertilizers with sustainable intensification of agricultural technologies will help develop resilient food systems. “A food system is the network of activities connecting people to their food. Food systems operate at multiple spatial scales and include production, distribution, and consumption components, connecting through complex social, ecological and economic relationships” (Schipanski et al., 2016, pp.601). The resilience of a food system refers to “the capacity of people to produce and access nutritious and culturally acceptable food over time and space in the face of external shocks (Schipanski et al., 2016, pp.601)”. The study looks at the production component of food systems for maize with emphasis on the benefits of adopting multiple agricultural intensification. This is situated within the context of environmental shocks or disruptions to food systems and government responses in the form of the Ghana Fertilizer Subsidy Program (GFSP) as well as smallholder maize farmers’ responses through investments in technology adoption. Cropping systems when integrated with soil fertility management techniques, can increase mineral fertilizer use efficiency and decrease the adverse environmental effects of the application of mineral fertilizers. (Jayne et al., 2019; Zhang et al., 2015).

The leading staple in Ghana is maize. It is also the leading crop produced and consumed by most farming households (Adu et al., 2014). Maize accounts for 50 percent of cereals produced in Ghana (Ragasa et al., 2014; Darfour and Rosentrater, 2016). It is produced under rainfed conditions and by mostly smallholder and resource-poor farmers (Adu et al., 2014; Darfour and Rosentrater, 2016). The drivers of demand for maize have been Ghana’s rising population and urbanization. Demand for maize is also driven by the now growing poultry and fish sectors in Ghana (Ragasa et al., 2014). Despite maize being the most widely grown staple crop, Ghana is still not self-sufficient in its production. This is mainly because maize farmers continue to experience low yields (Awunyo-Vitor et al., 2016). Technology adoption among smallholder maize farmers thus becomes very imperative to improving maize yields and food security. Ghana’s input subsidy program started with emphasis on only fertilizer in 2008 (Druilhe and Barreiro-Hurlé, 2012). However, in 2017, the subsidy was extended to cover improved seeds (GoG, 2017). Ghana’s FSP is modelled in the form of a public-private partnership with fertilizer importing companies and the private retail input dealers playing a key role (Banful, 2009; Banful, 2010; Houssou et al., 2017).

1.2 The Input Market and Ghana’s Fertilizer Subsidy Program (GFSP)

In 1991, Ghana opened up and privatized the import and marketing of mineral fertilizers, transferring control and regulations to the Ministry of Food and Agriculture (MoFA). In the same year that the Ghana Seed Company (GSC) was privatized, farmers and other private sector participants became empowered and took over the responsibility of producing improved seed. The private sector's overall involvement in the seed and fertilizer markets has benefited from these regulatory developments (IFDC, 2002). The government does

not purchase, distribute, or sell fertilizer under the fertilizer subsidy program because the input sector has been liberalized (Banful, 2009). Instead, the government distributes subsidized fertilizer to farmers through a passbook and, as of late, a voucher system is being used. There are daily record sheets contained in the passbook. The purpose of the daily record sheets is to help keep track of program participants more easily and for farmers to record their farming activities (Houssou et al., 2017). FSPs have been pivotal in promoting the adoption of new and improved technologies throughout SSA. There is evidence to support the idea that the private sector should create markets for agricultural inputs (Freeman and Kaguongo, 2003). In order to do this, the government and the private sector agro-input dealers have teamed up under the GFSP in providing farmers with subsidized fertilizer through the use of vouchers (Banful, 2010).

The year 2008 saw the launch of the voucher-based GFSP in response to the world food crisis and rising agricultural input costs, particularly for mineral fertilizers. The voucher system was designed to model a public-private partnership, in which state-employed agricultural extension workers were exclusively in charge of distributing and repaying subsidy vouchers. The idea behind the voucher-based subsidy scheme was to raise the amount of fertilizer that farmers would commercially demand by crowding-in the private sector into the fertilizer market and lowering fertilizer prices through subsidies (Banful, 2010; Baltzer and Hansen, 2011; Houssou et al., 2017). The vouchers issued to farmers were fertilizer-specific and region-specific. Famers purchased the relevant fertilizer with the voucher plus an amount of cash for a 50kg bag of fertilizer in the region of issue (Banful, 2010). Vouchers meant for one administrative region could not be used in a different administrative region. The cost of the subsidy was 50 percent of the market price for each 50kg of the subsidized fertilizer (Banful, 2009). The voucher-system was, however, replaced in 2010 with a waybill receipt system due to weaknesses associated with it. These include high administrative and overheads costs and poor targeting of beneficiaries leading to diversion of subsidized fertilizer (Benin et al., 2013). In addition, the negotiated fertilizer prices between the government and the private fertilizer importers were significantly higher than prevailing market prices before the subsidy program. This could have been a disincentive for farmers' commercial demand for fertilizer. Sale of fertilizer to farmers without vouchers was also considered illegal (Banful, 2009). The recent introduction of a farmer passbook to record farm activities was meant to help improve targeting by tracking beneficiaries under the program (Houssou et al., 2017).

Notwithstanding the improvements in the design over the years, access to the program in Ghana is largely determined by gender and political influence. Women are disadvantaged in the targeting of and accessing subsidized fertilizer. Subsidized fertilizer has also become a political tool for the ruling party to attract and win voters to their side. Distance to private fertilizer retail outlets is still a barrier to farmers accessing subsidized fertilizer. Despite government's increasing funding to the program over the years, access to the

program is still low, about 42.6 percent. However, poorer households largely access the subsidy program (Mustapha et al., 2016). Ghana' fertilizer subsidy program was mainly a response to food price hikes. However, high cost of fertilizer is only one of the many constraints farmers face. The other constraints include high cost of improved seed, high labour cost for on-farm and post-harvest activities, poor storage facilities and unfavourable prices for farm output. Only lowering fertilizer prices in the midst of these constraints will not enable farmers to increase fertilizer use (Banful, 2009). In addition, Africa's second phase of input use has put emphasis on giving out inputs to farmers with little or no attention on encouraging them to use it profitably and efficiently. Encouraging farmers to use complementary inputs and adopt good agronomic management practices including inorganic fertilizers could enhance the benefits of fertilizer subsidy programs in the long-term (Jayne et al., 2018; Giné et al., 2022). Giné et al. (2022) argue that it is worth investing in programmes that improve soil fertility and irrigation instead of subsidy programs due to their limited benefits on agricultural productivity and farmers' welfare.

Ghana's subsidy program has witnessed year-on-year increment since its introduction, as shown in Figure 1.1. A total of 2,510,278 MT of fertilizer has been subsidized to farmers from 2008 to 2022. For the 2018 cropping season for example, which was the tenth year of the implementation of the program, urea, NPK (15-15-15) and NPK (23-10-05) were all covered by the subsidy. The percentage of subsidy was still 50 percent of the full cost of 50 kg of urea, NPK (15-15-15) and NPK (23-10-05) at GHS126, GHS136 and GHS136, respectively (MoFA, 2016).

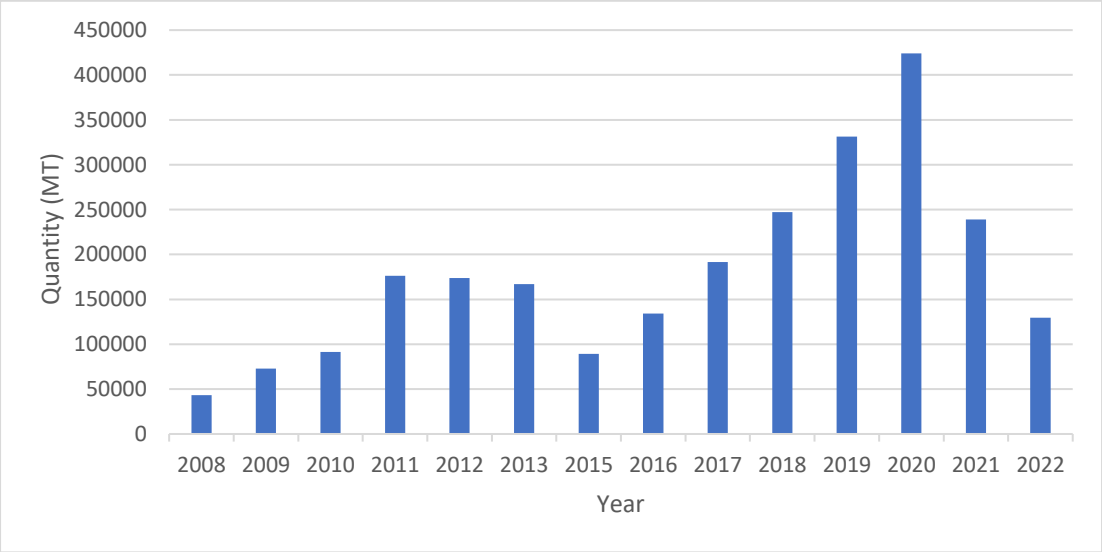


Figure 1.1: Total quantity of fertilizer subsidized between 2008 and 2022

Source: Author's calculation based on MoFA (2016; 2019; 2022)

This means that fertilizer was heavily subsidized in 2018 compared to the 2015 cropping season. Again, there was no subsidy for Sulphate of Ammonia (MoFA 2016). As can be observed in Figure 1.1, the quantity of subsidized fertilizer to farmers increased further in 2019 and 2020 but declined afterwards (MoFA, 2022). The fluctuations regarding the quantity of fertilizer that was subsidized to farmers indicates its financial burden on government. With better options beyond the politics associated with FSPs, government may discontinue the program. As these anecdotal reports exist of quantities of subsidized fertilizer by government to farmers and the cost of the program to government (MoFA 2016; 2019; 2022), limited empirical evidence exists on the success or otherwise of the program on beneficiaries' welfare and the program's contribution towards adoption of sustainable indemnification practices which are also climate-smart technologies.

1.3 Research Problem

Ghana's agriculture has the potential to lift many out of poverty, enhance food and nutrition security as well as create jobs. It has direct impact on the attainment of at least five of the Sustainable Development Goals (SDGs) (MoFA, 2018). A 1 percent growth in agriculture is associated with reducing poverty three times more than the other productive sectors of the economy such as mining, industry, and the services (Ivanic and Martin, 2014; Goyal and Nash, 2017). This is because majority of the people work in the agricultural sector, 70-80% of them produce for home consumption. They are also likely to sell the main crop towards the end of the season as opposed to the early part of the season (Gaddis et al., 2023). In addition, agricultural activities play a major role in pro-poor growth in rural areas, and positively increase income of poorest urban households though with lesser intensity compared to rural households (Sassi, 2023). Food insecurity and poverty have declined over the years in Ghana. For example, some indicators of food insecurity and poverty have declined since 1985 (Van Asselt and Ecker, 2017). Total calories of food consumed have increased from 1500Kcal per day per capita in 1985 to 3000Kcal per day per capita in 2010 (Van Asselt and Ecker, 2017) and 3016 kcal per day per capita in 2013 (Kushitor, 2023). This is 608 Kcal higher than the recommended daily calorie intake of 2408 Kcal for women in Ghana (Kushitor, S.B., 2023). The national prevalence rates of child stunting and child wasting, as indicators of chronic and acute child undernutrition, respectively, have also declined since 2008. Conversely, the national prevalence of poverty has also reduced from 62.9% in 1988 to 24.2% in 2016 (Van Asselt and Ecker, 2017; Cooke et al., 2016).

However, the reduction in both food insecurity and poverty has been linked to good governance (encompassing political, economic, and institutional), not agriculture (Asare-Nuamah et al., 2023). For example, Asare-Nuamah et al. (2023) found that improved economic governance creates job opportunities in the off-farm sector raising incomes among households who reinvest in agricultural production. The

positive relation between political stability and food security is explained in the context of absence of conflicts or violence. Asare-Nuamah et al. (2023) observed that conflicts and violence disrupt food systems and the ability of the government to pursue economic transformation. Food security is positively correlated with institutional governance, which includes rule of law and corruption control. Reducing corruptions has been found to improve the efficient use of limited resources and optimize their effects, which has positively increased food security in Ghana (Asare-Nuamah et al., 2023). However, World Bank (2018) observed that reduction in poverty in Ghana since the 1990s can be attributed to growth in agriculture, especially increased productivity of cocoa. Studies have linked low agricultural productivity in Ghana to declining soil fertility (Marfo-Ahenkora, 2023). Subsequently, this has led to increased use of inorganic fertilizers as an option to increasing crop productivity (Burke et al., 2017; Abebe, 2022; Dimkpa et al., 2023). Higher rates of fertilizer use are promoted across sub-Saharan Africa against the background that there is generally low fertilizer use among smallholder farmers (Liverpool-Tasie et al., 2017). Consequently, the introduction of fertilizer subsidies was to lower the cost of fertilizer and as a means of increasing fertilizer use and making their use profitable to farmers (Liverpool-Tasie et al., 2017; Ricker-Gilbert, 2020).

Despite the introduction of fertilizer subsidies, the majority of farmers still consider subsidized fertilizer expensive in Ghana. Jayne et al. (2015), however, reported an increase in fertilizer use between six to ten times more since 2010 than it was in the early 2000s. Benin et al. (2013) also reported a surge in the number of farmers applying synthetic fertilizers in Ghana. They also reported that the quantity of fertilizer use has increased from 8kg per Ha of land to 13.4Kg/Ha. However, both Ragasa and Chapoto (2017) and Benin et al. (2013) reported that synthetic fertilizer use is profitable (in terms of how much output is obtained from a kilogram of nitrogen applied) among maize farmers in Ghana. According to Ricker-Gilbert (2020), the recent rise in the application of synthetic fertilizers in Sub-Sahara Africa (SSA) is partly because of the implementation of fertilizer subsidy programs. Whereas fertilizer subsidies are considered as correctional measures for the imperfect market system in input delivery (Crawford et al., 2005), distance to fertilizer retail shops still negatively affects fertilizer use. This increases transport and other transaction costs (IFDC, 2012).

Though input subsidies are able to increase yield during a cropping season, available evidence suggests that the programs' expenses typically exceed their benefits (Jayne and Rashid, 2013; Zinnbauer et al., 2018). The cost even becomes larger if we account for environmental and health impacts of chemical fertilizer use. However, input subsidies are difficult to end once started because of political reasons. They have become a tool for gaining support from rural farmers by political leaders when seeking votes with promises normally made to either continue or expand subsidy programs (Morris et al., 2007; Mustapha et al., 2016; Jayne et al., 2018). Despite these challenges, proponents of subsidy programs believe that subsidies remain one of

the ways to improve Africa's agriculture and deliver on improved incomes and food security for smallholder farmers (Minot and Benson, 2009). The current policy direction of the government of Ghana shares this position (GoG, 2017). Consequently, there remain no exit strategies for fertilizer subsidy programs in SSA (Druilhe and Barreiro-Hurlé, 2012; Holden, 2019).

The goal of the current study is to empirically add to the body of literature by looking into whether Ghana's subsidy program has incentivized beneficiaries to invest in Sustainable Intensification Practices (SIPs) and gross farm inputs, improved household food security, and importantly, whether multiple adoption of SIPs without subsidy can improve household food security. The focus of current literature on fertilizer subsidies that looked at 'smart subsidies' is limited to how much commercial purchases have increased for only mineral fertilizers or improved seed due to participation in FSPs (e.g., Liverpool-Tasie et al., 2017; Ragasa and Chapoto, 2017), giving insufficient information on the contribution of FSPs to both private input markets and rural development, in terms of input purchases by farmers from local input dealers. FSPs remain controversial (Druilhe and Barreiro-Hurlé, 2012) largely because the distinction between input subsidies as a rural relief program as against a driver of national economic development (Sibhatu, 2017; Van den Broedk, 2017) has not been well understood in the literature. According to Lambert et al. (2009), farming households benefit rural economies through the purchase of farm inputs. Some rural economies rely heavily on farm operations. Farming households promote local businesses of suppliers of agro-inputs by purchasing farm inputs from them. Consumer products purchased by farm households also sustain local jobs and retail businesses. This explains both the direct and indirect connections farm activities have, with the markets for agricultural inputs and outputs.

In addition, though the connection between FSPs and food security has been established in some instances in the body of literature (Wossen et al., 2017; Carter et al., 2021; Simtowe and De Groote, 2021; Pauw, 2022) and largely on the availability dimension, that of the other food security dimensions such as access, utilization and stability (FAO, 1996) have not been explained or established in the present literature. This is possibly because the conceptualization of the dimensions of food security into metrics is a daunting task. In addition, food security is understood differently by different people as more than 200 definitions of food security exist in the literature (Makombe, 2023). As climate change is projected to increase the number of people prone to hunger in Africa by 16 million in the year 2030, threatening the achievement of the UN Sustainable Development Goal (SDG) 2 of Zero Hunger, improving food and nutrition security through sustainable agriculture, especially for developing countries, investments aimed at improving agricultural productivity that could ameliorate the negative effects of climate change, declining soil fertility as well as other external shocks to food security are worth pursuing (Mason-D'Croz et al., 2018). The pertinent question to pose is the degree to which Ghana's Fertilizer Subsidy Program (GFSP) has contributed to

promoting private investments in climate-smart and sustainable intensification technologies from smallholder farmers and at the same time, to achieving household food security in all the four dimensions (FAO, 1996). Meeting a household's or an individual's needs for food security is so critical to an extent that it requires building the capacity of the said individual or household to remain resilient over time in order to escape food insecurity in times of shocks or stressors. This is referred to as development resilience (Swindale and Bilinsky, 2006). Development resilience can be achieved through adoption of technologies that are climate change-coping strategies in nature and soil fertility restoring.

Governments are already overburdened with budget constraints of having to provide input subsidies (Jayne et al., 2018; Zinnbauer et al., 2018; Rakshit, 2018). The incentive for governments to invest in research and development of input-saving technologies for adoption by farmers is nearly non-existent (Rakshit, 2018). The provision of fertilizer subsidies to farmers is also justifiable in areas where soils are inherently low in nutrients (Scholz and Geissler, 2018). Sustaining agricultural growth and improving farm level productivity requires that farmers adopt integrated soil fertility and crop management practices which include improved seed, application of manure and compost, and integrating cropping systems with legumes, to achieve greater yield response to chemical fertilizers and increasing their profitability (Liverpool-Tasie et al., 2017; Jayne et al., 2019). It is important to promote the adoption of alternatives or complementarities to the use of chemical fertilizers due to the environmental risk factors associated with their use (Scholz and Geissler, 2018). This is important particularly when subsidy programs have largely been found not meeting the objectives that they were meant to achieve and constitute a great burden on national budgets in countries such as Ethiopia, Ghana, Nigeria, Kenya, Tanzania, Malawi and Zambia (Jayne et al., 2018; Zinnbauer et al., 2018).

The Ghana's FSP objectives include increasing farmers' access to inputs, increase the application rates of mineral fertilizer from the average of 8 kg/ha to at least 20 kg/ha among smallholder farmers and increase farmers' incomes (Benin et al., 2013; Jayne et al. 2015). Other objectives of GFSP include increasing agricultural productivity and food security, and support private sector involvement in agricultural input markets (Benin, et al., 2013). The Nigeria's E-wallet Fertilizer Subsidy Programme (EFSP) under the Growth Enhancement Support Scheme has similar objectives of increasing access to and use of mineral fertilizer among smallholder farmers, improving crop production and food security (Popoola, 2022). The Malawian fertilizer subsidy program had the objective of increasing both national and household food security (Dorward et al., 2008; Dorward and Chirwa, 2011). Other objectives of the program include targeting poor and vulnerable households with focus on poverty reduction (Holden and Lunduka, 2012).

Access to inputs which are also complementary such as crop varieties, organic fertilizers and hired labour has the potential to increase fertilizer use among maize farmers in Ghana (Ragasa and Chapoto, 2017).

However, little is understood regarding the impacts of the complementarity of intensification technologies on household food security, except what is reported anecdotally in reports and policy documents (FAO, 2015; MoFA, 2018; World Bank, 2018) and results from field research highlighting the benefits associated with intensification technologies (Rahman et al., 2021; Kumar et al., 2023), without empirical analysis using household survey data. These mentioned issues provide the theoretical foundation for studying the possible impacts of joint adoption of mineral fertilizers, improved seed and organic fertilizers on food security.

Food insecurity persists in Ghana, with a national prevalence rate of 11.7%, implying 3.6 million food insecure Ghanaian population (CFSVA, 2020). Food insecurity affects different people, whether it is students (Asalu et al., 2024), smallholder farmers (Nkansah-Dwamena, 2024), urban dwellers (Quarm and Begho, 2024), or whether it is in the northern parts of the country (Pienaah and Luginaah, 2024) or southern Ghana (Quarm and Begho, 2024). In addition, Ghana is currently experiencing an economic crisis that could plunge more households into food insecurity (Quarm and Begho, 2024). Quarm and Begho (2024) found moderate to severe food insecurity among Ghanaian urban households. Food expenditures have been significantly impacted by the economic crisis, with 81% of respondents in Accra and Takoradi cities of Ghana reporting that their money allocation to food has increased, and 75% have reduced their dietary diversity (Quarm and Begho, 2024). As the common drivers of food insecurity include climate change and variability (Damilare, 2024; Owusu-Ansah et al., 2024), declining soil fertility (Marfo-Ahenkora, 2023), low productivity of maize (Hall et al. 2024; Onawumi et al., 2024), coupled with the potential of ISFM and other intensification practices for the sustainable production of maize in Ghana (Onawumi et al. 2024), the thesis seeks to answer the following important research questions. How does participation in Ghana's Fertilizer Subsidy Program (GFSP) affect the adoption of Sustainable Intensification Practices (SIPs) and gross farm inputs? What is the impact of participation in Ghana's Fertilizer Subsidy Program (GFSP) on multiple dimensions of food security? Lastly, what are the impacts of the complementarity of Integrated Soil Fertility Management (ISFM) technologies on multiple dimensions of food security? The objectives of the thesis and empirical chapters have been formulated based on these research questions.

1.4 Research Objectives

The primary goal of the study is to investigate the impacts of Ghana's Fertilizer Subsidy Program (GFSP) on agricultural intensification technologies, private retail input market development and the dimensions of household food security

The study's specific objectives are to:

1. To assess the extent to which Ghana's fertilizer subsidy program affected investments in Sustainable Intensification Practices (SIPs) and gross farm inputs among smallholder farmers;
2. To investigate the impact of Ghana's fertilizer subsidy program on the availability, access, utilization and stability dimensions of household food security
3. To examine the impacts of the complementarity of Integrated Soil Fertility Management (ISFM) technologies on the availability, access, utilization and stability dimensions of food security.

1.5 The study's Relevance to Development Policy

The study adds to the empirical literature on agricultural policies in SSA. It dissects the complexity of agricultural support policies such as GFSP as a rural economic development strategy as against the popular and widely documented view of a driver of national economic development and poverty reduction. The study makes a case for the understanding of food security by policy makers as a muti-dimensional measure instead of as a single measure, and how GFSP has contributed to attaining the food security dimensions in Ghana. It also highlights other dimensions of food security among smallholder farmers that require improvement by policy makers.

The study specifically addresses the concern among policy makers that results showing the positive impact of ISFM technologies are largely based on experimental fields and not on household data that is also nationally representative. The study hopes to help policy makers formulate national policies that promote multiple technology adoption based on evidence from national household survey data. Drawing from the empirical evidence, the study argues a case for a national policy on the use of organic matter or manure because better food security outcomes are achieved when combined with mineral fertilizers. Food insecurity persists in Ghana coupled with the adverse consequences of climate change and variability. The study identifies key rural infrastructure, community and farmer institutions as well as farm household socio-economic characteristics through econometric analysis that policy makers could concentrate on in improving food security, achieving adoption of climate smart technologies and overall rural economic development.

1.6 Scope of the Study and Limitations

This study focuses on exploring the impacts of both GFSP and multiple technology adoption of climate-smart technologies on the dimensions of food security among smallholder maize growing farmers in Ghana. In addition, the study focuses on how GFSP increases farm household investments in SIPs and gross farm inputs among the smallholder maize farmers. The study employs a nationally representative pooled cross-sectional survey data of the Ghana Living standards Survey (GLSS) of rounds six and seven within profit,

utility and risk-averse theoretical frameworks to achieve the study's objectives. Both round six and seven of the GLSS data were each collected throughout a 12-month period to adequately capture continuously household total and consumption expenditures and possible fluctuations. Round six was conducted in 2012/13 and round seven was conducted in 2016/17. Round seven is the latest GLSS data. As the data is an observational one (non-experimental data), the study relies on econometric models (two-stage least squares with instrumental variables (2SL-IV), endogenous switching regression (ESR), propensity score matching techniques and multinomial endogenous switching regression framework) to control for possible sample selection bias and endogeneity in order to establish causal relationships. The study is limited to only maize growing households in Ghana. The other limitation of the study is the fact that in the GLSS data, farmers were not asked directly if they participated in the GFSP. Rather, farmers were asked to choose from sources from which they obtained fertilizer for which one of the sources included government. Subsequently, government as the choice of source of subsidized fertilizer is because farmers are able to link subsidized fertilizer from government since the subsidized fertilizer bags are labeled, in addition to the use of coupons and passbooks. It means that in the data set there are also farmers who did not participate in the GFSP (control group).

1.7 Thesis Outline

This thesis has six chapters. It consists of the chapters on introduction and conclusion, a detailed review of the literature and three empirical chapters. The chapter on introduction explains the study's background, an explanation of the liberalization of the Ghana's input market and how GFSP has leveraged on such a market liberalization, identifies the research problem, highlights the justification or need for the study and explains the study objectives. In addition, the introduction identifies the scope and limitations of the study as well as the study's significance for development policy perspective. Chapter two gives an overview of Ghana's agriculture. The chapter discusses past and present disruptions to food systems, and details the historical background of fertilizer subsidies in SSA in general, and particularly, Ghana. Arguments for and against fertilizer subsidies as well as evidence from the literature regarding the impacts of FSPs in SSA and Ghana are also presented in chapter two. How the definition and measurement of food security have evolved overtime, food security measurement and theoretical frameworks of household production decisions are also discussed in chapter two. In addition, chapter two describes the data and sampling procedure used for the data collection. The thesis's three empirical chapters are chapters 3 through to 5. The same data set is used for all the three empirical chapters and they all refer to it. Whereas chapters 3 and 4 concentrate on only farmers who purchased mineral fertilizers, chapter 5 concentrates on a larger sample size consisting of all maize growing households in the data set, some of whom did not purchase mineral fertilizers. Each empirical chapter gives a descriptive summary of maize growing households in the study whilst efforts were

made to avoid repetition. These efforts notwithstanding, the presentation of the thesis is such that repetition is sometimes not avoidable.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The review starts with an overview of Ghana's agricultural performance. past and present disruptions to food systems and. Historical background of fertilizer subsidies in SSA and Ghana, arguments for and against fertilizer subsidies, the empirical evidence on the impacts of FSPs on agro-input market development, crop output, farm income, poverty, maize retail prices and food security among beneficiaries in SSA and Ghana are also reviewed. As the study empirically examines the household level effects on food security, evolution of the definition and measurement of food security have been reviewed. The literature review concludes with theoretical framework on household production decisions, which informs the choice of data, models and the variables of interest for the empirical chapters.

2.2 An Overview of Ghana's Agriculture

Ghana's agricultural sector contribution to GDP increased in 2019 by 4.6 percent, as against 4.8 percent in 2018 and 6.1 in 2017 (GSS, 2019; GSS, 2020). Its share of GDP declined to 18.5 percent in 2019 from 19.7 percent in 2018. These declines have raised concerns among policy makers and researchers, especially when there is evidence of loss of livelihoods in agriculture because of increasing artisanal small scale mining activities fueled by foreigners investing in the local mining sector riddled with poor regulation, as in the case of Ghana's Akyem Abuakwa traditional area in the Eastern region (Amoako et al., 2023). The crop production sub-sector in Ghana was recorded as the second biggest economic activity in 2018. Its share of GDP was 14.5 percent in 2018 (GSS, 2019). However, it declined to the position of being the third largest economic activity in 2019 after information and communication as well as trade subsectors, contributing 13.8 percent as its share to GDP (GSS, 2020). The trade sub-sector of the services sector, including repair of vehicles and household goods, is the largest economic activity with 15.6 percent share of GDP in 2019 (GSS, 2020). The services sector remains the largest contributor to Ghana's GDP. Its percentage of GDP increased to 46.3 percent in 2018 from 46.0 in 2017, and 47.2 percent in 2019 (GSS, 2019; GSS, 2020).

Agriculture remains subsistence-based in Ghana. Production is largely under rainfed conditions, with low level of technology uptake. In the smallholder sector, value addition is almost non-existent (FAO, 2015; World Bank, 2018), though there are domestic small-scale agro-processing activities mostly among women, such as fish-smoking, cassava dough, "dawadawa", shea butter, groundnut paste, gari and flour processing (Mabe, 2022.). Close to 50 percent of the working population is employed in agriculture (FAO, 2015;

World Bank, 2018). Agriculture remains the major employer of people who live in rural areas, relative to those living in urban areas. According to World Bank (2018), under-employment seems to be the case for those employed in agriculture and are always likely to be in the rural areas. Ghana is a net importer of basic food items such as vegetable oils, poultry products, sugar and rice. The import bill keeps growing in recent years. Increasing population, urbanization and incomes are the drivers of the growing food importation (World Bank, 2018). Ghana's annual import bill exceeds the $2 billion the country earns from cocoa exports. The potential for growth in agriculture and its ability to lift many people out of poverty does exist.

Ghana's agriculture is predominantly smallholder farm-based. Farm holdings are mostly less than two hectares (MoFA, 2019). This is consistent with the finding of Lowder et al. (2016) who found small farm holdings worldwide to be less than 2/ha and are family operated. Small farm holdings and family operated lands constitute close to 12% and 75% of all lands under cultivation globally, respectively (Lowder et al., 2016). However, large commercial farms and plantations do exist for coconut, rubber, oil palm, and to a lesser degree, pineapples, rice, and maize (MoFA, 2019). Smallholder farmers produce close to 80 percent of the national food output under rainfed conditions in Ghana (FAO, 2015; World Bank, 2018; Awuni et al., 2023). This makes Ghana's agriculture vulnerable to the negative effects of climate change and variability. In addition, only 2 percent of the country's irrigation is being put to use (Awuni et al., 2023). Developing the agriculture sector has, therefore, been a priority for government since 2007, with emphasis on modernizing agriculture and making food less costly to farmers, in particular. A number of agricultural development programmes have been implemented at the national level by the Ghana's Ministry of Food and Agriculture (MoFA) in this regard. An example of such programmes is the Fertilizer Subsidy Program (Banful, 2009; Banful, 2010; FAO, 2015).

2.3 Past and Present Disruptions to Food Systems

Implementation of fertilizer subsidy programs in SSA in general and Ghana, in particular, has been linked to the occurrence of disruptions to food systems through shocks (Omolo et al., 2023). This is because the majority of people in Africa are employed in agriculture and live in rural areas. (Toenniessen et al., 2008; World Bank., 2019; Aragon and Rud, 2023; Tchimeutcheu and Ngono, 2023). The farmers are mostly small-scale and subsistent. They do face many challenges, including degradation of natural resources (Toenniessen et al., 2008) and food insecurity (Tchimeutcheu and Ngono, 2023). Any disruptions or shocks to their food systems make them most vulnerable to food insecurity. Drivers of farm-level productivity, sustainability and profitability thus become important for smallholder farmers to overcome such shocks. These drivers may include improved seed and their well-adapted accompanying technologies as well as access to output markets (Toenniessen et al., 2008). Poor or inadequate access to improved seed, complementary

technologies and output markets are probably the leading cause of low productivity among smallholder farmers in Africa. Disruptions to food systems in the form of global food price hikes, health pandemics and climate change also contribute to declining productivity and livelihood loss among Africa's smallholder farmers. The 2008 global food crisis brought to the fore the failure of African countries to achieve food security.

Climate change, drought, floods and increasing temperatures are also responsible for low crop output (Mittal, 2009). Aragón and Rud (2023) examined the heterogenous impact of temperature on subsistent farmers' food security, agricultural productivity and crop output in Malawi, Ethiopia, Uganda and Tanzania. Noting significant differences in technology adoption and farm level performance between large scale and subsistent farmers, Aragón and Rud (2023) found negative effects of increasing temperature on agricultural productivity, output and food security, irrespective of farm size. Galbert and Olinga (2023) found that, on average, the effect of temperature on crop output is higher than that of the observed rainfall in a year. According to Galbert and Olinga (2023), adaptive strategies such as irrigation techniques that can mitigate the effect of poor rainfall on crop output due to increasing temperatures. Galbert and Olinga (2023) argue that irrigation techniques should be promoted by research and policy makers in SSA. Omotoso et al. (2023) also found climate change as evidenced in the average temperature and variability in the rainfall patterns as well as occurrence of severe weather conditions such as floods and drought as having reduced crop yield. Building the resilience of production systems through the adoption of appropriate adaptive strategies to mitigate the adverse impacts of climate change is necessary (Omotoso et al., 2023). The climate change's effects are not only regional but local as well. In a wide-ranging literature review, Awuni et al. (2023) found reduction in agricultural productivity due to climate change in Ghana. As observed by Aragón and Rud (2023), smallholder farmers respond to shocks such as increasing temperatures by increasing land area under cultivation, whereas large scale farmers adopt pesticides as a coping strategy. Both farm types engage in off-farm enterprise as a coping strategy against total crop failure. However, these strategies are unable to reduce significantly the impacts of increasing temperatures on output and food insecurity (Aragón and Rud, 2023).

Another crisis experienced by food systems is the COVID-19 pandemic The pandemic affected all actors within the food systems value chain, including producers, input suppliers, transporters, processing plants, wholesalers and retailers. The overall direct impact on producers was a decline in profit and income, access to food not produced by the household and those consumed outside home as well as their purchasing power. Reduced availability of food was the subsequent indirect effect of the pandemic on the other actors including retailors, food vendors and consumers. The stability of the food available also becomes a problem (Bènè 2020). According to FAO (1996; 2008), availability, access, utilization and stability constitute the

dimensions to food security. These four dimensions of food security are not mutually exclusive. Though the access dimension was the hardest hit by the pandemic, disruptions in transportation and movement of people across and within borders, hoarding behaviour of some people, food prices instability, and change in consumer demand towards cheaper and less nutritious foods, affected the utilization, availability and stability dimensions (Bènè, 2020; Laborde et al., 2020). It is therefore important that in investigating the role of GFSP on food security, coping strategies by smallholder farmers such as household assets, irrigation, off-farm income, land size, use of pesticides, among others, are taken into account.

In investigating the causes of food insecurity across SSA using data from 29 countries between 1990 to 2019, Tchimeutcheu and Ngono (2023) concluded that food security is the product of food availability, utilization as well as stability dimensions. They did not find statistically significant effect regarding the food security dimension of access proxied by the prevalence of undernourishment as a percentage of the population. This finding is possible since the authors relied on national aggregate data which may not reflect the real experiences of farm households regarding access to food. In addition, the prevalence of undernourishment has generally declined across SSA since 1990-92 (FAO, 2013). For example, the undernourishment prevalence rate for Ghana declined from 44.4% in 1990-92 to less than 5% in 2011-13 (FAO, 2013). This achievement has been attributed to sustained economic growth since 1983 due to Ghana's political stability and market reforms. Increased prices for gold and cocoa as well as a sustained agricultural production have played major roles in improving food security since 1983 (FAO, 2013). The Implications of the occurrence of the various mentioned shocks and their impacts on smallholder farmers are that their food security situation may deteriorate if governments fail to implement policies aimed at boosting food production. Social safety-net policies including fertilizer subsidies are particularly suited to the problem (Laborde et al., 2020).

To understand the resilience of a food system, it is critical to consider the responses taken by many actors, including policy makers, in addition to the immediate effects of the shock. The capacity to cope and move past a shock is contingent upon the actions taken by individuals, communities, or society as a whole to lessen the impact of that shock, sometimes leading to unexpected outcomes. (Bènè, 2020). However, as noted from the discussions in the present literature, emphasis is on the impacts on food security due to shocks (Erokhin and Gao, 2020; Bènè, 2020; Laborde et al., 2020; El Bilali et al., 2023; Tchimeutcheu and Ngono, 2023; Agyei-Holmes et al., 2023), rather than the impacts of the responses on food security and building resilience. Secondly, building capacity is key to enhancing food system resilience, just as it is for communities or households. Therefore, overcoming the threats to food security and livelihoods, whether such threats are food price hikes, health pandemics such as COVID-19 or climate change adverse effects in

the form of drought, unpredictable rainfall patterns or floods, will require the adoption of complementary SIPs technologies as a package by smallholder farmers in SSA in general, and in particular, Ghana.

2.4 The Theory and Historical Context of Fertilizer Subsidies in Sub-Saharan Africa and Ghana

The theory of FSPs is to promote and increase the use of mineral fertilizers from their present use levels by smallholder farmers in SSA (Jayne et al., 2013; Jayne et al., 2016). The pledge made by African countries at the 2006 Abuja Fertilizer Summit to boost fertilizer application from 8 to 50 kg of nutrients per hectare reinforces this theory (Jayne et al., 2015; Jayne et al., 2016). The increase in the adoption of mineral fertilizer by farmers is considered an important driver in raising crop yield and achieving food security in SSA (Jayne et al., 2015; Jayne et al., 2016; Vanlauwe et al., 2023). Though great strides have been made over the years in increasing fertilizer use in SSA, fertilizer use amongst smallholder farmers remains low. For example, fertilizer use has risen by only 17 percent in SSA, excluding South Africa. Around 1.26 million tons were used between 1996 and 2000, up from 1.09 million tons between 1980 and 1989. During this period, intensity of fertilizer use, explained as the quantity of fertilizer consumed in kilograms per hectare of land under cultivation, increased by only 5 percent (Crawford et al., 2005). Most SSA countries still apply below the target of 50kg per nutrients application per hectare as envisioned by the Abuja declaration in 2006 (Masso et al., 2017). A number of reasons have been given for the low fertilizer use in SSA, including the higher fertilizer cost in Africa relative to Asia and Latin America as well as planting materials used by African farmers being less responsive to fertilizers (Kherallah et al., 2002). Subsidy programs are subsequently designed and implemented by African governments to quickly promote and expand fertilizer use among farmers (Jayne et al., 2018), incentivizing farmers to adopt new and improved farming practices (Ellis, 1993). For example, since 2010, there has been six to ten times more fertilizer use among smallholder farmers in Ghana than it used in the early 2000s. Much of this can be attributed to the GFSP. Approximately 40% of all fertilizer used between 2011 and 2013 came from this program. With the exception of Ethiopia, Nigeria, and South Africa, Ghana imported more fertilizer in 2012 than any other nation in sub-Saharan Africa (Jayne et al., 2015).

Large scale subsidies on inputs were a common feature of policies on agricultural development in SSA in the 1960s and 1980s. They were implemented as price subsidies with universal coverage and accessibility to all farmers (Chirwa and Dorward, 2013; Holden, 2019). Input subsidies implemented during this period are sometimes referred to as the first generation of input subsidies (Holden, 2019). Although only smallholder farmers were supposed to buy fertilizer and were not supposed to resale it (Chirwa and Dorward, 2013), large scale and cash crop farmers mostly benefitted (Holden, 2019). Though the fertilizer subsidies

were universal across SSA (Holden, 2019), their design was different across countries (Morris et al., 2007; Chirwa and Dorward, 2013). Huge and direct financial expenditures from the state characterized these fertilizer subsidy programs (Morris et al., 2007). Such subsidies were largely inefficient and had minimal impact on improving food security of smallholder farmers (Holden, 2019). Their implementations have also been linked to corruption and mismanagement of public funds.

As noted by Morris et al. (2007) and Crawford et al. (2005), the types of the first-generation input subsidies included the state-controlled input distribution system, Global 2000 Sasakawa projects, cooperative or out-grower programs, private sector fertilizer supplies facilitated by the public sector and, starter pack initiatives. They all had a common feature of raising the use of mineral fertilizers and other inputs among smallholder farmers, though with different approaches. With the state-controlled input distribution system, the basic feature is that the state controls the distribution of inputs to farmers. The state does this by giving input to farmers in a form of credit. The farmers repay the credit in-kind, often in the form of farm produce after harvest to the state or its agents. This characteristic is, however, not found in the current FSPs being implemented across SSA though Ghana implemented a similar one in 2009 under the Block Farm Program (FAO, 2015). The Asian green revolution benefitted from this type of input subsidy program. Some of the African countries that had state-controlled input distribution programs in the 1980s were Kenya, Zambia, Malawi, Tanzania and Zimbabwe (Crawford et al., 2005). The programs were however stopped because of the structural adjustment programs (SAPs), which was meant to get African countries out of debt crisis (Crawford et. al., 2005; Holden, 2019).

The Global 2000 Sasakawa projects witnessed a number of collaborative initiatives with African governments to showcase to farmers how agricultural output could increase with timely supply of farm inputs at reasonable prices and appropriate extension services. Pilot demonstration plots of half a hectare per farmer were established. After some time, participating famers who ‘graduated’ were required to keep applying the productivity-boosting technologies on their respective fields. As a result of learning from and adopting the participating farmers' good agronomic methods, other farmers began to spread the technologies (Crawford et al., 2005; Ito et al., 2007; Gizaki and Madukwe, 2019; Adebayo et al., 2020). Ethiopia, Ghana, Mozambique, Nigeria and Uganda were some of the countries that implemented the Sasakawa Global 2000 program in the 1990s (Crawford et al., 2005; Ito et al., 2007; Adebayo et al., 2020). The program overall recorded improved yields across the different countries (Seyoum et al., 1998; Crawford et al., 2005; Ito et al., 2007; Gizaki and Madukwe, 2019; Adebayo et al. 2020). However, the program could not live up to the general expectation of developing ‘second generation’ of agro-input market development. Farmers reverted to their old practices of low input use after the end of the program largely because access to inputs, finance and output markets still became a problem (Crawford et al., 2005).

With the out-grower schemes or farmer cooperatives, they are interlinked with input-credit-output-market transactions. The schemes give input on credit and extension services to their members during the cropping season. These members then agree to grow a particular cash crop and sell the crop to the out-grower scheme (Crawford et al., 2005). The sugar and coffee out-grower programs in Kenya and the out-grower schemes for cotton in Ghana, Zimbabwe and Mozambique are examples of this model. The farmer cooperatives have also been used to deliver subsidized inputs to beneficiaries in Zambia (Lolojih, 2009; Blekking et al., 2021). Another fertilizer promotion program has been the private sector fertilizer supplies facilitated by the public sector. With this program, the government invests in public goods such as roads, port facilities, markets and warehousing and research and development of responsive fertilizer crop varieties. The demand for inputs by farmers is then created as well as the incentives for private input companies to meet the needs of farmers (Crawford et al., 2005). Kenya has pursued this approach since 1993 following the government reforming its fertilizer marketing system (Crawford et al., 2005; Robert and Nie, 2015).

The government of Malawi in the 1998 and 1999 cropping season implemented the starter pack, eventually replaced by the Targeted Inputs Program (TIP). Increasing maize output, improving food security and soil fertility, and making available improved hybrid seed that was responsive to fertilizer use to smallholder farmers were the objectives of the program. As can be observed, unlike the other subsidy schemes that aimed at increasing fertilizer use, the starter pack program included the use of improved seed. It increased access to improved inputs to farmers with limited resources who otherwise would not have been able to purchase these inputs. However, the universal coverage nature of the program made it expensive to implement. There were also problems with targeting the right farmers who could truly not afford to buy improved inputs, as well as input retailers being pushed out of business because of lack of commercial purchases from smallholder farmers (Crawford et al., 2005; Jayne et al., 2018). Food insecurity still persist in Malawi and logistical challenges remain in the distribution of subsidized fertilizer leading to late deliveries to beneficiaries (Msuku and Moeinaddini, 2020).

The above-mentioned first-generation input subsidy programs, however, largely failed to sustain an increase in fertilizer use. The failure was because of high and unsustainable fiscal and administrative costs, and inadequate capacity or lack of it to effectively implement these programs as well as poor monitoring (Morris et al., 2007). As noted by Morris et al. (2007), the programs were designed as ‘one-size-fits-all’, in the sense that farmers’ needs, diversity of production systems within countries and across countries were never taken into consideration in the design of the programs. In addition, there was a problem of persistent and late delivery of fertilizer to farmers (Morris et al., 2007). It is also important to note that the exclusive focus on fertilizer by these schemes would not have solved the problem as they failed to increase adoption of agricultural intensification technologies. During the 1980s and 1990s, there was a halt in the implementation

of fertilizer subsidies to farmers in many African countries (Morris et al., 2007; Holden, 2019). Market reforms within the Structural Adjustment Programs (SAP) allowed governments to reduce their interventions in the agricultural markets (Kherallah et al., 2002). Subsequently, these reforms resulted in positive impact on governments' budgets (Morris et al., 2007). Market entry and participation by the private sector occurred in the cash crop, food and fertilizer markets in most of the countries where the reforms took place. There was an increase in aggregate agricultural output and overall farm household income (Kherallah et al., 2002). Kherallah et al. (2002) noted that the increase was, however, stronger for export crops relative to food crops. This is because the market liberalization favoured relative prices for export crops. In addition, the use of fertilizer became more profitable for export crops relative to food crops. For example, cash crop sectors became relatively profitable as in cotton for Benin, cashew nuts in Mozambique and coffee in Uganda (Kherallah et al., 2002). However, the reforms also led to rising fertilizer costs and significant reduction in fertilizer use as a result of the discontinuation of subsidies (Kherallah et al., 2002; Morris et al., 2007). Fertilizer use efficiency reduced, particularly for maize, making its production less profitable (Kherallah et al., 2002). Food insecurity also exacerbated among rural households (Morris et al., 2007).

2.5 Objectives of Some FSPs in SSA and Whether These Objectives Have Been Met

The GFSP has the objectives of providing affordable mineral fertilizers to farmers with the aim of increasing their yield per hectare to align with the global productivity standards (Adzawla et al., 2024; Aremu et al., 2023). Providing farmers with subsidized fertilizer helps them overcome financial barriers associated with access such inputs (Tsiboe et al., 2021). This demonstrates that the program's main goal was to establish an effective and sustainable distribution system that will help smallholder farmers and eventually support both the country's food security and economic expansion. Malawi's Farm Input Subsidy Programme (FISP) has the objective of reducing food insecurity by including legume seeds to improve household dietary diversity. The program focuses on both staple food crops and nutrient-rich non-staple foods (Matita et al., 2022). Be sides giving farmers access to improved seeds and fertilizers at subsidized prices, the Growth Enhancement Support Scheme of Nigeria aims to eradicate inefficiencies and corruption from the distribution process. Increasing yield is also an objective of the program (Helon and Ornan, 2022). Zambia's farmer Input Support Programme (FISP) has the objectives of addressing low agricultural productivity and food insecurity by subsidizing fertilizers and improved seeds to increase smallholder farmers' yields and incomes (Mofya-Mukuka et al., 2013). Kenya's National Fertilizer Subsidy Program (NFSP) implemented has the objective of enhancing agricultural productivity by making mineral fertilizers more accessible and affordable to smallholder farmers. This is expected to reduce food prices within Kenya (Njagi et al., 2024).

Although FSPs in SSA aims at addressing soil fertility, improve input uptake and improving yields, the empirical evidence sometimes points to the contrary. They are beset with challenges such as week input distribution systems, intermediaries in the distribution chain, fraud and inefficiency and farmers lacking the necessary knowledge which hinder its progress (Hounnou et al., 2023). Alabi (2020) observed that the distribution of fertilizer subsidies to farmers was imbalanced in Nigeria, favouring high-potential region such as the Northern and Southern states which are known for their agriculture productivity and potential for increased food security. To improve the effectiveness of these programs, policymakers should adopt clear objectives to align with national food security goals, develop targeted packages for various agro-ecological contexts and combine these subsides with complementary services like extension and research to get the maximum out of these programs (Alabi, 2020).

Some of the FSPs in SSA have met some of their stated objectives. Fertilizer usage among participating farmers have been found to have increased significantly in Ghana. This shows that the aim of the GFSP program to rise fertilizer use from 8kg to 20kg per hectare is on point (Tsiboe et al, 2021). In Nigeria, the Growth Enhancement Support Scheme (GESS) has improved access to affordable agricultural inputs among smallholder farmers. This has increased agricultural productivity and food security (Uduji et al., 2019); Helon and Ornan, 2022). Similar results of increased yield have been reported in Baba (2022) by the Nigeria's Fertilizer Voucher Program (FVP), a key component of the GESS. Kenya's NFSP has increased mineral fertilizer use among smallholder farmers from 31 kg/ha to targeted levels of 50kg/Ha (Omolo et al., 2023). The NFSP has also increased maize productivity by 32.3% among smallholder farmers in Kakamega County (kimoso, 2022). Despite these reported achievements, skepticism still exists regarding the success of FSPs in SSA. The next section discusses the arguments for and against FSP in SSA.

2.6 Arguments for and Against FSPs in SSA

Most countries in SSA have implemented subsidy programs at some point in time. The level of subsidy has varied from 20 percent or less to as high as 90 percent of the agricultural budget at one time in Nigeria (Morris et al., 2007), 61% to 74% in Malawi (Dorward and Chirwa, 2011), 35% in Zambia (Kelly et al., 2019) and 31.8% in Ghana (Smale and Thériault, 2019). Arguments in favour of fertilizer subsidies can broadly be classified into financial, economic and non-economic arguments (Crawford et al., 2005; Kelly et al., 2019). The financial arguments look at the benefits of fertilizer subsidies in the areas of increased crop output at the farm level or higher earnings for both producers and traders under current market prices, as well as to help maintain fertilizer use under rising prices due to shocks such as rising oil prices (Crawford et al., 2005). The economic arguments consider the ability of fertilizer subsidies to creating an enabling

environment for the adoption of innovations, especially in the area of farm credit to farmers to help them overcome their cash constraints, which otherwise would not have been possible without the subsidy. This helps achieve flourishing economic activities from higher earnings in agriculture due to increased crop output in the short, medium and long terms. Secondly, subsidies are a means of correcting the imperfect input and output markets common in countries in SSA (Crawford et al., 2005). The non-economic arguments consider benefits that FSPs can provide that in nature are not economic. These include restoring soil fertility (though lands remain less productive without fertilizer application), poverty reduction and social protection or safety net to resource poor farmers (Crawford et al., 2005; Morris et al., 2007). Achieving non-economic objectives however requires that FSPs target effectively the right beneficiaries (Morris et al., 2007).

Despite these arguments, subsidies are difficult to target the real poor-resourced farmers. The benefits are limited to wealthy individuals and prosperous farmers (Kherallah et al., 2002; Crawford et al., 2005; Jayne et al., 2018). The poor targeting of subsidies and selling of inputs by implementers of the program subsequently crowds out farmers' demand for commercial fertilizer. This causes a great disruption to the input market. Random modifications to subsidy schemes deter private investments as well into the fertilizer procurement and distribution activities. Price control and rationing have contributed to rent-seeking behaviour such as political or tribal affiliations among farmers. Subsidies have brought about unfair competition between the public sector and private enterprises (Crawford et al., 2005). In addition, the smuggling and diversion of inputs along the channels of distribution and the poor response of yield to fertilizer application on most smallholders' farms have contributed less than expected national food output in developing countries. A higher percentage of farmers also use fertilizer under poor soil fertility conditions due to agro-ecological and climatic conditions. This also contributes to the less than expected benefits of input subsidies (Jayne et al., 2018). Other arguments against subsidies include the bad experiences in the past from SSA and elsewhere in the implementation of input subsidies with huge financial burden on the public budgets, and subsidy programs proven unsustainable in the long-term. Subsidies are not effective in targeting comparatively low-income farmers and their implementation sometimes impede the creation of a sustainable system for delivering farm inputs (Crawford et al., 2005). Input subsidies were considered to weakly contributing to growth in agricultural productivity, food security and poverty alleviation. Subsequently, they were phased out in the 1990s (Morris et al., 2007; Jayne et al., 2018).

However, in the early 2000s, there was a growing resurging interest for fertilizer subsidies. Shortly after the Maputo Declaration in 2003 where African governments committed to raise expenditure on agriculture to at least 10 percent of their respective national GDPs, many countries including Ghana, Nigeria, Malawi, Tanzania and Senegal introduced FSPs (Chirwa and Dorward, 2013; World Bank, 2018). Other drivers for the reintroduction of FSPs in Africa were concerns expressed by political leaders, NGOs, and other decision-

makers in Africa over liberalized policies' inability to promote agricultural development, particularly the production of staple food crops in a sustainable manner, declining soil fertility and stagnating agricultural productivity. Alongside these drivers, numerous African nations continued to face political pressure within the populace for fertilizer subsidies to be re-introduced (Chirwa and Dorward, 2013). Based on the experiences from the implementation of subsidy programs in the past, a new generation of subsidies was designed to overcome the mistakes of the past. These subsidies were termed as 'smart subsidies.' For a subsidy program to be considered smart, it must have the characteristics of supporting the growth of the private fertilizer markets and carefully focusing attention on farming areas that have potential for the profitability of fertilizer use but farmers in these areas use fertilizer below the recommended level. The other characteristics are that a smart subsidy must be part of a broader approach to creating an enabling environment for the supply of complementary technologies, strengthening output markets and developing synergies in interventions in the agricultural sector (Morris et al., 2007). A smart subsidy program should also have an exit strategy. There remain genuine concerns on how these elements of a smart subsidy may be put into practice and whether the significant implementation difficulties experienced in the past could be overcome in implementing current programs (Jayne et al., 2018). Studies being undertaking now on the effects of fertilizer subsidy programs fail to assess if truly such programs are "smart", in particular, their capacity to raise farmers' market demand for complementary inputs, not just only fertilizer, and supporting private input markets to develop, as well as contributing to rural development. The following section presents evidence from the literature regarding the extent to which subsidy programs are meeting the smart and other objectives in SSA and Ghana.

2.7 Fertilizer Subsidy Programs' Impacts in SSA and Ghana: Evidence from the Literature

There have been extensive investigations in recent times on the impacts of subsidy programs on a number of household outcomes as well whether they are achieving the smart, financial, economic and non-economic objectives. These studies examined the impact of fertilizer subsidies on crowding in/out of the private input markets, a proxy for measuring the extent to which the subsidies are "smart" (Xu et al., 2009a; IFDC, 2013; Darko et al., 2016; Liverpool-Tasie et al., 2017; Ragasa and Chapoto, 2017); increased crop output and income, as proxies for measuring the financial or green revolution objective (Wossen et al. 2017); economic objective, in terms of adoption of innovations (IFDC, 2013; Xu et al., 2009a); and non-economic objectives such as poverty reduction (Wossen et al., 2017; Zinnbauer et al., 2018). Other studies have also investigated the effects of input subsidies on fertilizer retail price (Ricker-Gilbert et al., 2013); maize retail price (Ricker-Gilbert, 2013; Takeshima and Nkonya, 2014; Takeshima et al., 2015); and household food security.

IFDC (2013), Mason and Jayne (2013), and Zinnbauer et al. (2018) assessed the impact of fertilizer subsidy program on private retail input market development in Zambia. They found that the program crowds out investment from the private sector. Zambia's fertilizer subsidy program has problems with late delivery of fertilizer to farmers and it is fraught with leakages and diversion (IFDC, 2013; Zinnbauer, 2018). The program proved to be unsustainable without significant support from the donor community. Takeshima and Nkonya (2014) also found crowding out of the private sector in the fertilizer market in Nigeria due to the country's fertilizer subsidy program. For example, a farmer receiving 100kg of fertilizer under subsidy lowers the probability of a household purchasing fertilizer that is not subsidized from the retail input market by 10 to 21 percent. There could be greater implications considering the share of households using fertilizer in Nigeria. Influence from those with political connections also plays a role in the distribution of subsidized fertilizer (Takeshima and Nkonya, 2014). Liverpool-Tasie (2014), however, had contrary findings in the Kano state of Nigeria where subsidized fertilizer increased the quantity of fertilizer bought from the private retail input market. It was as a result of the program's implementation strategy. Suppliers had to set up shops in every Local Government Area (LGA) during specific times in order to deliver the program's subsidized fertilizer to farmers. This greatly decreased the transaction and transportation costs related to obtaining fertilizer, in addition to just bringing the product to areas where input providers might not have been previously present (Liverpool-Tasie, 2014). Poor targeting of beneficiaries under subsidy programs continues to militate against the 'smart' subsidy objectives. For example, Zinnbauer et al. (2018) found poor targeting of beneficiaries for the program, leakages and diversion of fertilizer associated with the Zambia's fertilizer subsidy program. Houssou et al. (2017) also found that large scale and well-to-do farmers are the main beneficiaries of Ghana's fertilizer subsidy program. This is contrary to the main goal of the program of supplying subsidized fertilizer to smallholder farmers (Houssou et al., 2017).

On the economic objective of input subsidies, IFDC (2013) found the adoption rate of fertilizer among farm households to be around 30 percent in Zambia. They argued that in order for Zambia to meet its agricultural goals under the CAADP framework, the country must increase its fertilizer consumption. The fertilizer imports ought to double and consumption must increase by 248,000Mt to about 500,000Mt per annum (IFDC, 2013). Morgan et al. (2019) investigated the effect of Zambia's fertilizer subsidy program on the adoption of soil fertility management practices (fallowing, intercropping, crop rotation, and animal manure), a non-economic objective, among maize growing households. They found the probability and extent of fallowing and intercropping maize with other crops reduced due to the subsidy program. The program, however, increases the continuous cropping of maize on the same plot over time. They did not find statistically significant correlation between participation in the subsidy program and adoption of manure (Morgan et al., 2019). Ricker-Gilbert (2020) found increased use of mineral fertilizers across sub-Sahara Africa due to fertilizer subsidy programs. As high as 41.4%, 55.5% and 77.3 % of crop growing households

in Nigeria, Ethiopia, and Malawi apply mineral fertilizers, respectively. The average application rates of mineral fertilizers across all households are 45kg/Ha in Ethiopia, 146kg/Ha in Malawi and 128.2kg/Ha in Nigeria (Sheahan et al., 2014). Omonona et al. (2019) found fertilizer use of over 50% among sorghum farmers in Nigeria with an application rate of more than 150kg. For the average nutrient application rate, Sheahan et al. (2014) estimated 25.2kg/Ha for Ethiopia, 56.3kg/Ha for Malawi and 64.3kg/Ha for Nigeria. However, according to Ricker-Gilbert (2020), fertilizer use efficiency still remains low in SSA among maize farmers due to the fact that maize is mostly grown under rainfed conditions, poor and declining soil conditions, limited knowledge on good agronomic practices including timely weeding and timely application of fertilizer. Late delivery of fertilizer to farm households also contributes to the low fertilizer use efficiency (Ricker-Gilbert, 2020; Vanlauwe et al., 2023). Besides the call for scaling down on fertilizer subsidies, Riker-Gilbert also suggested that fertilizer subsidies should be issued to farmers on the condition that they undertake soil fertility improvement practices such as planting of trees, use of organic manure and contour ridges on the farm. The question is: "What about if current subsidy programs are also contributing to soil fertility improvement practices?" To Omonona et al. (2019), fertilizer use efficiency determines the profitability of use rather than its use or how much is subsidized. Fertilizer use efficiency for maize, for example, is in turn determined by good agronomic practices such as weed management, crop rotations and application of organic fertilizer. This highlights the fact that access to mineral fertilizer is not a sufficient condition for improving maize response to inorganic fertilizers, rather the complementarity of inputs (Burke et al. 2022). It is better to promote these complementary technologies that increase crop response to nitrogen fertilizers (Omonona et al., 2019; Kopper et al., 2020), instead of expanding input subsidies (Omonona et al., 2019).

Regarding the financial objective of input subsidies, Wossen et al. (2017) found increases in maize output and income of beneficiaries following the introduction of a mobile phone-based input subsidy program in 2012 in Nigeria. Beneficiaries received subsidized fertilizer and seed through electronic vouchers. They also found positive and statistically significant impact among beneficiaries on per capita total food and non-food consumption expenditures. Helon and Ornan (2022) has found increase in income of about $251 of beneficiaries of Nigeria's Growth Enhancement Support Scheme (GESS). Carter et al. (2021) found increase in maize yield and technology adoption (mineral fertilizer and improved seed) in Mozambique. In the Senegal River Valley, Weibigue (2021) found increased efficiency in agricultural production due to Senegal's FSP with a significantly improved rice productivity. Pauw (2022) found a growth of 42.6 percent in maize output and 44.3 percent in rice due to Ghana's FSP. However, from a study of 460 rice farmers in the Volta region of Ghana, Vondolia et al. (2021) did not find positive effect of GFSP on productivity among beneficiaries, though farmers who participated in the subsidy program applied fertilizer more than farmers who did not participate by 45 percent.

Fertilizer subsidy programs often have multiple objectives. They may have both increasing crop output and reducing poverty at the same time as program objectives. However, increasing crop output will not necessarily reduce poverty in the short term (Kelly et al., 2019). Notwithstanding this, some studies have linked poverty reduction to participation of fertilizer subsidy programs. Mason et al. (2020) found reduction in poverty headcount ratio and severity by 1.5% and 9%, respectively, among farm households due to Zambia's input subsidy program. They found little evidence of spillover effects on households not directly participating in the program. Poverty headcount ratio among program beneficiaries reduced by 17.7 percent due to the increased consumption expenditures. The e-voucher subsidy program was considered marginally cost-effective with a benefit-cost ratio of 1.11. Thus, every one dollar invested in the program yielded 1.11 dollar returns (Wossen et al., 2017). There has been modest increase in farm incomes. However, overall cost of the program exceeds its benefits. As noted by Ricker-Gilbert (2020), cost of subsidy programs often exceeds their benefits due to low fertilizer use efficiency.

Ricker-Gilbert (2013a) found little or no statistically significant effect of fertilizer subsidies on retail prices for maize in Malawi. Doubling the scale of the subsidy program in Malawi in total metric tons, on average, only lowers maize prices by 1.2 to 1.6 percent. In per capita terms, doubling the program's scale lowers maize retail prices by about 2.5 percent, on average (Ricker-Gilbert, 2013a). The Nigeria's subsidy program also had minimal effects on the price growth rates for grains between the post-planting and post-harvest seasons (Takeshima et al., 2015). Fertilizer subsidies have produced little or no effect on retail prices for maize in Zambia. Doubling the scale of Zambia's subsidy program in metric tons only lowers the prices for maize on average by 2 to 2.8 percent at the district level. In per capita terms, doubling the scale of the program will lower maize price by about 1.8 percent. The implication of the lack of large effects on maize retail from fertilizer subsidies is that the welfare benefits only accrue to those who receive the subsidy. Non-beneficiary farmers and consumers from urban centers do not benefit in a major way (Ricker-Gilbert et al., 2013a). Zambia's subsidy program has not been able to substantially reduce poverty and improve food security through maize prices (Zinnbauer et al., 2018). However, farmers have been found to sell more of maize immediately after harvest and to purchase less during both the harvest and off seasons in Zambia, indicating self-sufficiency of maize production among both male and female-headed households due to participation in the subsidy program (Simtowe and De Groote, 2021). Whereas timely availability of fertilizer has been found to have a positive effect on crop output, excess rainfall and contact with extension agents have been found to have a decreasing effect on crop productivity (Xu et al., 2009b). Poor quality of extension delivery might have accounted for this.

There is, however, positive impact of the Malawi's subsidy program on food security indices such as availability of kilocalories for farm households per capita per day, the number of months a household is

considered food secured, and the probability of a household being food secured throughout the whole year (Sibande et al., 2015). Famers who benefited from subsidized fertilizer were more likely to have available kilocalories per household member per day and were more likely to be food secured the whole year. Assima et al. (2019) found that heterogeneity effects exist based on geographical zones in Mali on the dietary quality of women of child bearing age due to participation in fertilizer subsidy program. As there was improvement in overall dietary diversity in Niger Delta, negative effect on the same outcome was found in the Koutiala Plateau. The dietary diversity score was broken into components based on grouped food sources (Assima et al., 2019). Subsidized fertilizer had negative effect on dietary diversity sourced from gift food in Niger Delta. Subsidized fertilizer effect on dietary diversity from purchased food was positive in the Niger Delta. It was, however, negative in the Koutiala Plateau. Segregating diet diversity by food source suggests that income from non-farm sources including remittance is an important determinant linking subsidized fertilizers program to women's nutrition outcomes (Assima et al., 2019). This is because with non-farm income, the household can purchase what is not produced in the house.

Though achieving food security is one of the stated goals of GFSP (GoG, 2017), the present literature stopped at measuring only the availability of food through increased yield (e.g., Pauw, 2022), except Wiredu et al. (2019). Wiredu et al. (2019) found improved food security of rice producing households in northern Ghana due to fertilizer subsidy program, using consumption of calories, protein and fats, the three food macronutrients as proxy for calculating the access dimension of food security. They, however, did not extend their analysis to the other dimensions of food security (utilization and stability). Studies largely consider an increase in crop productivity as the same as achieving food security (Andani et al. 2020). Andani et al. (2020) found a correlation between increase in maize productivity and participation in fertilizer subsidy in North Eastern Ghana.

However, these studies have not explored the contribution of fertilizer subsidies to meeting all the dimensions of household food security. The individual or household's capacity to meet its basic nutrition and health need is central to the concept of food security (Tadasse, 2016). It means that the contribution of policy interventions such as GFSP to food security is not enough. It has to be complemented by the individual's own contribution in the form of adopting complementary technologies such as improved seed, mineral and organic fertilizers which can jointly contribute to increasing productivity and food security. The concept of food security has, however, evolved of the years and the term 'food security' is also often confusing and its measurement remains complex in the literature (FAO, 2013).

2.8 The Evolution of the Definition and Measurement of Food Security

Food security is a common term in the agricultural and development economics literature that has evolved over the years. It has gained prominence in these disciplines since 1974, following the World Food Conference where the term 'food security' originated (FAO, 2006). Food security then was defined as the supply of food, which gave consideration to the availability and stability of basic foodstuff prices at the international and national levels (FAO, 2006). As highlighted in Maxwell and Smith (1992), FAO (2006) and FAO (2008), the focus of measuring food security then was increasing the availability of food at the national level for the increasing population. The explanation of the concept of food security was revised in 1983 to emphasize both physical and economic access to basic food needs by individuals at all times (FAO, 2006). Thus, the supply-side of provision of food shifted to a demand-side. Subsequently, the focus of food security became increasing food access by building the capacities of individuals (Maxwell and Smith, 1992; FAO 2006; FAO, 2008). Individuals and households thus become central in the explanation of the access dimension of food security. The definition of the concept of food security was revised further during the World Food Summit in 1996 to refer to a condition when all individuals have economic and physical access at all times to safe, sufficient, and nutritious foods which meets their dietary needs and food preferences to achieve an active and healthy life (FAO, 1996; FAO, 2013). The concept of food security became multiple dimensional at this stage to include availability, access, utilization, and stability for achieving nutritional well-being (FAO, 1996; FAO, 2006). These dimensions, Berry et al. (2015) argued, however, excluded the idea that food systems are vulnerable to shocks. The concept of stability/vulnerability was added as one of the dimensions of food security in 2009 at the World Food Summit. It indicates the ability of food systems to withstand shock, either natural or man-made, within the short-term (Berry et al., 2015). Availability, access, utilization, and stability dimensions are now widely accepted as the four dimensions of food security as declared by the World Food Summit in 1996 (FAO, 1996; Upton et al., 2016).

Availability refers to food being made available either locally produced or from imports. Accessibility dimension is explained in terms of the ability to purchase food and the food being accessible through transportation to consumers. Sociocultural accessibility is added to such physical and financial accessibility to guarantee that the cuisine is culturally acceptable and that social safety nets such as GFSP are present to assist the vulnerable groups. The utilization dimension is the individual having a healthy life due to the intake of food in adequate amounts in quantity and quality (FAO, 2006; Peng and Berry, 2019).

The capacity of the country, community, or (household) member to absorb shocks to the food chain system brought on by natural calamities (earthquakes, climate), as well as those brought on by human activity (wars, economic crises), is the fourth dimension. Hence, it is clear that there are various levels of food security. For complete food security, all four of these aspects must be present (FAO, 1996; Peng and Berry, 2019).

As a long-term measurement of food security, more recent advancements have emphasized the significance of sustainability as the fifth dimension (Berry et al., 2015; Peng and Berry, 2019). Berry et al. (2015) considers the stability dimension of food security as a short-term measure whereas the sustainability dimension of food security is a long-term measure that persists into the future. Both stability and sustainability constitute the time dimension of food security (Berry et al., 2015). According to Berry et al. (2015), not integrating sustainability as a dimension of food security may create a situation where the present policies and programmes become the very cause of increased food insecurity in the future. As noted earlier, fertilizer subsidy programs are reducing fallow periods, crop rotation practices, and use of manure (Morgan et al., 2019). In addition to sustainability, preserving the environment, agro-ecosystems, and natural resources has also become integral to the study of food security (Berry et al., 2015). Measuring the effect of GFSP or farmers' own investments on food security must take into account all these dimensions.

2.8.1 Conceptualization and Measurement of Food Security

There is a consensus regarding the importance of measuring food security among rural development practitioners. It, however, remains contentious and unclear in the empirical literature on how food security should be measured (Upton et al., 2016). Food security measurement requires the use of multiple indicators instead of a single indicator. However, as it can be observed from the literature reviewed so far, this is not the case. Multiple indicators are useful and can capture the complex reality of food security (Leroy et al., 2015). The measurement of food security has also progressed over the years (Upton et al., 2016) just as its conceptual and practical definition have evolved over the years. Food security is measured either at the aggregate (national) and or individual/ household levels. The most common approach to measuring food security by aggregate is assessing the national level food availability due to food production output (FAO, 2013). Assessment of the success of the green revolution (Toenniessen et al., 2008; Otsuka and Kalirajan, 2006; Hazell, 2009; Till, 2021) and the Malawian fertilizer subsidy program (Oygard et al., 2003; Crawford et al., 2005) is largely based on this approach. One other aggregate measure is the prevalence of undernourishment. It is the availability of sufficient food energy adequate enough to cover the basic needs for a sedentary lifestyle (FAO, 2013). FAO (2013) concluded that Ghana has reduced the prevalence of undernourishment by 50% over the last two decades. This achievement was largely due to long-term rural development and poverty reduction strategies implemented by successive governments (FAO, 2013). Other aggregate measures include nutrition and distribution gaps. They compare prevalence of food insecurity across countries. The food nutrition gap measures the degree of food shortage by country, based on population, national availability, and an estimated minimum dietary energy requirement of 2100 calories per person per day. The distribution gap assesses the difference between projected availability and the

additional food needed to increase the food consumption of food deficit income groups (Shapouri et al., 2011; Upton et al., 2016).

According to Upton et al. (2016), though aggregate assessments rely on strong assumptions in explaining the food security of heterogenous groups, they give little or no information about the utilization of food or changes over time. Aggregate assessments do not also account for household demographic characteristics as a function of calorie intake (Pérez-Escamilla and Segall-Corrêa, 2008). Food security measurements at the household level from survey data give adequate information regarding individual food consumption and includes availability, access and utilization (Upton et al., 2016). Examples of household food security metrics include dietary diversity and food consumption indicators, the Coping Strategies Index, Household Food Insecurity Access Scale (HFIAS) and the Household Hunger Scale (HHS), and Subjective or experiential indicators (Upton et al., 2016).

Dietary diversity and food consumption measures rely on survey data on food consumption (Upton et al., 2016; Sahu et al., 2017). They employ recall data on foods eaten and their frequency or weights and measures based on direct observation. An indicator is then constructed for food consumption and/or dietary diversity (Upton et al., 2016). These include the Food Variety Score (FVS) or Household Dietary Diversity Index (HDDI), the Dietary Diversity Score (DDS), the Food Frequency Score (FFS), and the Food Consumption Score (FCS) (Upton et al., 2016). The Food Variety Score (FVS) or Household Dietary Diversity Index (HDDI) is a count of the number of different food items consumed in the past week ((Upton et al., 2016). The Dietary Diversity Score (DDS) is a count of food groups consumed (Upton et al., 2016; Sahu et al, 2017). Food Frequency Score (FFS) is a sum of food groups that integrates the frequency of consumption of each food group. The Food Consumption Score (FCS) builds on the FFS by weighting food groups based on their nutritional quality (Upton et al., 2016). Household Dietary Diversity Score (HDDS) and Food Consumption Score (FCS) are often considered indicators of both quantity and quality (for measuring the access dimension of food security) (Leroy et al., 2015). These measurements have the advantage of measuring the daily calory intake of a member of a household. This helps in understanding access to culturally acceptable food sources or composition (Jones et al., 2013). For example, Tambo and Wunscher (2017) employed food consumption expenditure, food gap, Household Hunger Scale (HHS) and Household Dietary Diversity Score (HDDS) in assessing the impact of farmers innovations on household food security in Ghana. They found increases in household income, consumption expenditure, and food security. However, increases in productivity and income effects due to farmer innovations did not improve nutritious diets, measured by household dietary diversity. However, there is paucity of literature on whether fertilizer subsidy programs are contributing to nutritious diets. The food gap refers to the number of months within the past 12 months that households had difficulty satisfying their food needs due to depletion of own food stocks or lack of money to purchase food (Tambo and Wunscher, 2017). This measure is referred to as

the months of inadequate household food provisioning (MIHFP) in Bilinsky and Swindale (2005). The food gap is a subjective measure of food security (Tambo and Wunscher, 2017).

In assessing the effect of cash crop production (cacao and oil palm) on food security in the Ashanti region of Ghana, Anderman et al. (2014) considered three dimensions of food security: food availability, which was determined by the number of months per year that households reported having insufficient food; food access, which was determined by the coping mechanisms they used to obtain enough food; and food utilization, which was determined by the variety of household diets and anthropometric measurements of children's nutritional status such as height-for-age, weight for age and weight-for-height. Anderman et al. (2014) found substantial inverse connections between each of these pillars of food security and the level of cash crop production in a household. For example, farmers who allocated a larger percentage of their land to oil palm and/or cacao production struggled to find enough food to eat (availability) and also adopted more stringent coping strategies to have access to food (Anderman et al., 2014). Food security continues to be a problem in Ghana in most parts of the year. This is despite efforts to promote commercialization among both cash crop and staple food crop producers (Dzanku et al., 2021). In assessing the implications of gender and geography of agricultural commercialization for food security in Ghana, Dzanku et al. (2021) did not find positive correlation between commercialization and food security. Dzanku et al. (2021) measured food security using dietary diversity score, food consumption per capita and the number of months food is available in the house. Households living in districts with higher commercialization potential were still found to be relatively food insecure. Dzanku et al. (2021) noted that relying on food markets to achieve food security might not give positive outcomes under certain conditions. Though these studies (Anderman et al., 2014; Dzanku et al. 2021) have investigated at least more than one dimension of food security, the contribution of their variables of interest has not accounted for the time dimension of food security; the stability or sustainability dimension.

Some studies have looked at the effect of shocks on food security. For example, Onyango et al. (2023) employed the FAO (2015) self-reported assessment of household food insecurity to measure the experience of food insecurity during COVID-19 in Ghana. Onyango et al. (2023) found hikes in food prices to have affected food insecure households the most. Demographic characteristics had less impact on food insecurity during COVID-19. The pandemic affected more wage income and total household income (Onyango et al, 2023). The implication is that government policies (such as GFSP) should aim at contributing to the growth total household incomes since they are affected in times of shock. In addition, one way of coping with shocks is building the capacity of resilience at the household level. To small farm households, fertilizer subsidy and their own investment in the form of adoption of complementary technologies could be the best options for building resilience. Ansah et al. (2023) found in Ghana that a household's resilience capacity is able to moderate or mediate the effect of shocks due to heat stress and drought on food security. Ansah et

al. (2023) employed household food security measures such as (household calorie consumption proxied by total household food consumption based on 12 food groups (kcal), Per capita food expenditure proxied by per capita total consumption expenditure (in Ghana cedis), and HDDS proxied by household dietary diversity score based on consumption of 12 food items over the past 7 days (Ansah et al. 2023). As pointed out earlier, the response to shocks (such as GFSP) on reducing sources of food insecurity (i.e., availability, access, utilization and stability) remains less explored in the literature.

2.9 Sustainable Intensification Practices (SIPs) and Integrated Soil Fertility Management (ISFM) Practices and Their Impacts on Agricultural Productivity

SIPs have the objective of increasing agricultural output and at the same time ensuring the long-term sustainability of farming systems by protecting natural resources and maintaining agro-ecological balance (Haggar et al., 2021). Specific examples of SIPs in Ghana include: chemical fertilizers, improved seeds, organic fertilizers, soil and water conservation (SWC) techniques, cereal-legume rotation, and cereal–legume intercropping. Intercropping is the practice of growing cereals and any locally cultivated legumes, such as soybeans, groundnuts, and cowpeas, on the same field, either randomly or in alternating rows. Likewise, rotation entails growing legumes and cereals consecutively on the same piece of farmland throughout time. Grass strips, drainage/ditches, stone terraces, contour plowing, and contour bunds are examples of SWC techniques. Crop residue, household garbage, and animal manure are examples of organic fertilizers (Kotu et al., 2017). Whereas the definition of SIPs is broad in scope in the literature and sometimes encompasses ISFM, ISFM definition mostly refers to limited number of the SIPs technologies. Integrated Soil Fertility Management (ISFM) refers to practices that combine the use of inorganic fertilizers, organic resources, improved seeds, and good agronomic practices to enhance crop productivity and soil health. (Vanlauwe et al., 2010; Abukari and Abukari, 2020; Nogueira De Sousa and Angélica Moreira, 2024). ISFM practices must adapt to local conditions (Vanlauwe et al., 2010) and should lead to sustainable agricultural productivity (Nogueira De Sousa and Angélica Moreira, 2024)

Some studies have shown that adoption of multiple SIPs, particularly those that combine commercial inputs with traditional methods, is linked to higher maize yields in Ghana (Kotu et al., 2017). Climate-resilient agricultural practices, including row planting and drought-resistant maize varieties, have been found to play a significant role in the productivity and marketability of maize (Martey et al., 2020). The simultaneous adoption of Striga-resistant maize varieties and mineral fertilizer led to a significant significantly increased maize yield by 872 kg/ha in Ghana (Martey et al., 2023). Intercropping cowpea as a living mulch 1–2 weeks after planting maize was found to have a significant positive effect on yield from a two-year field experimental study in northern Ghana (Abdul Rahman et al., 2024).

Adoption of ISFM technologies such as inter cropping, minimal tillage, mulching, and combining organic and inorganic fertilizers, has the potential to significantly boost agricultural productivity and crop yields in SSA (Dimkpa et al., 2023). In a review, Kugedera et al. (2023) found ISFM to increase maize yields by 15–145% in the semi-arid regions of SSA. Under ISFM, sorghum yields range from 690 to 3500 kg/Ha and maize yields from 4200 to 5500 kg/Ha. Morgan et al. (2015) found the adoption of ISFM practices in Kenya to have increased both technical and allocative efficiency of maize farmers by 26% and 30%, respectively. In northern Ghana, Integrated Soil Fertility Management (ISFM) greatly increases net income and maize yield. Combined adoption of ISFM technologies such as farmyard waste, inorganic fertilizers, and crop rotation resulted in 86.52% increase in maize yield and a 51.29% gain in net revenue (Boansi et al., 2024)

Current intensification of agriculture in Ghana emphasizes on monoculture which relies solely on the adoption of monocultural practices. However, these practices prioritize short-term gains over long-term and sustainable agricultural productivity. This includes relying heavily on conventional farming practices that neglect soil health (Kotu et al., 2017). Farmers also rely on outdated and ineffective methods such as applying spoiled animal waste, building unnecessary ridges, and rotating crops in a way that actually reduces soil fertility and increases water runoff. (Naazie et al., 2023). Shrestha et al. (2021) argue that current intensification approaches are not sustainable as they prioritize maximizing short-term yields at any cost, regardless of the devastating impact on the environment, and neglecting best management practices.

Despite the reported evidence of either SIPs or ISFM on increased yield in Ghana (Kotu et al., 2017; Martey et al., 2020; Martey et al., 2023; Dimkpa et al., 2023; Kugedera et al., 2023), their impact on other important food security and welfare indicators such as household food and total consumption, dietary diversity and food consumption score have not been studied. In addition, food security has not been conceptualized into the four dimensions. An understanding of the contribution of ISFM to the dimensions of food security could help drive ISFM promotion by policy makers and its adoption among smallholder farmers. This is particularly important because the current primary cause of Ghana's increased food production, Jayne et al. (2015) argue, is through land expansion and not through increased productivity. The majority of crops' average yields fall between 20% and 60% short of their potential yields, suggesting substantial room for improvement (Jayne et al., 2015).

2.10 Theoretical Frameworks of Farm Household Models

Agriculture remains a major employer in Ghana and the leading employer in rural areas. It is therefore important to understand and account for the behaviour of these farmers when assessing government interventions such as GFSP and their decision to participate in technology adoption through farm household models (Lopez, 1986). Agricultural household models are an ideal tool for analyzing the impact of these interventions on marketed surplus since they account for both consumption and production behavior (Lopez,

1986). A number of theoretical frameworks of farm household model choices such as profit maximizing, utility maximizing and risk-averse behaviours are explored to explain the linkages between Ghana's FSP and farm households' food security outcomes, as presented in Figure 2.1. Farm household is the unit of micro-level analysis. Farm household models are applicable to peasant farming or family-owned farming systems. Due to imperfect markets, decisions regarding production, allocation of family labour and consumption are interlinked (Louhichi et al., 2020).

Farm producing households in developing countries are efficient though they may be poor (Schultz, 1964). This is contrary to the previously held view that smallholder farmers are poor because they are inefficient. Both Schultz (1964) and Singh et al. (1986) argued that smallholder farmers in developing countries have both subsistence and profit motives. A maize producing household's profit maximization consists of both the behaviour or motivation of the household and the performance of the farm as a business (Mendola, 2007). They consist of the basic units of micro-economic theory of a household and firm in developing countries (Singh et al., 1986) such as Ghana. The household's profit maximization theory is, however, limited by the presence of trade-offs between profit maximization and other goals of the household, and the role of uncertainty and risk in the production decisions of the farm household. Regarding the utility maximization of the farm household, it considers the farm household as a dual entity, playing the role of a farm family and a farm enterprise, taking into account household consumption decision-making (Mendola, 2007). Thus, the household makes decisions about consumption and production simultaneously as shown in Figure 2.1 (Singh et al., 1986; Lopez,1986; Hunt, 1991; Mendola, 2007). Part of what is produced is sold to meet the cash requirements of the household by buying food that is not produced by the household as well as non-food items. As part of consumption is also the purchase of farm inputs. Shocks, prompted the implementation of fertilizer subsidy programs across sub-Sahara Africa, including Ghana as noted earlier. Participation in the GFSP affects farm input use in general, and specifically, adoption of SIPs which in turn affect production. As portion of the produce from production is available for consumption by the household (Mendola, 2007), the household also makes the decision to store some against future shocks. Still coping against shocks, the household also makes a decision to buy assets such as radio, bicycle, motorcycle, etc., from the marketed surplus from production, as indicated in Figure 2.1. According to Singh et al. (1986) and Lopez (1986), government agricultural policies such as fertilizer subsidies will affect the activities of the farm household such as production, consumption, food security and supply of inputs including family labour (Lopez, 1986; Louhichi et al., 2020). The implication of this theory (utility maximization) is that although GFSP is targeted at an individual farmer of 2Ha of land under cultivation or less (GoG, 2017; Pauw, 2022), it benefits the whole household, not just the individual who obtained subsidized fertilizer. It also assumes a positive relationship between GFSP and farm households' input purchases under missing or imperfect markets. As a result of the market failures faced by farm households, production and consumption decisions

must be addressed at the same time, but not separately (Singh et al., 1986; Louhichi et al., 2020). Thus, the household's input purchases will promote the development of the local retail input markets and other local businesses. Benefiting from GFSP may also entice a household to participate in the private input market (leading to crowding-in) owing to income, soil fertility and learning effects of input subsidies, as indicated in Figure 2.1. According to Ricker-Gilbert and Jayne (2016), income effect occurs when subsidy artificially reduces the price of fertilizer and increases the purchasing power (for farm inputs) of farmers in real terms. Soil fertility effect occurs when there is increased nutrient stocks in the soil for use by subsequent crops after harvest. However, provision of mineral fertilizers through FSPs may hardly produce such effects compared to organic fertilizers from compost and other organic sources. Learning effect occurs when a farmer learns how to use fertilizer and other complementary inputs effectively (Ricker-Gilbert and Jayne, 2016). The expected utility or profit maximization of a household is a function of adoption of a package of technologies (Feder et al., 1985). However, there is presently limited empirical evidence linking farm household's adoption decision to SIPs either due to participation in GFSP or without it.

Mendola (2007) argues that the limitation of both profit and utility maximization theories is that they do not take into account the effect of household behaviour under risks and uncertainties that prevail in production conditions of smallholder farmers. Since smallholder farmers produce under risks and uncertainties brought about by shocks (Ellis, 1992), they are exposed to risks and will be cautious in their decision-making. They are therefore assumed to show risk-aversion in their decision making (Mendola, 2007). Subsequently, as indicated in Figure 2.1, they will adopt ISFM technologies which are also considered as climate-smart technologies, to avoid or mitigate against the negative effects of these risks and may also participate in government programs such as GFSP (Mendola, 2007). Adoption of ISFM may impact on household food security, as indicated in Figure 2.1. Mendola (2007) observed that a farm household's risk-averse behavior may be the result of missing or imperfect markets such as insufficient channels to self-insure or share risk with other farmers. According to Feder et al. (1985), the household decision-making under such circumstances has to be dynamic. Unlike static models that relate to the degree of adoption of a technology at a given point in time and the factors influencing the adoption (Feder et al. 1988), dynamic adoption models can be explained in two ways. The first is a dynamic model with improved skills of the farmer where he or she attains higher profit margins or pay-off from a lower pay-off owing to learning and skills improvement (Feder et al., 1985; Ghadim and Pannel, 1999). This is explained as learning effects as noted earlier in Ricker-Gilbert and Jayne (2016). It induces farmers to increase their use of the new technology (Feder et al., 1985). The second is a dynamic model with uncertainty and trialing where the farmer is not certain about the yield and, output prices and prices of inputs in the current and future years are not known to the farmer. Due to learning effects stemming from trials or demonstrations of the crop, information about its yield and price performance are likely to reduce the farmer's uncertainty. This improves the farmer's

decision-making (Ghadim and Pannel, 1999). Static models mostly assume that a farmer adopts only one modern technology and has to decide on whether to adopt and to what extent to adopt the technology (e.g., mineral fertilizer or improved seed only).

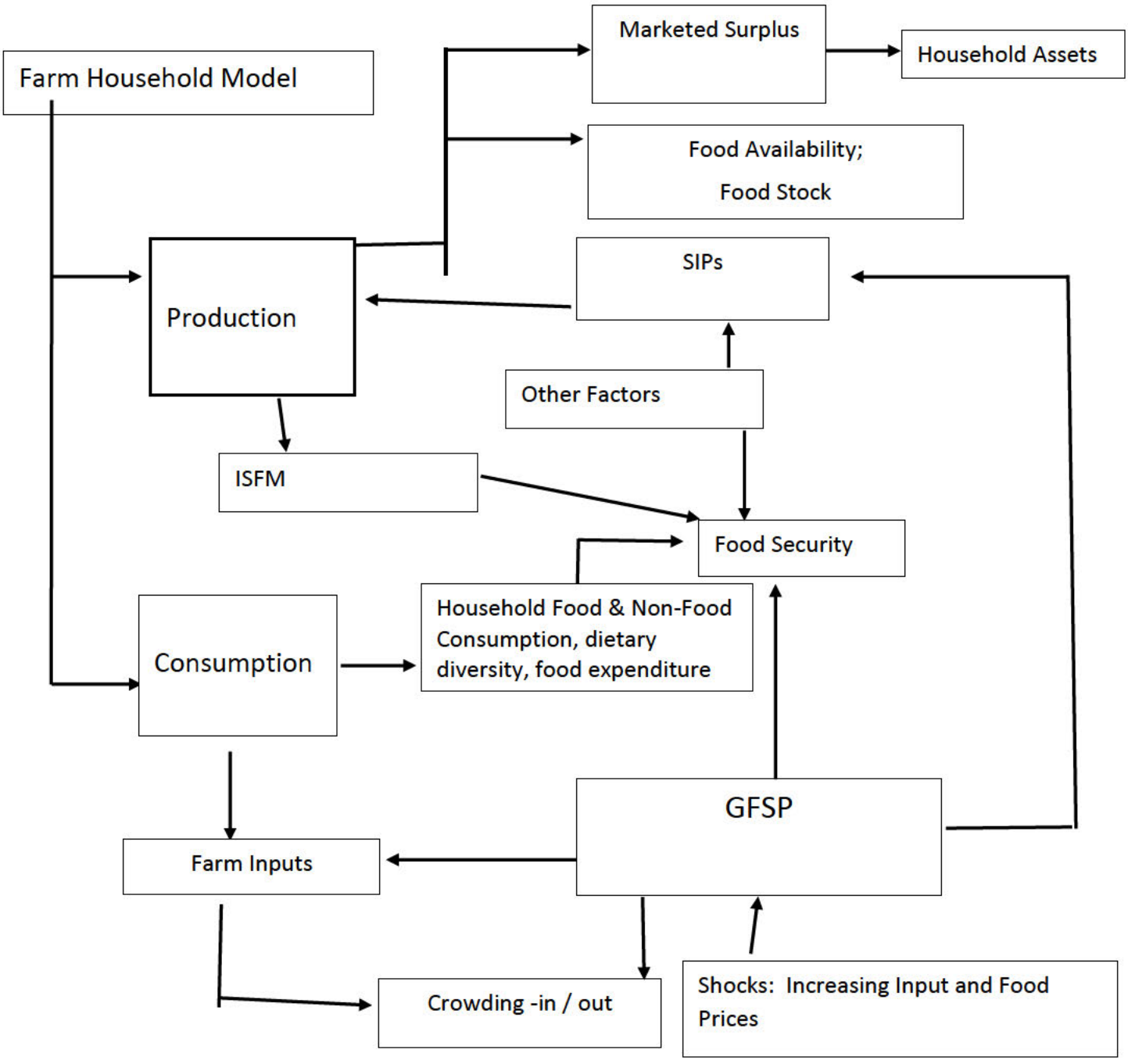


Figure 2.1: Theoretical framework of household decision-making and impacts on food security

Profit and utility maximization models most of the time are static. They assume that smallholder farmers are risk-neutral. The social contexts within which smallholder farmers operate is, therefore, ignored (Mendola, 2007). In reality, farmers adopt a mix of technologies to overcome their production constraints (Teklewold et al., 2013), though the adoption of new technologies may be gradual and partial and may be concentrated in a particular geographical location. Technology adoption can, therefore, produce varying effects on farmers' food security outcomes within and across different geographical locations (Winkelmann, 1998; Kerr and Kolavalli, 1999). Due to the non-availability of panel data for Ghana (Ragasa and Chapoto, 2017), the study employs a pooled cross-sectional data to see how the food security outcomes respond to some socio-economic, demographic and institutional factors of interest as they change over time. As can be observed in Figure 2.1, other factors including education, improved infrastructure (e.g., better road networks and markets), exogenous technological change and agricultural policies contribute to improving food security. An example of agricultural policies in our context is the introduction of fertilizer subsidies (Winkelmann, 1998; Kerr and Kolavalli, 1999). From Figure 2.1, possible negative effects might be associated with the implementation of input subsidies. For example, the tendency for fertilizer subsidies to crowd out private input dealers in the markets by reducing commercial demand for fertilizer and other inputs by farmers exists, as indicated in Figure 2.1.

2.11 Theoretical Contribution of the Study

Although literature has investigated the impact of the varied objectives of fertilizer subsidies (financial, economic and non-economic) in SSA, limited evidence links fertilizer subsidies to achieving the 'smart objective' in terms of increasing purchase for SIPs and gross farm inputs from the private retail agro-input markets by smallholder farmers, as well as the four dimensions of household food security. The empirical evidence on the impacts of fertilizer subsidies in SSA in achieving the smart objective is limited to increasing the purchase of mineral fertilizers as observed in Xu et al. (2009b), Ricker-Gilbert et al (2011), Takeshima and Nkonya (2014) and Ricker-Gilbert and Jayne (2016). Specifically, the present literature has not explored the potential of fertilizer subsidy programs to achieving a non-economic objective of restoring soil fertility, mitigating the negative effects of climate change, sustainable agricultural intensification, and at the same time, the economic objective of promoting input market and rural development. The paucity of literature in this regard is both local and international, as noted in section 2.6. Arguably, an important variable such as the impact of GFSP on the four dimensions of household food security, is also absent in the literature, though there exist some few studies linking fertilizer subsidies to some dimensions of food security in SSA in terms of the diet quality of women of reproductive age (Assima et al., 2019) and kilocalories per capita per day, the probability of a household being food secure and the number of months

of household food security (Sibande et al., 2015) in Mali. At the local level, the emphasis is largely limited to the availability dimension of food security as noted in the literature reviewed (Tsiboe et al., 2021; Pauw. 2022). In addition, several studies have investigated the impacts of shocks on household food security such as global food crisis (e.g., Golay, 2010; Headey, 2013), climate change and variability (Aragón and Rud, 2023; Galbert and Olinga, 2023) and COVID-19 (e.g., Agyei-Holmes et al. 2023) on some dimensions of food security. The impact of a key government response such as GFSP and farmers' own investments such as SIPs remains unexplored in the present literature. None of the literature reviewed so far has also offered an alternative to replacing fertilizer subsidy programs or complementarities. This is despite the agreements in the literature that fertilizer subsidy programs are unsustainable (e.g., Crawford et al., 2006), poorly targeted (e.g., Kherallah et al., 2002; Crawford et al., 2006; Jayne et al., 2018; Zinnbauer et al., 2018) and may not be effective strategies to promote further fertilizer use since it is profitable without a subsidy (Ragasa and Chapoto, 2017). Complementary adoption of technologies could be a replacement for fertilizer subsidy programs or enhance their benefits as it has been found to increase agricultural productivity (Liverpool-Tasie et al., 2017). However, limited evidence exists on their pay-offs on the dimensions of food security. This might have been the cause of lack of government policies promoting complementary technologies for adoption. This could also explain why food insecurity still persist in Ghana (FAO, 2013; Darfour and Rosentrater, 2016; CFSVA, 2020). Consequently, a clear answer to how GFSP contributes to adoption of SIPs and gross farm inputs, dimensions of food security and the impact of Integrated Soil Fertility Management (ISFM) on the dimensions of food security is missing in the literature. This study seeks to answer these questions by investigating smallholder maize farm households in Ghana using a nationally-representative data.

2.12 Study Area

The study areas for this study are the formerly ten administrative regions of Ghana. The study uses pooled cross-sectional data from the Ghana Living Standard Survey (GLSS) for rounds seven and six for only maize farmers. The GLSS data set is nationally representative and covers all the administrative regions and agro-ecological zones of Ghana. Ghana has six agro-ecological zones (Oppong-Anane, 2006; Osei and Stein, 2017) as shown in Appendix A. The evergreen rain forest, deciduous rain forest, transition and coastal savanna zones make up the southern half of the country. These agro-ecological zones have two rainfall patterns, allowing for two annual growing seasons (major and minor growing season). The Guinea and Sudan Savanna agro-ecological zones make up the northern half of Ghana. These zones have only one major or growing season (May to October) (Oppong-Anane, 2006). Appendix A indicates as well the formerly ten administrative regions of Ghana.

The Ghana Statistical Service collects the GLSS data with technical assistance from the World Bank. The GLSS is the Ghana's customized version of the World Bank's Living Standards Measurement Study (LSMS). The LSMS makes relevant data available for policy and decision-makers to measure socio-economic indicators and find out their determinants. The first Ghana Living Standards Survey was conducted in 1987/88. The GLSS collects detailed information from households throughout the country (GSS, 2014).

The information covers demographic characteristics, household agricultural production, asset ownership, access to financial services, education and skills training, household income, consumption and expenditure, housing conditions, employment and time use The GLSS data are not a panel. They are a set of repeated cross-section surveys. The reason for using pooled cross-sectional data is that it raises variance beyond what can be observed within a one time-period survey, and allows similar patterns to be identified across time-periods. Pooled data increases the sample size. Statistical reliability of the results and accuracy of the estimated parameters are achieved with pooled data relative to a single cross-sectional data (Gerdtham et al. 1998; Zieman et al. 2002). Households are the unit of analysis of GLSS data (GSS, 2019). The GLSS7 is the newest wave undertaken between 2016 and 2017. The GLSS6 data was collected between 2012 and 2013. The period of data collection for each wave is always 12 months. This is to allow enumerators to continuously record consumption and expenditures at the household level and changes that may occur.

The GLSS data is a pre-coded data. The data are mostly in the raw form, though there are variables that have been generated already by GSS for their official publications (e.g., GSS, 2019; GSS, 2014). The researcher has to harmonize the data and generate variables of interest. This was done to have a household micro-level data set that is nationally representative. This study has adapted the procedure used by Tsiboe (2020) in the generation of variables and harmonization of data from the two different rounds of the GLSS. Details on how the variables used in this study were generated and harmonized are provided in Appendix B. Other previous studies have harmonized data from different rounds of GLSS (Dagunga et al., 2020; Nkegbe et al., 2024) and the World Bank's Living Standards Measurement Survey (LSMS) (Carletto et al., 2007; Lebrand and Yin, 2022). However, this study is unique and different from the previous ones as it generates and harmonizes data at the household level of maize growing farmers from two rounds of the GLSS. Information on agriculture, household food and non-food expenses, access to credit, household assets and community infrastructure were used. It makes it possible to assess the impact of policy and household input use at the plot level taking into account household socio-economic, institutional and community characteristics. The study makes use of information collected from both the household and community level questionnaires of the GLSS data.

2.13 Sample Design

The waves of the Ghana Living Standards Survey (GLSS) are always designed to give national and regional representative indicators. The same sampling methodology, the same questionnaires covering the same broad range of topics are often used for each wave. A two-stage stratified sampling procedure is always employed (GSS 2014; GSS 2019). For example, for the GLSS6, at the first stage, 1200 Enumeration Areas (EAs) were selected to form primary sampling units (PSUs). The PSUs were allocated into the ten administrative regions of Ghana using probability proportional to population size (PPs). The EAs were further divided into urban and rural localities of residence. A complete listing of households in the selected PSUs was undertaken to form the secondary sampling units (SSUs). At the second stage, 15 households from each PSU were systematically selected. Hence, the total sample size comes to 18,000 households nationwide for the GLSS6 (GSS, 2014, pp.2). The GLSS7, the newest wave, has a total sample size of 15,000 households nationwide, in 1,000 AEs comprising 561 (56.1%) AEs that are considered rural and 439 (43.9%) in AEs that are urban (GSS, 2019). However, the focus for this study is on maize growing households in two respects. Firstly, maize growing households that participated in the GFSP and secondly, maize growing households that adopted intensification or integrated soil fertility management (ISFM) practices. The pooled sample size for only maize-growing households for GLSS6 and GLSS7 was 10,166. The pooled sample size for maize-growing households who reported expenditure on mineral fertilizer for GLSS6 and GLSS7 is 4,365. The GLSS7 consists of 1,977 and GLSS6 consists of 2,388. Out of the pooled sample size of 4,365 for maize growing households who reported expenditures on mineral fertilizers, only 481 farm households participated in the GFSP. The Ghana Living Standard Surveys always have specific focus. The GLSS6 focused on labour force. The agriculture module was the focus for the GLSS7. However, as noted earlier, same questions are often asked across the different waves. Whilst some questions such as household demographic characteristics are relevant to all the empirical chapters, some questions are relevant to specific empirical chapters only. This will be indicated in the separate empirical chapters.

2.14 Summary

This chapter highlights the decline in recent times of the contribution of Ghana's agriculture sector to national GDP. In addition, the position of the crops sub-sector slipped from being the second largest economic activity in 2018 to being the third largest economic activity in 2019. Agriculture in Ghana remains largely subsistence, contributing almost 80% of the national food output. These have risen concerns among policy makers about meeting the country's food security needs and achieving SDGs

1 and 2. Climate change and variability and other shocks including increased cost of mineral fertilizer have compelled the government to implement the Ghana's Fertilizer subsidy Program (GFSP). Beyond Ghana, this chapter highlights some of the objectives of other FSPs in SSA.

The chapter highlights that the earlier work on fertilizer subsidies centered on their evolution and concepts, advantages and disadvantages associated with their implementation. These disadvantages finally led to their halt. The SAP has also largely been reported in the literature as the major reason for halting FSPs in SSA. What was lacking in the early studies was the contribution of subsidy programs to household welfare and input market development. With the introduction of the smart subsidies in recent years, investigations have corrected the mistakes made in the past to some extent. There is sufficient information now on the impacts of FSPs on household welfare and input market development, as the chapter observed. In terms of input market development, studies are heavily centered on demand for commercial mineral fertilizers due to participation in the programs. However, recent studies have not looked at the contribution of FSPs to sustainable intensification practices and, farm inputs, in general, among smallholder farmers. This chapter also highlights how both the definition and measurement of food security have evolved over the years. Lessons from such evolution have explained that the understanding of food security has moved from just the mere supply of food to being muti-dimensional and economically and physically accessible at all times in safe, nutritious and in sufficient quantities to individuals at all times for an active and healthy wellbeing. This chapter highlights that improving access to food requires building the capacity of individuals and their food systems to withstand shock, stressing that both stability and sustainability constitute the time dimension of food security. The chapter also indicates that meeting households' food security needs requires farmers' own investments. Conversely, the measurement of food security requires the use of multiple indicators instead of a single indicator.

In this chapter, exploring household production decisions within theoretical frameworks establishes a linkage between Ghana's FSP and farm households' food security outcomes. It also takes into account farm households' responsive or inducive behaviour under production risks and uncertainties in the form of investing in climate smart technologies. Mimicking a dynamic model approach of farm households' behaviour under uncertainties due to the lack of panel data in Ghana, this chapter provides an analytical framework using a pooled cross-sectional data to explain how the food security outcomes respond to GFSP, complementary climate-smart technology adoption, some socio-economic, demographic and institutional factors of national policy interest. The chapter concludes with a description of the study area and sample design. The succeeding chapters (three, four and five) comprise of empirical chapters presented in accordance with the three specific objectives of the study

using the same data set. However, chapter 5 employs the full data set of all growing maize households. The next chapter discusses the factors that determined participation into the GFSP and the extent to which the GFSP affected adoption of agricultural intensification technologies and gross farm inputs.

CHAPTER 3: HOW DOES PARTICIPATION IN GFSP AFFECT THE ADOPTION OF SIPS AND GROSS FARM INPUTS?[1]

3.1 Introduction

Input subsidies are being considered as a policy strategy through which African countries can move towards a green revolution similar to that of the Asian countries. The use of mineral fertilizer, for instance, is crucial for achieving a green revolution in Africa due to increasing population and declining soil fertility (Benin et al., 2013). Challenges do exist in the implementation of input subsidy programs across Sub-Saharan Africa (SSA). The benefits of input subsidies only accrue to those with high incomes and well-to-do farmers due to poor targeting (Kherallah et al., 2002; Crawford et al., 2006; Jayne et al., 2018). There is diversion of inputs and smuggling along the distribution chain. The marginal increase in crop yield due to an additional quantity of fertilizer application is also low (Crawford et al., 2006; Jayne et al., 2018). Efforts have been made in recent years by governments in SSA on the design and better implementation of input subsidies. The current subsidies have often been termed 'smart'. A smart subsidy, according to Morris et al. (2007), should among other things, have the characteristic of supporting the growth of the private agro input companies.

Climate change and variability also remains a problem in SSA, and Ghana is no exception. Rising temperatures and desertification are projected to increase in Ghana. At the same time, rainfall is projected to decline (Asante and Amuakwa-Mensah, 2015). Risks from climate change and declining soil fertility may endanger the quest for a green revolution. At the same time, they may induce an adoption behavior among farm households in coping with the risks. Opportunities that a fertilizer subsidy program presents to farmers in the form of reduced input prices may also incentivize farmers to adopt improved agricultural technologies for increased productivity (Hemming et al., 2019). According to Lamessa et al. (2019), threats such as climate risks and variability, and opportunities such as fertilizer subsidies could induce farmers' participation in agricultural technology adoption. There however remain a paucity of literature on how input subsidies induce climate adaptation and sustainable agricultural intensification, besides achieving the objective of a green revolution. This is particularly important for policy makers since sustainable agricultural intensification that is smallholder-driven is being promoted as a critical development pathway for improving farmer

[1] This chapter gave rise to the following publication: Jinbaani AN and Wale E. 2023. How does participation in Ghana's fertilizer subsidy program (GFSP) affect the adoption of sustainable intensification practices (SIPs) and gross farm inputs? Development Studies Research, 10:1, 2180047, DOI: 10.1080/21665095.2023.2180047. https://doi.org/10.1080/21665095.2023.2180047

livelihoods and boosting productivity in SSA (Djurfeldt et al., 2019). It supports the findings of Tsega et al. (2019) that SIPs (such as improved seeds, urea, and compost) increase agricultural productivity.

Current studies on the impact of fertilizer subsidy programs in Ghana (Houssou et al., 2017; Wiredu, 2015; Tsiboe et al., 2021) and elsewhere (Mason and Jayne, 2013; Liverpool-Tasie, 2014) did not measure if the programs are truly 'smart', especially, their ability to increase farmers' commercial demand for sustainable intensification practices and support private input markets to develop. The study, therefore, evaluates the effect of Ghana's fertilizer subsidy program on adoption intensity of SIPs and gross farm inputs among maize-growing farm households using a nationally representative data. The SIPs are mineral fertilizer, organic fertilizer, improved seed, irrigation, mechanization and pesticides. The gross farm inputs, which are also climate risks adaption strategies, in addition to the SIPs, include expenditures on storage and storage bags, rent for bullocks for ploughing, local and imported hand tools, and other farm expenses.

It will be useful to estimate the effect of GSFP on gross farm inputs, in addition to SIPs. One way farming households benefit rural economies is through farm input expenditures. This is because farm operations have forward and backward linkage effects with the agricultural input and output markets (Lambert et al., 2009). This study is different from existing studies, which solely looked at the demand for commercial fertilizer due to a government's subsidy program (e.g., Xu et al., 2009a; Ricker-Gilbert et al., 2011; Takeshima and Nkonya, 2014 and Ricker-Gilbert and Jayne, 2016). It is more informative to examine the impact of subsidy on complementary SIPs since agricultural productivity is not just a question of fertilizer alone. The relationship between adoption intensity of SIPs and participation in GFSP has not received much attention in the empirical literature. This notwithstanding the risks of climate variability and declining soil fertility facing Ghanaian farmers.

Two-stage least squares with instrumental variables (2SLS-IV) and endogenous switching regression (ESR) are employed in this chapter to control for sample selection bias. Since farmers decide on their own to participate in the GFSP and invest in SIPs such a decision may be affected by both observed (such as farm and household sizes) and unobserved factors (e.g., innate abilities of head of farm households). The use of the ordinary least squares to estimate the effect of GFSP on adoption intensity of SIPs may lead to sample selection bias.

The remainder of the chapter is organized as follows. The methodology is presented in section 3.2. The methodology consists of the conceptual and modeling framework, the empirical specification and data used in the analysis. The results and discussions are contained in section 3.3. The final section presents the conclusions and policy recommendations.

3.2 Methodology

3.2.1 Conceptual Framework and Estimation Strategy

According to Ricker-Gilbert and Jayne (2016), income, soil fertility and learning effects could increase (crowd in) commercial purchase of other inputs, following the introduction of input subsidies. Income effect occurs when subsidy artificially reduces the price of fertilizer and increases the purchasing power (for farm inputs) of farmers in real terms. Soil fertility effect occurs when there is increased nutrient stocks in the soil for use by subsequent crops after harvest (Ricker-Gilbert and Jayne, 2016). Soil fertility effects may not be the case for cropping systems in Ghana due to inherent poor soil conditions. Depletion rates of soil nutrients in Ghana are estimated at 35 kg N, 4 kg P, and 20 kg K per hectare annually (Bationo et al., 2018). Improvements in soil fertility through organic sources are therefore necessary. Following Vondolia et al. (2021) and Holden and Lunduka (2012), a production function is specified as:

$$f(SFI(F, IS, O(L), I, Y, SIPs), \quad (3.1)$$

where $f(.)$, is the production function, $SFI(.)$ is soil fertility improvement which is dependent on mineral fertilizers F, improved seed IS, organic fertilizer O. The organic fertilizer depends on use of labour L. Farm income is represented by I. But since farm household income is seasonal and fluctuates, it is represented by value of farm household assets in the model estimation. Maize output Y and $SIPs$ is other sustainable intensification practices such as pesticides, irrigation and mechanization. Since the data for this study has farmers' expenses on these inputs, the Slutsky equation that describes mineral fertilizer price changes due to GFSP on substitution and maize output effects can be employed.

The differentiation with respect to fertilizers gives the following equation:

$$\frac{\partial T}{\partial Ft} = \frac{\partial T}{\partial Fp}(SFI(Fp, Op(L), IS, I, Y, SIP) + \frac{\partial Fp}{\partial Y}(SFI(Fp, Op(L), IS, I, Y, SIP) \times \frac{\partial Y}{\partial Fp} \quad (3.2)$$

$\frac{\partial T}{\partial Fp}(SFI(Fp, Op(L), IS, I, Y, SIP)$: Substitution effect; (3.3)

$\frac{\partial Fp}{\partial Y}(SFI(Fp, Op(L), IS, I, Y, SIP) \times \frac{\partial Y}{\partial Fp}$: output effect, (3.4)

where F_p is the price of mineral fertilizer and all other variables as defined before.

To estimate the effect of participation in GFSP on investments in SIPs and gross farm inputs, such investments are measured as continuous variable using expenditure equations. The expenditure equations have the advantage of explaining the crowding-in/ crowding-out effect of GFSP. There is

also an added advantage of explaining adoption intensity of SIPs and gross farm inputs due to GFSP. Adoption intensity is measured using expenditure incurred on inputs as this is common in the literature (Issahaku and Abdul-Rahaman, 2019; Ma et al., 2017).

Learning effect occurs when a farmer learns how to use fertilizer and other complementary inputs effectively. In the end, income, soil fertility and learning effects, according to Ricker-Gilbert and Jayne (2016), could increase farmers' demand for commercial fertilizer. This chapter, therefore, adapts the "crowding in" and "crowding out" effects framework as in Xu et al. (2009a), Ricker-Gilbert et al. (2011) and Ricker-Gilbert and Jayne (2016) in a selection model approach. The choice of SIPs is because farmers also have an induced behavior towards coping with climate risks (Lemessa et al., 2019).

The framework considers that the total quantity of fertilizer accruing to a farm household is obtained from two sources: government source under input subsidy and commercial purchases from private input dealers. This can be mathematically shown as:

$$T = G_s + C_p, \tag{3.5}$$

where T is the total quantity of fertilizer bought by the farm household, G_s is the quantity of fertilizer obtained under subsidy and C_p is the quantity of fertilizer obtained from private input dealers (Xu et al., 2009a; Ricker-Gilbert et al., 2011; and Ricker-Gilbert and Jayne, 2016). The framework assumes that farmers' additional demand for fertilizer is met through commercial purchase from the input market. This is because a subsidy program could only provide a limited quantity of fertilizer to beneficiaries (Xu et al., 2009a).

Following Xu et al. (2009a) and Ricker-Gilbert and Jayne (2016), the impact of a subsidy program on total fertilizer consumption, T, by a household is a function of:

$$\frac{\partial T}{\partial G_s} = \frac{\partial G_s}{\partial G_s} + \frac{\partial C_p}{\partial G_s} = 1 + \frac{\partial C_p}{\partial G_s}, \tag{3.6}$$

where the derivative $\frac{\partial C_p}{\partial G_s}$ explains the change in households demand for fertilizer from commercial sources having obtained subsidized fertilizer. If $\frac{\partial C_p}{\partial G_s} \leq 0,$ subsidized fertilizer is said to displace or crowd out the purchase of fertilizer from commercial sources. On the other hand, if $\frac{\partial C_p}{\partial Gs} \geq 0,$ subsidized fertilizer obtained by the household increases the household's demand for fertilizer from

commercial sources. Subsidized fertilizer has no impact on commercial fertilizer purchases by household if $\frac{\partial C_p}{\partial G_s} = 0.$ Due to expected income and learning effects from the GFSP, it is hypothesized that $\frac{\partial C_p}{\partial G_s} \geq 0$ (3.7)

The GFSP is said to be set with problems such as elite capture where large-holder and affluent farmers disproportionately benefit from the program (Houssou et al., 2017) and smuggling of fertilizer into neighboring countries such as Togo, Burkina Faso and Cote d'Ivoire. The implication is that not all the quantity of fertilizer released by government gets to farmers due to these leakages. Subsequently, G_s in equation (3.6) cannot adequately account for participation in the subsidy program or its effect on sources of fertilizer acquisition and quantity of fertilizer as in Xu et al. (2009a) and Takeshima and Nkonya (2014). I_s, participation in the subsidy program through having obtained subsidized fertilizer from government source, replaces G_s. Thus, G_s is the actual allocation from government to each administrative region for onward distribution to farmers in each district which is prone to leakages along the distribution chain, whereas I_s is the actual quantity of fertilizer received by a maize growing household. The leakages could emanate from mere inefficiencies and corrupt practices along the chain. Total consumption of fertilizer by a farming household is now:

$$T = I_s + C_p, \quad (3.8)$$

where variables are as described in equation (3.1). Thus, this framework accepts the possibility of leakages in the distribution of subsidized fertilizer unlike Ricker-Gilbert and Jayne (2016). In addition, the input demand function of a farm household is not only fertilizer in the case of this study, but SIPs and expenses on all other variable inputs that are considered as climate risks adaptation strategies employed on the farm herein referred to as 'gross farm inputs.' This is important particularly when the effects of fertilizer subsidy programs (soil fertility, learning and income effects) on maize yield have been found not to last after a cropping season though farmers have benefited from such programs over time (Ricker-Gilbert and Jayne, 2016). Adoption of complementary technologies such as SIPs and gross farm inputs in achieving food security and reducing poverty may play a better role than fertilizer subsidy programs (Xu et al., 2009b). However, conceptual approaches adopted by the existing studies evaluating fertilizer subsidy programs are limited to program's effects on yield as in Tsiboe et al. (2021) and increased consumption of fertilizer as in Liverpool-Tasie (2014) and Ricker-Gilbert and Jayne (2016), to the detriment of the program's enduring effects even after

Table 3. 1: Definition of Variables

Variable	Description
SIPs_Expenses	Total amount spent in Ghana Cedis (GHS) on the purchase of SIPs (mineral fertilizer, improved seed, pesticides, organic fertilizer, rent for irrigation and mechanization services) per hectare
Gross_Expenses	Total amount spent on the purchase of the following farm variable inputs in GHS/Ha: SIPs technologies; storage and storage bag; rent for bullocks for ploughing; local and imported hand tools; and other farm expenses.
Sex	1 if household head is a male; 0 otherwise
Agri_equipment (log)	Value of agricultural equipment in working condition (e.g., cart, spraying machine, water pumping machine, protective/ safety equipment, plough, simple harvester) in (GHS)
Adult ES	Adult Equivalent Scale
Education	Number of years spent in formal schooling by household head
Non-farm enterprise	1 if head of household engages in non-farm enterprise; 0 otherwise
Land size	Size of land allocated to maize (in hectares)
Marital status	1 if head of household is married; 0 otherwise
Ecological zone	1 if household is in the southern agro-ecological zone; 0 otherwise
Urban residence	Area of residence - 1 if a household resides in an urban area; 0 otherwise
TLUs	Tropical Livestock Units per household
Aid scheme	1 if mutual aid schemes found in the community; 0 otherwise
Irrigation	1 if the household belongs to a community which has irrigation fields; 0 otherwise
Access to extension	1 if agricultural extension officers visit farm households; 0 otherwise
Radio owned	1 if household owns a functional radio; 0 otherwise
Motorcycle owned	1 if household owns a motorcycle; 0 otherwise
Land_ownership	1 if any household member owns farm land; 0 otherwise
Use mobile phone	1 if any household member uses a mobile phone; 0 otherwise
National Grid	1 if the household is connected to the national grid; 0 otherwise
Membership_Cooperative	1 if the farm household participates in cooperatives in the community; 0 otherwise
Age	Age of head of household (in years)
Agric_loan	Amount of money received by the household as loan for agricultural purposes (GHS)
Subsidy	1 if the household was part of the fertilizer subsidy from government; 0 otherwise
Year_2017	Year of data collection, 1 if 2017; 0 if 2013
Market	Distance to the nearest big market (Km)
Agric_Office	Distance to the nearest agriculture office (Km)
Total_assets (log)	Value of household total assets in GHS

exit, such as adoption of SIPs by farmers. Furthermore, access to agricultural input and output markets is a major constraint facing farmers. The household's demand for input is, therefore, modeled as utility maximization constraint, as in Sadoulet and de Janvry (1995) and Liverpool-Tasie (2014). Household socioeconomic factors are predicted to influence input demand in this case. In addition, it

is assumed that farmers have two options to access fertilizer: commercial fertilizer from the private retail market and government-subsidized fertilizer under GFSP. The study's interest is those who obtained fertilizer from government. Following Singh et al. (1986) and Liverpool-Tasie (2014), the input demand function in equation (3.8) becomes:

$$ESIPs_i = \int (I_s, X, CF, HA) \quad (3.9)$$

where $ESIPs$ is i^{th} household's adoption intensity, I_s is participation in the subsidy program which could have a problem of self-selection or could be endogenous due to the problem of omitted explanatory variables; X is household's socio-economic factors, which include sex of head of household, household head level of education, land size, marital status; CF is community and institutional factors, which include community mutual aid scheme, presence of irrigation scheme in a community, access to extension, household connection to the national grid, membership to a cooperative; and HA is household's assets as a measurement of wealth, which include total value of household assets (consumable durables), value of agricultural equipment in working condition (GHS) and motorcycle owned by a member of a household. Description of the variables used in the study is contained in Table 3.1.

3.2.1.1 Empirical Estimation Strategy

The problem of self-selection arises when farmers who have comparative advantage with the subsidy program over others due to certain individual unobserved characteristics are participating in the program. Such farmers will thus be benefitting more than they would if there was random selection of beneficiaries (Heckman, 1979; Maddala, 1983; Maddala and Lahiri, 2009). The study employs two-stage least squares with the instrumental variable (2SLS-IV) approach. For robustness check, the study also estimates endogenous switching regression model. The choice of 2SLS-IV is because it still performs better under model misspecification. Tests for hypotheses are accurate and less biased even when a model is mis-specified (Bollen et al., 2007). The two-stage model gives optimal results since the estimated values are based on variables that are uncorrelated with the error term. The IV technique recovers an estimate of treatment impact on the treated (ATT) when variation in the impact of treatment among people is not associated with the instrument (Ikudayisi et al., 2020).

Following Heckman (1979), Maddala (1983) and Angrist and Imbens (1995), equation 3.9 can be rewritten as an adoption decision function of SIPs emanating from a household's participation in the

GFSP in the 2SLS-IV model as follows:

$$ESIPs_i = \alpha_0 + \beta_i X_i + \partial_i I_i + D_i + u_i \quad (3.10)$$

where $ESIPs_i$ is the expenditure for SIPs or gross farm inputs and it is a $T \times 1$ vector of observations on an outcome variable; α_0 is a constant; X_i is a $T \times (K \times 1)$ of observations on the explanatory variables including community and institutional factors; K is the number of explanatory variables. There are $K + 1$ columns in X_i to accommodate the constant term; β_i is a $(K + 1) \times 1$ vector of unknown regression coefficients to be estimated for the ith showing the effect of X_i on $ESIPs_i$ for all N observations; I_i is the household's participation decision; ∂_i is a parameter to be estimated showing the effect of I_i; and $u_i$is a $T \times 1$ vector of unknown and unobservable random disturbance. error term. The equation for the participation decision is written separately to show how participation is related to households' covariates as:

$$I_i^* = X_i + Z_i \gamma + \varepsilon_i, \quad (3.11)$$

where I_i^* is the latent variable for a farmer i^{th} decision to participate or not, i.e.,

$I_i = 1$ if $I_i^* > 1$ and $I_i = 0$ if $I_i^* \leq 0$.

The treatment participation decision - I_i^* - could be endogenous due to self-selection. This means that ordinary least squares regression cannot be used for estimation since $E[u_0|x, I_i] \neq 0$. By introducing Z_i in equation (3.7), it is assumed that $E[u_1|x, z] = E[u_0|x, z] = 0$. Thus, Z_i is an instrumental variable. It is correlated with the treatment decision variable, I_i, but uncorrelated with the outcomes $ESIPs_i$ and the error terms u_i, except through I_i (Maddala, 1983).

With the instrumental variable (s), a two-stages least squares becomes a suitable estimation strategy. Following Angrist and Imbens (1995), the two stages least square estimation is carried out by first regressing the endogenous variable on all the household covariates included in equation (3.10), including the instruments. During the second stage, the outcome equation (SIPs or gross farm expenses) is estimated using the predicted values of the instruments estimated in the first stage equation. The outcome equation can be specified as:

$$ESIPs_i = \alpha_0 + \beta_1 X_1 + \partial \hat{\imath}_1 + u_{i1}, \quad (3.12)$$

where $\hat{\imath}$ is the predicted value from the first stage regression equation and $u_i = \{\epsilon + \partial[I - \hat{\imath}]\}$.

There is the likelihood that I_i in equation (3.10) considered as endogenous based on a priori expectation or theoretical consideration in the model may actually be exogenous. The question of

whether I_i endogenous or otherwise can be checked using the Durbin-Wu-Hausman test. If the test proves positive for the presence of endogeneity, OLS cannot be used since the results will be biased and inconsistent. Instead, 2SLS-IV should be used (Cameron and Trivedi, 2005). This is explained in testing the following hypothesis:

$H_0: \theta_1 = 0$, i.e., I is exogenous

$H_A: \theta_1 \neq 0$, i.e., I is endogenous,

where θ is the estimator and the statistic is $\chi^2(1)$ distributed (Cameron and Trivedi, 2005).

We specify two separate models for estimating SIPs adoption intensity and gross farm adoption intensity, model 1 and model 2, respectively, as follows:

$$ESIPs_1 = \alpha_0 + \beta_1 X_1 + \partial I_1 + u_{i1}, \quad (3.13)$$

$$ESIPs_2 = \alpha_0 + \beta_2 X_2 + \partial I_2 + u_{i2}, \quad (3.14)$$

where variables are as defined before. Equations (3.13) and (3.14) are estimated using *ivregress* and *ivregress post estimation* commands in Stata 17. The natural logarithm of $ESIPs_1$ *and* $ESIPs_2$ is used in the estimation to solve the problem of outliers (Burbidge, 1988; Li, 2009).

Distance from each farmer's dwelling to the nearest market and distance to the local Agriculture Office are the instruments used in this study. Distance to both market and Agriculture Office could influence a household's decision to participate in the subsidy program since a famer has to obtain a voucher or a passbook to participate in the subsidy program. The voucher is obtained either at the Agriculture Office or at the government accredited input retail shop where an Agriculture officer may be stationed. The subsidized fertilizer is also picked at the accredited input retail shop. However, both distance to market and Agriculture Office do not influence how much a farm household invests in SIPs and gross farm inputs. Adoption intensity of gross farm inputs is the proxy for measuring if the GFSP is a 'smart' subsidy. A positive coefficient will indicate an affirmative, as implied in equation (3.7).

The endogenous switching regression (ESR) is also a two-stage estimation procedure that corrects selection bias by accounting for both observed and unobserved factors (Lokshin and Sajaia, 2004), similar to the Heckman's selection correction procedure (Heckman, 1979). ESR has the advantage of estimating simultaneously the two equations by using the Full Information Maximum Likelihood (FIML) to obtain consistent standard errors. The *movestay* command implements the FIML in Stata (Lokshin and Sajaia, 2004). Farm outcomes, like expenses on green revolution technologies and gross

farm inputs, can be observed for the entire sample of beneficiaries and non-beneficiaries of the fertilizer subsidy program, unlike the Heckman model (Abdulai and Huffman, 2014). In the switching regression approach, farm households divided into subsidy and non-subsidy households based on the source from which they obtained mineral fertilizer.

The study uses pooled cross-section data as described in the next section. The justification for the use of pooled cross-section data is as follows. If we assume that β_is in equations 3.13 and 3.14 are equal across the N observations, among other assumptions (see Dielman, 1983, p. 112):

$$\beta_1 = \beta_2 = \cdots = \beta_N = \bar{\beta}; \tag{3.15}$$

then the observations can be pooled and a single regression performed to obtain a more efficient estimator of $\bar{\beta}$. Dielman (1983) proved that the estimator is also unbiased. Upon the assumption that $E(u_i u_1') = \sigma^2 I_T$, the $\bar{\beta}$ is estimated efficiently and without bias using an estimator described by Dielman (1983) as the classical pooling estimator, specified as:

$$\bar{\beta}_l = (Z'Z)^{-1}Z'Y. \tag{3.16}$$

According to Dielman (1983), equation (3.16) does not have to include individual and time-effect parameters. From equation (3.16), the vectors of the random disturbance (u_i) can be specified as:

$$u_{it} = c_i + s_t + v_{it}, \tag{3.17}$$

c_i is the time-invariant individual effects, the s_t are time-period effects, and the v_{it} are the remaining random effects. Equation (3.17) is based on the assumptions that, firstly, c_i's are fixed parameters with $\sum_{j=1}^{N} C_i = 0$; secondly, the s_t's are fixed parameters with $\sum_{t=1}^{T} S_t = 0$; and the V_{it}'s are independent and identically distributed with mean zero and common variance σ_v^2. These assumptions commonly inform the use of the analysis of covariance (ANCOVA), least squares with dummy variable (LSDV) technique and other multiple regression methods in pooled cross-sectional data analyses (Dielman, 1983). This justifies the use of 2SLS-IV and ESR techniques using pooled cross-sectional data in this study.

3.2.1.2 Data Source and Description

The study uses pooled cross-sectional data from Ghana Living Standard Survey (GLSS) for round seven and six for only maize farmers. The Ghana Statistical Service collects the GLSS data with technical support from the World Bank. The information covers demographic characteristics, household agricultural production, asset ownership, access to financial services, education, housing conditions, among others. The GLSS data are not a panel. They are a set of repeated cross-section surveys. The pooling of successive cross-sections of various observational units is referred to as

pooled cross-sectional data (Micklewright, 1994). With panel data, the same sample of units is observed multiple times (Hannan and Young, 1977). The reason for using pooled cross-sectional data is that the level of participation of maize-growing households in the GFSP across the survey years is very low (11%, from Table 3.1). Pooled data, therefore, increases the sample size (Micklewright, 1994; Gerdtham et al., 1998; Zieman et al., 2002). Statistical reliability of the results and accuracy of the estimated parameters are achieved with pooled data relative to a single cross-sectional data (Gerdtham et al., 1998; Zieman et al., 2002). The study also aimed to understand which of the survey years (2013 or 2017) had a higher impact on the adoption of SIPs and other climate-smart technologies, considering the fact that the GFSP was reorganized in 2017 by government.

Households are the unit of analysis of GLSS data (GSS, 2019). The GLSS7 is the newest wave undertaken between 2016 and 2017. The GLSS6 data was collected between 2012 and 2013. For this study, the pooled sample size for only maize-growing households and who reported expenditure on mineral fertilizer for GLSS6 and GLSS7 is 4,365. The GLSS7 consists of 1,977 and GLSS6 consists of 2,388 maize growing households. Out of the pooled sample size of 4,365, only 481 farm households participated in the GFSP. Out of the 481 beneficiary farm households, 357 maize growing farm households participated in 2013 as against 124 maize farm households in 2017.

Following Tsiboe et al. (2021), data on the sources from which farm households had bought fertilizer determined whether households have benefitted from the subsidy program or not. Government labels bags of fertilizer for the subsidy program. Personnel of the Ministry of Food and Agriculture (MoFA) are stationed at the point of sales so that farmers obtain subsidized fertilizer at the price agreed upon by both government and the fertilizer companies. As a result, farmers can link their fertilizer purchases to MoFA when they get subsidized fertilizers from government. The private sector (i.e., buying from the open market retail input shops), cooperatives, the MoFA, non-governmental organizations, and others were the sources through which farmers could acquire fertilizer in the survey. If a household listed MoFA as their source of fertilizer, they were considered to have participated in the government fertilizer subsidy program. On the other hand, if households listed the private sector as their preferred fertilizer source, they were considered not to have participated in the subsidy program. This assumption is valid since the questionnaire provided that farmers stated only one source from which they obtained mineral fertilizer. Households who stated that they got their fertilizer from cooperatives, NGOs, or others were removed from the sample to make the data easier to understand and interpret.

3.3 Results and Discussions

3.3.1 Descriptive Statistics

Table 3.2 presents descriptive statistics for the survey households. Accordingly, only 11% of the maize growing households benefitted from the fertilizer subsidy program. This indicates low coverage of the program nationwide. The low coverage could be the result of smuggling of fertilizer into neighboring countries and elite capture. It could also be attributed to the restructuring of GFSP in 2017 with stricter targeting of beneficiaries of having 2Ha or less of land under cultivation. This was unlike the approach at the beginning of the program in 2008 up to 2016 when it was a universal fertilizer subsidy program (Pauw, 2021). Households are mostly headed by male (81%). Adoption intensity of SIPs and gross farm inputs are measured in total expenditure per Ha. On average, the adoption intensity in SIPs across the sample was about 525 Ghana Cedis (GHS)[1] ($106.10) per hectare and about GHS619 ($125.10) for gross farm inputs per hectare. Thus, in constant 2015 U.S. dollars, SIPs and gross farm inputs were 7% and 8.2% of per capita GDP in 2013, respectively (worldbank.org).

Household wealth is hypothesized to positively influence adoption intensity of SIPs and Gross farm inputs. Value of agricultural equipment owned by a household, number of livestock units per household, farm size, and ownership of a motorcycle by a member of the household are the measures of wealth. Differences in adoption of technologies among farming households are often attributed, among other factors, to household wealth and access to capital (Abdulai and Huffman, 2014). The ecological zones of Ghana can be broadly classified into southern and northern zones, which tend to describe the climatic and soil conditions with the northern zone being drier and having only one rainfall season, unlike the southern zone, which has a bimodal rainfall season and with relatively more fertile soil conditions. Membership to farmer cooperatives may promote technology adoption leading to increased productivity and income (Zhang et al., 2020). Number of years of schooling measures household head's level of formal education. The choice of education for only the head of household, and not other members of the household, is because the head of household makes decisions regarding new technologies to be adopted (Akudugu et al., 2012; Murari et al., 2017). Access to extension remains an important channel through which farmers receive information. The visits of agricultural extension agents to farm households in a community could positively influence technology adoption (Emmanuel et al., 2016). Access to credit was measured in how much loan (in GHS) a household member received for agricultural purposes and the presence of mutual aid schemes in a community. Mutual aid schemes are community savings and loan schemes.

Table 3.2: Descriptive statistics

Variable	Mean	Std. Dev.
SIPs Expenses	524.53	865.235
Gross_Expenses	618.89	1301.639
Sex	0.819	0.385
Agri equipment (log)	226.76	3061.4
Adult ES	4.083	2.358
Education	5.616	4.789
Non-farm enterprise	0.328	0.47
Land size	1.072	1.675
Marital status	0.75	0.433
Ecological zone	0.396	0.489
Urban residence	0.078	0.269
TLUs	1.6	4.837
Aid scheme	0.565	0.496
Irrigation	0.11	0.314
Access to extension	0.8109	0.393
Radio owned	0.573	0.495
Motorcycle owned	0.164	0.37
Land ownership	0.707	0.455
Use mobile phone	0.584	0.493
National Grid	0.416	0.493
Membership Cooperative	0.612	0.487
Age	48.329	15.6
Agric loan	19.021	199.792
Subsidy	0.11	0.313
Year 2017	0.43	0.49
Market	11.076	5.789
Agric Office	14.995	9.8
Total assets (log)	23.563	139.23

Source: GLSS data (2012/13 and 2016/2017). [1]Notes: GHS4.95 is to US$1.00, using the Bank of Ghana Inter Bank Exchange Rate – End period for January 2019 (Bank of Ghana, 2023).

They are improvements over the traditional rotating savings and credit associations and are more functional (Karlan et al., 2017; Mwansakilwa et al., 2017). The use of a mobile phone and connection to the national grid of a household dwelling are hypothesized to increase adoption intensity of SIPs. The reason for the larger set of variables as presented in Table 3.2 was to improve prediction and enhance the explanatory power of the model. In addition, they had their respective relationships with the participation decision (Zhang and Zhang, 2018). Since the government of Ghana considers GFSP as one of the tools for meeting agricultural and rural development objectives, controlling for more variables that were relevant for policy consideration was found important.

3.3.2 Results

The determinants of participation in the GFSP and its impact on adoption of SIPs and gross farm inputs are, respectively, presented in models (1) and (2) of Table 3.3. The significance of the R-squared indicates the strength of the model in explaining the joint effects of the probability of participation in the GFSP and the covariates among maize farming households in Ghana. Estimation from first stage equation in models (1) and (2) produced covariate coefficients that do have similar sign and statistical significance. This is because, as observed by Ma et al. (2017), the underlying objective of the first stage equation is to address the issue of self-selection into participating in the GFSP due to unobserved factors, which may bias the impact of participation on adoption of SIPs and gross farm inputs. The sample t-statistic showed systematic differences between participants (subsidy households) and non-participants (non-subsidy households) across most of the variables used in the first stage equation, as indicated in Appendix C. From Table 3.3, the coefficients for both the p-values for both Durbin (score) chi2(1), and Wu-Hausman F(1,3004) are greater than one with their respective p-values less than 0.5, implying that the null hypothesis that, $\theta=0$, thus participation in GFSP is exogenous can be rejected. Hence the use of 2SLS-IV is justified. This confirms the presence of selection bias in the participation of the GFSP, which was corrected in the second stage estimation process for each of the models.

The log value of farm equipment by a member of a household, years of education by the head of the household, and engagement in non-farm enterprise by a household member positively and significantly influence participation decision in the program. Access to extension services and presence of mutual aid schemes in the community also have positive and significant effects. Again, log value of agricultural equipment, number of years of education, and engagement in non-farm enterprises may indicate that households with more asset endowment and better opportunities get to disproportionately benefit from the GFSP. This finding is in support of the idea of elite capture of the GFSP (Houssou et al., 2017). On the other hand, the factors including access to irrigation could also represent greater incentives for participation as they are complementary inputs. If multiple inputs can generate better marginal benefits when employed together than what each input can do separately, the complementarity will be a source of incentive. Presence of an irrigation scheme in a community, marital status of household head, and distance to the nearest agricultural office also have positive and significant effects. For example, in the case of the marital status of head of household, accessing subsidized fertilizer under GFSP could be sometimes difficult due to long queues at the point of collection. Married women, therefore, rely on their husband to collect the subsidized fertilizer on their behalf. Membership to a farmer-based organization and the adult equivalent scale have a negative but

Table 3.3: Determinants of Participation in the GFSP and its Impact on Adoption in SIPs and Gross Farm Inputs (n = 4,365)

Variables	Model (1) subsidy	Log of SIPs adoption intensity	Model (2) subsidy	Log of gross farm adoption intensity
Subsidy		3.105*** (1.002)		2.298*** (0.858)
Sex	-0.009 (0.019)	0.318*** (0.12)	-0.009 (0.019)	0. 306*** (0.072)
Agri Equipment	0.005** (0.003)	0.078*** (0.012)	0.005*** (0.003)	0.079 (0.01)
Adult_ES	-0.004* (0.003)	0.034*** (0.012)	-0.004* (0.003)	0.037*** (0.01)
Education	0.003** (0.001)	-0.021*** (0.006)	0.003** (0.001)	-0.017*** (0.005)
Non-Farm Enterprise	0.023** (0.012)	-0.152*** (0.054)	0.023** (0.012)	-0.118** (0.046)
Farm Size	0.004 (0.003)	0.053*** (0.12)	0.004 (0.003)	0.055*** (0.01)
Marital Status	0.03* (0.017)	-0.026 (0.078)	0.03* (0.017)	0.037 (0.066)
Ecological Zone	0.007 (0.017)	0.362*** (0.068)	0.007 (0.016)	0.371*** (0.071)
Urban Residence	0.017 (0.019)	0.045 (0.083)	0.07 (0.019)	0.081 (0.071)
TLUs	0.001 (0.001)	0.004 (0.005)	0.001 (0.001)	0.007* (0.004)
Aid Scheme	0.045*** (0.015)	0.128** (0.054)	0.044** (0.015)	0.153*** (0.046)
Irrigation	0.051** (0.023)	-0.339*** (0.102)	0.051** (0.023)	-0.296*** (0.087)
Access to. Extension	0.022* (0.015)	-0.118* (0.07)	0.022* (0.015)	-0.09* (0.06)
Radio owned	0.003 (0.012)	0.093* (0.051)	0.003 (0.012)	0.089** (0.044)
Motorcycle owned	-0.002 (0.016)	0.186*** (0.068)	-0.002 (0.016)	0.239*** (0.059)
Land Ownership	-0.01 (0.014)	0.178*** (0.061)	-0.01 (0.014)	0.172*** (0.053)
Use_mobile phone	0.015 (0.017)	0.015 (0.071)	0.015 (0.017)	0.012 (0.061)
National Grid	-0.005 (0.012)	0.102** (0.051)	-0.005 (0.012)	0.097** (0.044)
Membership_Cooperative	-0.035*** (0.013)	0.237*** (0.064)	-0.035*** (0.013)	0.211*** (0.055)
Age	0.0004 (0.0004)	-0.004** (0.002)	0.0004 (0.0004)	-0.004** (0.001)
Agri_Loan	-0.005 (0.004)	0.056*** (0.02)	-0.005 (0.004)	0.086*** (0.019)
Total assets	0.004 (0.005)	0.087*** (0.022)	0.003 (0.005)	0.086*** (0.098)
Year 2017	-0.095*** (0.018)	0.757 *** (0.115)	-0.095*** (0.018)	0.626*** (0.098)
Market	-0.009 (0.001)		-0.001 (0.001)	
Agri_Office	0.002*** (0.001)		0.002*** (0.001)	
Constant	0.036 (0.038)	4.21*** (0.178)	-0.036 (0.038)	4.46*** (0.152)
R-squared	0.47	0.63	0.47	0.65
Wald chi-squared		589.06		779.864
Durbin (score) chi2(1)		17.60***		10.4869***
Wu-Hausman F(1,3004)		17.55***		10.433***

Notes: Standard errors in parenthesis; *, ** and *** significant at 10%, 5% and 1% levels, respectively. **Source**: GLSS Data (2012/13 and 2016/2017)

significant influence. The coefficient for the year dummy is negative, indicating that participation in the GFSP was lower in 2017 compared to 2013. This is despite a 13% increase in the quantity of subsidized fertilizer supplied by government from 166,807MT in 2013 to 191,744MT in 2017 (MoFA, 2019). The negative coefficient for the year dummy could be attributed to smuggling of subsidized fertilizer into Ghana's neighboring countries.

For the second stage regression model, the parameter estimates are presented in columns (3) and (5) of Table 3.3 for the logs of adoption intensity of SIPs and gross farm inputs, respectively. The coefficient of determination, (63%) and (65%), and Wald chi-squared value (589.06) and (779.864) at 1% significance level, at the lower part of Table 3.3, show that all the covariates jointly have significant influence on adoption intensity of SIPs and gross farm inputs. Participation in the subsidy program had a significant and positive effect on the log of adoption intensity of SIPs $(\beta = 3.105, p < 0.01)$ in column (3) and the adoption intensity of gross farm inputs $(\beta = 2.298, p < 0.01)$ in column (5) of Table 3.3. Moreover, log transforming the dependent variables (adoption intensity of SIPS and gross farm inputs) addresses the problem of outliers (Burbidge, 1988; Li, 2009) as observed in the data. The regression coefficients are interpreted as elasticities (Benoit, 2011). Thus, a percentage in the outcome variables (intensity of SIPs and gross farm inputs) due to a unit change in each of the explanatory variables. The positive and significant effect of participation in the subsidy program on the logs of SIPs and gross farm adoption intensities is an indication that it has crowded in private investment at farmer-level and in the retail agro-input sector. Thus, the GFSP is a smart subsidy, besides contributing to adoption of climate risks mitigating measures such as SIPs.

The finding is contrary to some studies that have examined the crowding in or crowding out effect of fertilizer subsidy programs on single inputs; either commercial demand for fertilizer or improved seed in Sub-Saharan Africa. For example, Mason and Ricker-Gilbert (2012), using a nationally representative household panel survey data, found subsidized improved maize seed in Malawi and Zambia decreased farm households' demand for commercial seed. Farmers who received subsidized fertilizer also did not purchase significantly more commercial seed compared to farmers who were not part of the subsidy. Mason and Jayne (2013) also found subsidized fertilizer crowding out household's demand for fertilizer from commercial sources in Zambia. Liverpool-Tasie (2014), however, found that households receiving subsidized fertilizer increased their likelihood of participation and quantity of fertilizer purchased from the private retail market in the Kano state of Nigeria. These studies are, however, limited to studying the correlation between subsidized seed or

subsidized fertilizer on commercial demand for seed or fertilizer, respectively. Such an approach does not take into account commercial demand for other farm level inputs.

Adult equivalent scale, farm size and marital status have significant and positive effect on adoption of SIPs and gross farm inputs. This means that increasing farm size among smallholder farmers has the potential to increase adoption intensity of SIPs as well as gross farm inputs. This finding supports that of Chang et al. (2011) where they found farm size to positively and significantly increase fuel expenses for agricultural machinery in the USA. The finding also reinforces the positive role the farm sector can play on rural development and poverty reduction, through investments into the non-farm sectors such as agro-input purchases (Van den Broeck et al., 2017). The finding on the positive and significant effect of household labour, in adult equivalent scale, on adoption intensity of SIPs may be due to more labour endowment employed in farming activities. Because of the complementarity of agricultural technologies, there is more adoption intensity in adopting productivity-enhancing technologies among farm households with relatively higher adult equivalent scale.

Farming households that live in the southern agro-ecological zone are more likely to invest in SIPs and gross farm inputs. The favourable climatic conditions in the southern agro-ecological zone may explain why households cultivating maize in the South tend to invest more in SIPs relative to maize farmers in the northern agro-ecological zone. Presence of mutual aid schemes in communities, amount of loan a household received for agricultural purposes, and connection to the national electricity grid of the household's dwellings significantly increased intensity of adoption of both SIPs and gross farm inputs. The result showing the positive and significant role of mutual aid schemes on raising adoption intensity of SIPs and gross farm inputs supports the argument of Dagunga et al. (2020) that community mutual aid schemes provide members with credit and savings, which enable them to invest in farm technologies. The positive and significant effect of access to electricity and credit (agricultural loan) on increased adoption intensity of SIPs and gross farm inputs is in support of Jain et al. (2009) who found access to electricity and credit to have positive and significant influence on technology adoption in a number of states in India.

Value of an agricultural equipment owned by a household, radio, motorcycle and land ownership, and TLU, as proxies for household wealth, have positive effect on the adoption intensities. The study further tests the effect of household wealth on the adoption intensities using the value of the physical assets of a household. It was also found to be positive and statistically significant. The presence of irrigation fields in a community has significant but negative effect on adoption intensity of SIPs and gross farm inputs. Access to agricultural extension had significant but negative effect on SIPs. The negative but significant effect of extension visits deserves a special mention considering the critical

role played by agricultural extension officers in GFSP. The finding is contrary to that of Emmanuel et al. (2016) and Anang et al. (2020) who found access to agricultural extension services to have significantly promoted the adoption of chemical fertilizer and improved seed, respectively, among rice producing farmers in the northern parts of Ghana. These studies and many others only looked at the effect of extension services on the adoption of a single technology (chemical fertilizer or improved seed). However, agricultural technologies are complementary. Hence, the need to look at the effect of important policy variables such as agricultural extension on adoption of a package of technologies at the farm level. The negative but significant effect of the presence of irrigation fields in a community on adoption intensity of SIPs and gross farm inputs is contrary to *a-priori* expectation. It could be due to the fact that maize cultivation in Ghana is mostly under rainfed conditions (Adu et al., 2014). The effect of number of years of education of head of household on SIPs and gross farm inputs is significant but negative. This is again contrary to *a-priori expectation*. The reason is that, according to Uematsu and Mishra (2010), formal education could be a barrier to technology adoption, especially among smallholder farmers. This is because educated smallholder farmers have a higher tendency to engage in off-farm work.

Age of head of household had a negative and significant effect on SIPs and gross farm inputs. The study finds male-headed farm households investing more in SIPs and gross farm inputs by about 32% and 31%, respectively, compared to female-headed households. The coefficient for the year dummy is positive and significant on adoption intensity of SIPs and gross farm inputs. It means that adoption intensity of SIPs and gross farm inputs were higher in 2017 compared to the base year (2013), though participation in the program was lower in 2017 compared to the base year. This could be due to the restructuring of the GFSP in 2017 with an implementation approach which aims at motivating farmers to use input and output markets (MoFA, 2017). This might have motivated beneficiaries of GFSP to invest more in SIPs.

It can be observed from Table 3.3 that some socioeconomic factors had opposite and indirect effects. For example, whereas education, non-farm enterprises and access to extension had positive effect on participation in GFSP, the same factors had decreasing effects on investments in farm level inputs. The implication is that the relationship between an agricultural support programme and the intended outcomes (such as mitigation of climate change impacts and rural economic development) may be complex. This complexity emanates from the multi-dimensional nature of the cause-effect relationships, the difficulty of controlling unintended impacts and other confounding factors. For example, as non-farm income may drive food security (Frelat et al., 2016), it might as well fail to drive investments in SIPs. This is because smallholder farmers are largely subsistent, with close to

58% of food consumed coming from the farm (Sibhatu and Qaim, 2017). Thus, income from non-farm sources may be spent on purchased foods instead of investing in SIPs. It implies that the importance of SIPs in mitigating climate change impacts has to be intensified through education, especially as the study also finds that those who had better access to education are also less likely to invest in SIPs.

The study also employs an endogenous switching regression (ESR), as a robustness check, to estimate the effect of GFSP on adoption intensity of SIPs and gross farm inputs. The ESR also addresses the problem of selection bias on both observed and unobserved factors (Lokshin and Sajaia, 2014). The ESR provides that the selection (participation in GFSP) and the outcome equations (SIPs and gross farm inputs) are estimated jointly (Lokshin and Sajaia, 2004). Column two in Appendix D and Appendix E contains the selection equation which estimates the determinants of participation in the GFSP. From both appendices D and E, the estimates of the variables used as instruments (distance to the nearest and biggest market and distance to the nearest Agric. Office) for potential endogeneity in the first stage estimation showed that they were not significantly different from zero. This implies consistent estimation of the coefficients (Wooldridge, 2002; Abdulai and Huffman, 2014). The ESR model had a good fit with its independent variables with the Wald test of independence statistically significant at 1%. Between the two equations (fertilizer subsidy, and SIPs and gross farm inputs), the coefficients of correlation (Rho_1) and (Rho_2) were likewise estimated to be positive and statistically significant at 1% in both appendices D and E. It implies that taking advantage of the GFSP was a choice made on an individual basis based on both observable and unobservable characteristics of farmers (Azumah and Zakaria, 2019).

The results of the impact of participation in the GFSP, in terms of household characteristics, community and institutional factors, on SIPs and gross farm inputs are presented in the third and fourth columns of appendices D and E, for both subsidy and non-subsidy households. ESR estimates the factors that determined participation in the GFSP as well as SIPs and gross farm inputs among GFSP participants and non-participants (Abdulai and Huffman, 2014; Azumah and Zakaria, 2019). The results on the determinants of participation in GFSP from the ESR model are consistent with those of the main model employed in this chapter (Two-stage least squares with instrumental variables (2SL-IV). The direction of the coefficients is consistent across the two models. The p values across the two models are also largely consistent. However, the estimates of the average treatment effect on the treated (ATT) explain the direct impact of GFSP on SIPs and gross farm inputs.

The estimates of the average treatment effects on the treated (ATT) are presented in Table 3.4. The results indicate that there is positive causal effect of participation in the GFSP on both adoption

intensity of SIPs and gross farm inputs. Participation in the GFSP increases adoption intensity of SIPs by 0.655 and gross farm inputs by 0.442 at 1% significance level. In percentage terms, participation in the GFSP increases adoption intensity of SIPs by about 62% and about 54% for gross farm inputs. The results reaffirm the role of GFSP in crowding in investment in SIPs and overall farm inputs.

Table 3.4: Impact of GFSP on Adoption of SIPs and Gross Farm Inputs: Estimates Based on Endogenous Switching Regression (n = 4,365)

	Mean Outcome				
Variable	**Subsidy Households**	**Non-Subsidy Households**	**ATT**	**t-value**	**Change (%)**
Log of Expenses on SIPs	1.718 (0.005)	1.063 (0.004)	0.655***	77	61.61
Log of Gross farm inputs' expenses	1.269 (0.007)	0.827 (0.003)	0.442***	67.40	53.57

Notes: Standard errors in parenthesis, *** significant at 1% level.

Source: GLSS Data (2012/13 and 2016/17)

3.4 Summary

This chapter sought to study how GFSP affected adoption of agricultural intensification technologies and gross farm inputs. Ghana is one of the countries in SSA implementing fertilizer subsidy program aimed at increasing agricultural productivity and developing the private sector input markets, among others. Based on the conceptual framework that introduction of FSPs could have positive outcomes such as income, soil fertility and learning effects among smallholder farmers, the study identified through the use of two-stage least squares with Instrumental Variable (2SL-IV) approach that GFSP increased the intensity of adoption of SIPs and gross farm inputs. The SIPs were both mineral and organic fertilizers, improved seed, pesticides, irrigation and mechanization. The gross farm inputs included SIPs and all other variable inputs that were employed at the farm plot level. Further analysis using Endogenous Switching Regression (ESR) as a robustness check revealed similar finding of positive effect of GFSP on SIPs and gross farm inputs. In percentage terms, the ESR revealed that participation in the GFSP increased adoption intensity of SIPs by about 62% and about 54% for gross farm inputs. These finding are important for policy considering that the assessment of crowding-in/out effects of FSPs on private input market demand has largely focused on the commercial demand for mineral fertilizers, and sometimes improved seed, neglecting SIPs and gross farm inputs. This is despite the fact that these inputs are climate smart and sustainable. Their purchases at the local input

markets also promote rural economic development because of the forward-backward linkages between rural input and output markets. The results also showed that only 11 percent of maize growing households benefited from the program. This is very important in the light of the fact that almost every farm household in Ghana grows maize and it is the leading crop produced and consumed in the country. Male-headed households were also found investing more than female-headed households in both SIPs and gross farm inputs. Participation among maize growing farm households in the GFSP were influenced by socio-economic factors such as value of agricultural equipment owned, education of head of household and engagement in non-farm enterprises.

Besides participation in the GFSP, the study found that the presence of mutual aid schemes in farming communities, amount of loan received for agricultural purposes, asset ownership, and connection of household dwellings to the national electricity grid also increased the adoption intensity of SIPs and gross farm inputs. This finding is important for policy given the over-emphasis placed on GFSP by government in an attempt to achieve the Ghana-version of the African Green Revolution. Prioritizing investments into these areas could sustainably help government achieve a green revolution in Ghana.

Considering the positive impact of participation in the GFSP, policies should be directed towards improving its access to households with poor resource endowments. Its coverage rate should be increased by improving on targeting and reducing leakages. Government's focus should not be exclusively on GFSP. Institutional factors such as mutual aid schemes and farmer cooperatives should be strengthened and well-resourced. This will enhance their ability to give credit to constrained households (e.g. female-headed households) so that they can invest more on SIPs and farm inputs for overall agricultural development. The finding that the complementarity of agricultural equipment, number of years of education, and income from non-farm sources were motivators for participating in the GFSP reinforces the need for improved access to credit for credit-constrained households. The following chapter investigates the impact of Ghana's fertilizer subsidy program on multiple dimensions of household food security.

CHAPTER 4: IMPACTS OF PARTICIPATION IN GHANA'S FERTILIZER SUBSIDY PROGRAM (GFSP) ON DIMENSIONS OF FOOD SECURITY[2]

4.1 Introduction

Agricultural input subsidies have once again become central to agricultural development in sub-Sahara Africa (Tsiboe et al., 2021; Ahmad et al., 2022). Recent input subsidies across sub-Sahara Africa have progressed from just improving access to agricultural inputs to being market-smart with emphasis on efficient targeting of beneficiary farmers and the development of private input markets (Jayne et al., 2018; Pauw, 2022). Despite being implemented in various countries, input subsidies remain controversial and debated agricultural policy strategies (Jayne et al., 2018). Input subsidies were common in Africa in the 1960s and 1970s. Their use, however, declined in the 1980s and 90s (Hemming et al., 2018), largely because of inefficiencies, poor targeting and capture by affluent and influential people, stifling the growth of the private input markets (Morris et al., 2007). Unlike in the 70s and 80s, input subsidies seem to have favor with both the multilateral institutions such as the World Bank and the IMF on one hand, and African governments on the other. Input subsidies have also proven to produce visible pay-offs before election cycles. For these reasons, input subsidies will possibly remain in African countries for some time (Jayne and Rashid, 2013; UNECA, 2018; Walls et al., 2023). Recent review of empirical studies by Jayne et al. (2018) related to the impact of input subsidies in SSA during periods that they have been argued to be 'smart' have revealed that increase in agricultural productivity was only within the short-term. Welfare benefits associated with such programs including reduced food prices, poverty reduction and improved agricultural wages were less than expected (Jayne et al., 2018). For example, Zambia's subsidy program has not been able to substantially reduce poverty and food insecurity (Zinnbauer et al., 2018; Kaoma and Mpundu, 2023). Poor targeting of beneficiaries, leakages, and diversion of fertilizer have been blamed for the poor performance of Zambia's fertilizer subsidy program (Zinnbauer et al., 2018). In Nigeria, the program also had minimal effects on increasing prices for grains between the post planting and post-harvest seasons (Takeshima et al., 2015) though fertilizer use has been found not to be profitable (Liverpool-Tasie et al., 2017). These studies and many others show stronger evidence of associations between input subsidy programs on one side, and poverty reduction and market performance on the other.

[2] This chapter has led to the following article: Jinbaani AN and Wale E. Impacts of Participation in Ghana's Fertilizer Subsidy Program (GFSP) on multiple dimensions of food security. Currently under review with Cogent Food & Agriculture .

However, a problem of disconnect emerges which highlights limited evidence on the linkages between agricultural policies (such as fertilizer subsidy programs) and food security and nutrition outcomes. This is despite the important role of agriculture in influencing dietary diversity (Kadiyala et al., 2014; Singh et al., 2023). Kadiyala et al. (2014) Singh et al. (2023) observed that changes in relative food prices do not influence dietary diversity much compared to improvement in agricultural productivity (Kadiyala et al., 2014; Singh et al., 2023)

The GFSP introduced in 2008 has the objectives of improving: agricultural productivity, food security, access to, affordability and adoption of inputs as well as developing private sector input markets (Houssou et al., 2017; GoG, 2017). In Ghana, fertilizer application significantly explains the differences in yield across maize farms. For example, 22 to 26Kg of additional yield could be achieved from applying one kilogram of additional fertilizer (Ragasa and Chapoto, 2017). This explains the importance of making fertilizer affordable through a subsidy program to poor farming households who cannot afford the cost of fertilizer at prevailing market prices. Low adoption rate of fertilizer is still found among farmers in Ghana (Ragasa and Chapoto, 2017). There is also the problem of large scale and well-to-do farmers being the main beneficiaries of Ghana's fertilizer subsidy program. This is contrary to the main goal of the program of supplying subsidized fertilizer to smallholder farmers (Houssou et al., 2017). However, Iddrisu et al. (2020), Tsiboe et al. (2021) and Pauw (2022) highlighted some positive impacts of GFSP.

Iddrisu et al. (2020) found an increase in the subsector productivity of maize, sorghum, and rice by about 8.3%, 4.5%, and 3.8%, respectively, in 2017 in Ghana due to GFSP. Improvements in the productivity of maize, sorghum, and rice were estimated to be four-times, three-times, and six times more in 2020 compared to 2017 levels, respectively. Household consumption expenditure, a proxy for welfare, also increased under the program. Their modeling in calculating household consumption, however, excluded households consuming their own food. This is contrary to what is typical of a smallholder Ghanaian farm household that is largely subsistent. A growth of 42.6 percent in maize output and 44.3 percent in rice output in 2020 is attributed to GFSP based on the findings of Pauw (2022) who used national output data. However, from a study of 460 rice farmers in the Volta region of Ghana, Vondolia et al. (2021) did not find positive effect of GFSP on productivity among beneficiaries, though farmers who participated in the subsidy program applied fertilizer more by 45 percent. Again, these studies have not linked Ghana's FSP to the multiple dimensions of food security.

Budget allocation to GFSP constituted 20 percent of agriculture's budget in its first year of implementation (2008), 42.36 percent in 2013 and 26.60 percent in 2017 (Tsiboe et al., 2021). Despite this huge financial cost, limited empirical studies exist linking GFSP with food security and nutrition

outcomes, especially on the four dimensions of household food security. Where even empirical evidence exists, such evidence is restricted to only one or two dimensions such as output or yield (Iddrisu et al., 2020; Tsiboe et al., 2021; Pauw, 2022) as well total food and non-food consumption expenditures per capita (e.g., Wossen et al., 2017). As input subsidies are on-going programs across SSA, this study may provide lessons for evidence-based decision making by policy makers regarding realigning the objectives of subsidy programs towards achieving food security and nutrition outcomes. This ultimately contributes to Ghana's efforts towards achieving the UN sustainable development goals 1 and 2 (no poverty and zero hunger, respectively) as governments' programs in developing countries must align with the SDGs in order to assess their impact at the community level (Reddy et al., 2024). Such needed evidence is particularly important at a time when food insecurity persists and is increasing across sub-Saharan Africa (Bjormlund et al., 2021).

Employing a nationally representative pooled cross-sectional data of the Ghana Living Standards Survey (GLSS) for rounds six and seven, this chapter examined the impacts of participation in Ghana's FSP on multiple dimensions of food security among maize growing farm households. Moreover, the chapter aimed to understand in which of the survey years (2013 or 2017) was there better participation in GFSP, considering the fact that the GFSP was reorganized in 2017 by government to improve the targeting of beneficiaries with the aim of ensuring that only those of 2Ha of land under cultivation benefited from GFSP. The data is non-experimental and hence the problem of self-selection bias was addressed using propensity score matching (PSM) techniques. Two doubly robust estimators (inverse probability weighting, and inverse probability weighted regression adjustment) were used as robustness checks. Following Austin (2009), the methods of standardized means and variance ratios were used to assess the extent to which the PSM achieved balance in the distributions of the covariates between GFSP participants and non-participants.

4.2 Methodology

4.2.1 Conceptual Framework and Empirical Methods

Ghana's fertilizer subsidy program (GFSP) is a nation-wide fertilizer subsidy program targeting smallholder farmers of 2Ha of farmland holding or less (Pauw, 2022). The distribution of the subsidized fertilizer among beneficiaries is, therefore, non-random. To evaluate GFSP's impact on household food security using observational data, propensity scores methods are appropriate when selection bias owing to non-random treatment assignment is a possibility (Rubin, 1974; Rosenbaum and Rubin, 1983; Cameron and Trivedi, 2005) and when estimating average treatment effects of program beneficiaries is the parameter of interest (Cameron and Trivedi, 2005; Caliendo and

Kopeinig, 2008). These methods of estimation mostly assume selection on observable variables only (Cameron and Trivedi, 2005). It is, however, required that before estimating treatment effects there is careful testing of the propensity scores (Rubin, 2008; Garrido et al., 2014).

A propensity score is a single score that expresses the probability of a household participating in the GFSP given household's observable socio-economic, institutional and community characteristics such as presence of irrigation schemes and mutual aid schemes in communities (Rosenbaum and Rubin, 1983; Emsley et al., 2008). Selection bias due to confounding from the observed household characteristics which could affect participation in the GFSP is eliminated by adjusting for the scalar propensity score (Rosenbaum and Rubin, 1983). Other methods for removing selection bias due to confounding include stratification, regression methods, or inverse probability weighting (Emsley et al., 2008). The study employs the following propensity score matching techniques: propensity score matching without replacement, nearness neighbor matching, inverse probability weighting, and inverse probability weighted regression adjustment.

Following Hirano et al. (2003) and Kaliba et al. (2021), let T_i represent maize growing households participating in the GFSP and T_i^* is the status of participation that is actually observed. Participation in GFSP (T_i) is binary such that $T_i = t,$ and $t \in= \{1,0\}$ represents participation and non-participation of maize growing households, respectively. For each household in the sample $i(i = 1,..., N)$ where N is the sample size, $Y_i,\ T_i,\ and\ X_i$ can be observed, where Y_i is the measure for the dimensions of food security (availability, access, utilization and stability dimensions), T_i is the variable for participation as explained before, and X_i is the matrix of covariates that may explain the food security measures. The covariates include age and sex of head of household, farm size, adult equivalent scale, among others as shown in Table 4.1. T_i and X_i are observed for all households in the sample except that Y_i is observed only when $T = 1$. Thus, Y_i is missing at random. We specify the control group (non-participating households) as C_i and the observed outcomes for the control group as Y_j^C and that of the subsidy households as Y_i^T. For each household in the sample, i, only $Y(1)$ or $Y(0)$ is observed but never both. This brings a problem of identification. The unconfoundedness assumption is employed to solve the problem of identification following Rubin (1974), Rosenbaum and Rubin (1983) and Hirano et al. (2003). Thus, conditional on pretreatment covariates, participation in the GFSP is independent of potential food security outcomes. The propensity score can be specified as:

$$p(x) = pr[T = 1|X = x]; p(x) = F\{h(X_i)\} \quad (4.1)$$

where $p(x)$ is the conditional probability measure of treatment participation given household pretreatment covariates, X; $F(.)$ is the normal or logistic distribution and $h(X_i)$ is a function of covariates with linear and higher order terms (Becker and Ichino, 2002). Higher order terms used include age square to obtain an estimate of the propensity score that satisfies the balancing test. Equation 4.1 was then estimated using maximum likelihood from the logit model following Cameron and Trivedi (2005). It follows an assumption which requires that conditional on the observed covariates x, impacts of food security outcomes are independent of a household's participation in the GFSP. Thus, there will not be confounding factors as there will not be omitted variable problem once x is included in the regression (Cameron and Trivedi 2005; Abadie et al., 2004). This assumption is often referred to as the Conditional Independence Assumption (CIA) (Rosenbaum and Rubin, 1983; Cameron and Trivedi, 2005), also referred to as selection on observables or unconfoundedness as in Abadie et al. (2004). If this assumption holds, it means that sample selection models or selection on unobservables are not necessary for controlling endogeneity and propensity score and matching estimators can be applied (Cameron and Trivedi, 2005). A second assumption, referred to as the overlap or matching assumption is necessary for identifying some measures of food security impact in the population. The assumption holds that, for each value of the covariate x, there are both participant and control (non-participant) households. There is, therefore, an overlap between the subsidy and non-subsidy households. Thus, for each participating household in the GFSP, there is a matched household who did not participate in the GFSP with similar covariates x (Rosenbaum and Rubin, 1983; Caliendo and Kopeinig, 2008). Thus, if all the maize growing households of given covariates decided to participate in the GFSP, there would be no comparison group on similar individuals who decided not to participate in the program against which to compare (Abadie et al., 2004). Matching households on individual covariates of x may be impractical or creates a problem of dimensionality. To address the problem of dimensionality, Rosenbaum and Rubin (1983) proposed that matching is done along the propensity score, $P(X)$, instead of along the individual covariates, x. This restriction ensures that the balancing property test is performed only on observations that overlap, or in other words, found within the common support. This improves the quality of the matches used for estimating the average treatment effect on the treated (ATET) (Becker and Ichino, 2002). The conditional independence and matching or overlap assumptions constitute the strong ignorability assumption (Rosenbaum and Rubin, 1983). The third assumption is the conditional mean independence assumption, which implies that the food security outcomes of non-subsidy households does not determine participation (Cameron and Trivedi, 2005). To obtain consistent estimates of treatment effects, the study relied on these three assumptions that permit identification of causal

effects between the food security outcomes of subsidy and non-subsidy households (y_{i1}, y_{i0}), respectively.

The sample estimates for the average treatment effect (ATE) and average treatment effect on the treated (ATET), given that probability to participate in GFSP is random and given the pre-treatment covariates and $p(X)$ is also random (Rosenbaum and Rubin, 1983), can be defined, respectively, as follows:

$$\widehat{ATE} = \frac{1}{N_T}\sum_{i=1}^{N_T}[\delta_i, p(X_i)] \quad (4.2)$$

$$\widehat{ATET} = \frac{1}{N_T}\sum_{i=1}^{N_T}[\delta_i | I_i = 1, (p(X_i)] \quad (4.3)$$

where $N_T = \sum_{i=1}^{N} I_I$, thus, the number of participating farmers in the sample, δ is the difference between the outcomes of participating and non-participating farmers, $y_1 \; and \; y_{0,}$ respectively. According to Cameron and Trivedi (2005), obtaining δ_i is not straight-forward due to an unobserved component in the formulae that requires estimation. However, as noted earlier adjusting for the scaler propensity score is able to remove selection bias due to confounding factors. However, Smith and Todd (2005) argue that there could still be some unobservable biases (hidden bias) not controlled for. This may affect the results of GFSP participation and food security dimensions (Smith and Todd, 2005; Magrini and Vigani, 2016). That being said, this assumption is no more restrictive than the weak instrument assumption in Heckman two-step procedure or the Instrumental Variable (IV) approach when applied to cross-sectional data (Jalan and Ravallion, 2003; Magrini and Vigani, 2016). This notwithstanding, the study employs the Rosenbaum bounds approach to dealing with the issue of "hidden bias". The approach helps to ascertain the degree to which selection into GFSP must be impacted by unobserved factors in order to undermine the findings of causal effects on the dimensions of food security from the matching techniques (Rosenbaum, 2002; DiPrete and Gangl, 2004). Thus, the Rosenbaum bounds approach is specifically used to verify the estimated results (Magrini and Vigani, 2016). The critical level of the hidden bias (Γ) is presented in Appendix F to show how much unobserved heterogeneity must be introduced to the $ATET$ model in order to question the accuracy of its findings (DiPrete and Gangl, 2004; Magrini and Vigani, 2016). The magnitude of hidden bias greater than one means that the conclusion that participation in GFSP has a positive and significant impact on food security dimensions is questionable (Martey et al., 2019). Following the procedure of Gangl (2004), the *rbounds* command in Stata was employed to perform Rosenbaum sensitivity analysis using *psmatch2*. The $\widehat{ATET}$ is appropriate when we are considering the average gain for participation among the participants in the context where programs are narrowly targeting beneficiaries (Heckman and Robb, 1985; Heckman et al., 1997). The $\widehat{ATE}$ is most appropriate when

participation in a program is universal. Universal in the sense that every farmer in Ghana of up to 2Ha land under cultivation can participate in the program. It is, therefore, possible to estimate the average gain or impact of participation from a randomly selected sample from the population (Cameron and Trivedi, 2005). The study reports on both the ATE and ATET. This is because though GFSP is universal across the country, specific farmers of 2Ha of land or less under cultivation are targeted, in principle. Though $p(X)$ solves the problem of dimensionality, it is not enough to estimate the ATE of interest since it is a continuous variable. For example, y_i can not be observed for two households that have the same value of $p(X)$. Nearest-Neighbor Matching (NNM) can overcome this problem where treated and control units are matched by taking each treated unit and searching for the control unit with the closest $p(X)$ (Becker and Ichino, 2002). The NNM provides that the non-subsidy household units (y_{i0}) and the subsidy household units (y_{i1}) are matched together with an estimated value of the propensity score, p_i. NNM in a single closet match by a distance between any two households ($i \; and \; j$) can be specified as:

$$y_{i0,} = \min_j ||p_i - p_j|| \tag{4.4}$$

The NN represents the number of controls matched with the treated observation $i \in T$ by N_i^C and the weights defined as $w_{ij} = \frac{1}{N_i^C}$ if $j \in C(i)$ and $w_{ij} = 0$ otherwise. The matching estimator then becomes:

$$T^Z = \frac{1}{N^T}\sum_{i=T} Y_i^T - \frac{1}{N^T}\sum_{j \in C} w_j Y_j^C, \tag{4.5}$$

where Z stands for the nearest matching and the number of units in the treated group is represented by N^T; the weights w_j are defined by $w_j \sum_i w_{ij}$. In deriving the variance for the NN estimator, Becker and Ichino (2002) showed that the weights are assumed to be fixed and the outcomes are assumed to be independent across units. The NN match method allows individual observations to be used as a match more than once. It reduces the bias as compared to matching without replacement, but not the variance. Substantial bias could arise due to matching on multidimensional covariates. Subsequently, the study employed the bias adjustment approach. The bias adjustment approach incorporated into the NN match is able to produce estimators with no or limited remaining bias (Abadie et al., 2004). Bias from the estimates of average treatment effects also disappears with increasing sample size. However, the variance is nonzero since the matches remain fixed (Imbens, 2004). Specifying more multiple covariates in the NN method ensures that the matching uses the weighting matrix to define a vector norm. Two choices of the weighting matrices were used in this study; the inverse variance-weighting matrix (IVWM) and the mahalonobis. The IVWM accounts for the differences in the scale

of the covariates (Abadie et al., 2004) whereas the mahalonobis accounts for the inverse sample covariate covariance. The study uses the IVWM as the benchmark estimator. Following Austin (2009), the standardized differences method was used for testing if the propensity score model has been correctly specified. It does this by comparing the means and prevalence of pretreatment covariates (Rosenbaum and Rubin, 1985; Austin, 2009).

However, Austin (2009) also showed that observing balance in the measured covariates does not mean that the model is correctly specified. He recommends the use of variance ratios to complement the comparison of means between treated and control groups. Variance ratios compare the similarity of the distribution of pretreatment covariates between the treatment and control units in the matched sample. Imai et al. (2008) also recommend the use of higher order moments such as variance to compare pretreatment covariates between treated and untreated units. Consequently, interaction terms of household farm equipment and adult equivalent scale, level of education of household head and membership to a mutual aid scheme, as well as access to agricultural extension services in the year 2017 were employed, in addition to the age squared of a household head. A perfectly balanced covariate has a standardized difference closer to zero and variance ratio close to unity (Austin, 2009). It can be observed from Table 4.1 that the variance ratio of all the interaction terms is either one or very close to one, implying that the model was correctly specified. The description of the covariates is, however, explained in Table 4.2.

Besides controlling for bias and model misspecification, the study also used "doubly robust" estimators to obtain consistent estimators even under circumstances where only one of the models is specified correctly (Robins and Ritov, 1997; Imbens, 2004). The "doubly robust" estimators are a combination of weighting and regression, employing parametric models for both the propensity score and the regression functions (Imbens, 2004). The first stage equation and the weighted least squares regression to estimate the effect of participation using IPW and IPWA are as follows, respectively:

$$D_{it}^{*}(T_i) = X_i\delta + u_i \quad \{1, \text{if } t_i = 1, and\ 0, otherwise \tag{4.6}$$

$$\min_{\propto_1,\beta_1} \sum_{i=1}^{N}(y_i - \propto_1 - \beta_1 Z_1)W_1 \text{ if } D_{it}(t=1)$$

$$+ \min_{\propto_0,\ \beta_1} \sum_{i=1}^{N}(y_1 - \propto_0 Z_i)W_0 \qquad \text{if } D_{it}(t=0) \tag{4.7}$$

Conversely, $\min_{\propto_1,\ \beta_t} \sum_{i=1}^{N} W_t\,(y_i - \hat{y}_i)^2$, $t \in = \{1,0\}$,

where T_i represents maize growing households participating in the GFSP and $T_i^*$is what is observed as the status of participation. T_i is a binary variable such that $T_{i\,=\,i,}$ and $i \in = [1,0]$ representing, respectively, participating and non-participating households. Y_i is the measure for the food security

outcomes (availability, access, utilization and stability), and Z_i represents the covariate matrix that affects food security outcomes (Kaliba et al., 2021).

Table 4.1: Balancing Diagnostics of Covariates for Propensity Score Matching

	Standardized	Differences	Variance	Ratio
	Raw	Weighted	Raw	Weighted
Agric_equipment	0.265	0.080	0.746	1.062
Adult_ES	-0.112	-0.090	0.527	1.054
Agri_equip_Adult_ES	0.106	0.070	0.792	0.873
Non_farm enterprise	0.164	0.053	0.088	1.031
Sex	0.082	0.043	0.825	0.906
Farm_size	0.097	0.023	0.097	0.934
TLUs	0.068	0.033	1.380	1.071
Age	-0.037	-0.056	0.439	0.958
Extension	0.361	0.015	0.567	1.017
Mech_use	0.135	-0.051	0.042	0.977
Irrigation	0.137	-0.003	0.372	1.991
Insecticide_use	0.043	0.036	0.014	1.021
Weedicide_use	-0.228	0.061	0.130	0.914
Age_sq	-0.043	-0.058	0.497	0.879
Farm-size__sq	0.007	-0.022	0.116	0.929
Year_2017	-0.546	0.014	0.117	0.991
Educ_Years*Aid_scheme	0.252	-0.017	0.739	1.057
Extension*2017	-0.167	0.000	0.818	1.000

Source: Authors' estimations using GLSS 6 and 7 data

The motivation for the choice of covariates X, in equations (4.1) and (4.6) is based on the literature on the determinants of participation in FSPs in SSA, including GFSP and the impact of participation in GFSP, T, on food security. These variables include household demographic characteristics (age, sex, farm size, adult equivalent scale), socio-economic factors (ownership of agricultural equipment by a household, Tropical Livestock Units (TLUs) owned by the household, non-farm enterprise participation by head of the household) and institutional and other production technological factors

(access to extension services and irrigation, use of mechanization, insecticides use, weedicides use). A year dummy variable and some interaction terms are also included in the model. The demographic characteristics such as male headed households, farm size, adult equivalent scale are predicted to increase the probability of participation in the GFSP whilst increasing age of heads of households is likely to reduce the probability of participation in GFSP. Ownership of agricultural equipment by a household, Tropical Livestock Units (TLUs) owned by the household, non-farm enterprise participation by head of the household are expected to reduce participation in GFSP since these variables represent wealth endowments of a household and such households can afford to buy fertilizer at the prevailing market prices, hence, may not participate in the GFSP. Access to extension, irrigation and mechanization services may increase the probability of participation in the GFSP by a farm household. Famers may adopt insecticides and weedicides to control insect pests and weeds in maize production which may increase their likelihood of participation in the GFSP so that they can reduce their cost of production and increase yield. In a review, Kelvin (2024), found agrochemicals essential in increasing crop yield. However, the adoption of sustainable agricultural practices which include the use of organic materials and regulatory measures is recommended to reduce the side effects associated with the use of these agrochemicals (Kelvin, 2024). Participation in GFSP is also expected to have positive effect on all the dimensions of food security.

4.2.2 Data Source and Description

As in the previous chapter, this chapter uses the same GLSS data. The Ghana Statistical Service collects the GLSS data with technical assistance from the World Bank. The information covers demographic characteristics, household agricultural production, asset ownership, access to financial services, education, and housing conditions, among others. The GLSS data are not a panel. They are a set of repeated cross-section surveys. Households are the unit of analysis of GLSS data (GSS, 2019). For this study, the pooled sample size for only maize-growing households and who reported expenditure on mineral fertilizer for GLSS6 and GLSS7 is 4,365. The GLSS7 consists of 1,977 and GLSS6 consists of 2,388 maize growing households. Out of the pool, only 481 farm households participated in the GFSP (11%). Thus, 357 maize growing farm households in 2013 as against 124 maize farm households in 2017. This is because the sample size for GLSS6 was higher than that of GLSS7 since it had more enumeration areas. Specifically, the GLSS7 had 14,009 households for 1000 enumeration areas (GSS, 2019). The GLSS6 had 16,772 responded households for 1200 enumeration areas (GSS, 2014). Subsequently, maize growing households in the study sample was higher in the GLSS6 than in the GLSS7 data. The reasons for using pooled data were to increase the sample size

and to achieve statistical reliability of the results. Accuracy of the estimated parameters is also achieved with pooled data compared to a single cross-sectional data (Gerdtham et al., 1998; Zieman et al., 2002). Data on the source of fertilizer purchased determined if households participated in the GFSP, following Tsiboe et al. (2021). The source of obtaining subsidized fertilizer was from the government through the Ministry of Food and Agriculture (MoFA). As noted earlier, such fertilizers were always labeled, making it easy for farmers to link subsidized fertilizer to MoFA. Farmers who indicated the private sector (i.e., buying from the open market retail input shops) were considered to have not participated in the GFSP. Households who stated that they got their fertilizer from cooperatives, NGOs, or others were removed from the sample to make the data easier to understand and interpret.

To estimate the dimensions of food security, the study employs food consumption and dietary diversity measures using recall data on foods eaten and their frequency, following Upton et al. (2016) and Sahu et al. (2017). As observed by Upton et al. (2016), food security measurements at the household level from survey data give adequate information regarding individual food consumption. They also have the advantage of accounting for household demographic and socio-economic characteristics as a function of food calorie intake (Pérez-Escamilla and Segall-Corrêa, 2008). Following the definition of food security by FAO (1996, 2008) and the empirical work of Magrini and Vigani (2016), a household's food availability is proxied by the supply of food per unit of farm land under cultivation using maize yield per hectare. Food access is measured using a household's food consumption expenditure per adult equivalent. It has the advantage of taking into account a household's intake of calories and micronutrients. Food utilization is measured using Household Food Consumption Score (HFCS). HFCS is a composite score and has the advantage of incorporating dietary diversity, food frequency, and relative nutritional importance of different food groups consumed by a household (Magrini and Vigani, 2016). Thus, the HFCS is an indicator of both quantity and quality of food consumed by the household (Leroy et al., 2015). Following WFP (2008) and Tiwari et al. (2013), HFCS is calculated as the number of different food groups consumed by the household in the last seven days before the interview, with each group given a weight representing the nutrient density of that food group. The seven food groups used in the study were: "cereals", "roots and tubers", "pulses and legumes", "dairy products, oils and fats", "meat, fish, and eggs", "fruits", and "vegetables". The stability dimension was measured as an additional indicator of household resilience, following Magrini and Vigani (2016), using the availability of food stock at the time of the interview from the previous harvest. Keeping food in stock for household consumption explains coping against food shortages in the future (Magrini and Vigani, 2016). This type of measurement is important particularly when the pre-occupation of smallholder farmers in Ghana is

to meet their family food consumption requirements. Value of physical assets per adult equivalent was used as an additional measure of household food stability and resilience. This is because households may deplete household assets such as consumer durables to survive during shocks (Deaton, 1991; Doss et al., 2018). Total household expenditure per adult equivalent was used as a proxy for household income only for the purpose of comparison with previous literature (Magrini and Vigani, 2016). It is also considered as a better measurement of well-being compared to household income since household income is more susceptible to seasonal fluctuations and measurement error (Tambo and Wunscher, 2015).

4.3 Results and Discussions

4.3.1 Descriptive Statistics

Descriptive statistics for the surveyed households are presented in Table 4.2. The level of participation in the subsidy program in 2013 was about 15% among maize growing households. This declined to 6.3% in 2017, following the restructuring of the program. The restructuring ensured that only farmers of land size of 2Ha or less under cultivation, in principle, benefitted from the GFSP. This was unlike in the past when the program was universally targeted (Pauw, 2022). The level of participation in the overall sample was 11%, indicating that nationwide there was low coverage of the program. The food availability dimension in terms of average yield of maize was 1530.2 Kg/Ha. From the pooled sample in Table 4.2, about 82% of heads of households were male. The average age of the head of household was 48 years. The size of land allocated to maize production was 1.2 Ha. The value of an agricultural equipment owned by a household on average was GHS227.00[1]. There was about 33% use of insecticides as against 62% use of weedicides. Fall army worm infestation of maize fields has made the use of chlorpyrifos, emamectin-benzoate and lambda-cyhalothrin-based insecticides as control measures common in Ghana (Adams et al., 2024). The use of any form of mechanization including tractor services, the use of a planter or a thresher but excluding the use of the hoe and the cutlass was 36%, implying that mechanizing agriculture in Ghana is still a problem and the use of mechanization is lower compared to the use of agrochemicals such as weedicides. Access to irrigation was 11% and that of extension was 81% in the pooled sample. However, access to extension in the year 2017 was 59% as shown in Table 4.2. Square terms such as age-square and farm size-square were 258 years and 4 Ha, respectively. The number of years of education of heads of households who were also from communities that had mutual aid schemes was 4 years on average.

Food access and stability dimensions also increased in 2017 compared to 2013, as shown in Table 4.2. Consumption expenditure per adult equivalent scale increased from GHS1206.00 in 2013 to

Table 4.2: Definition of Variables and Descriptive Statistics

Variable	Description	2013		2017		Pooled sample	
		Mean	SD	Mean	SD	Mean	SD
Outcome variables							
Availability dimension	Yield, measured as maize output in Kg per hectare	1932.3	101.63	1000.8	173.74	1530.2	775.96
Food access dimension	Consumption expenditure on food and beverages per adult equivalent in Ghana Cedis (GHS) over a 12-month period	1205.7	121.16	1331.7	125.93	1260.0	123.4
Food access and household welfare/ income	Total expenditure (per adult equivalent) on food and non-food items in GHS	2000.4	190.86	2347	227.6	2150	208.2
Food utilization	Composite household food consumption score (HFCS) from specific food groups and their weights	56.6	19.01	46.2	16.6	52.1	18.8
Stability dimension	Maize grains stored from the last harvest (in Kg) at the time of interview	318	142.45	363	123.5	377	134.6
Stability dimension	The total value of household assets per adult equivalent in Ghana Cedis)	15	6.66	35	19.71	23.5	13.92
Socio-economic variables							
Subsidy	1 if the household was part of the fertilizer subsidy from government; 0 otherwise	0.15	0.36	0.06	0.24	0.11	0.31
Sex	1 if head is a male; 0 otherwise	0.82	0.38	0.81	0.39	0.82	0.39
Farm_Size	Size of land allocated to maize (in hectares)	1.096	1.432	1.04	1.948	1.072	1.675
Agri_Equipment	Value of agricultural equipment in	178.52	215.03	290.28	395.21	226.77	306.14

	working condition (GHS)						
Adult_ES	Adult Equivalent Scale	3.99	2.28	4.21	2.45	4.08	2.36
Agri_equip*Adult_ES	Interaction between value of agric. equipment and Adult Equivalent Scale	2.14	2.73	3.23	2.84	2.60	2.83
TLUs	Tropical Livestock Units	1.84	4.79	1.29	4.88	1.6	4.84
Age	Age in years of household head	47.50	15.32	47.62	15.30	48.00	15.32
Non-farm_Enterprise	1 if head of household engages in non-farm enterprise; 0 otherwise	0.34	0.47	0.32	0.47	0.33	0.47
Mech_use	Farm household used farm machinery	0.37	0.48	0.34	0.47	0.36	0.48
Insecticide_use	Farm households applied insecticide	0.33	0.47	0.32	0.47	0.33	0.47
Weedicide_use	Farm households applied weedicides	0.62	0.49	0.61	0.49	0.62	0.49
Irrigation	1 if the household belongs to a community which has irrigation fields; 0 otherwise	0.09	0.29	0.13	0.34	0.11	0.31
Age_sq	The square of the age of head of household	257.24	168.28	258.77	160.54	257.90	164.98
Extension	1 if agricultural extension officers visit farm households; 0 otherwise	0.98	0.15	0.59	0.49	0.81	0.39
Year_2017	Year of data collection, 1 if 2017; 0 if 2013	-	-	-	-	0.43	0.50
Educ_Years*Aid_scheme	Interaction between years of education and if community had mutual aid scheme	3.90	4.68	2.14	4.08	2.85	4.42
Farm_size_sq	Square of land size allocated to maize cultivation	3.25	20.92	4.88	40.78	3.95	93.83
Extension*2017	A household's access to agricultural extension in 2017	-	-	0.59	0.49	0.25	0.44

Source: Authors' calculations using GLSS 6 and 7 data. [1]Notes: GHS4.95 is to US$1.00, using the Bank of Ghana Inter Bank Exchange Rate – End period for January 2019 (Bank of Ghana, 2023).

GHS1332.00 in 2017, on average. In addition, total expenditure per adult equivalent scale, on average, increased from GHS2000.00 in 2013 to GHS2347.00 in 2017. For the stability dimension, maize grains in stock increased from 318 Kg in 2013 to 363 Kg in 2017. In addition, total value of household assets per adult equivalent scale increased from GHS15.00 in 2013 to GHS35.00 in 2017. However, the utilization dimension of food security declined from HFCS of 57 in 2013 to 46 HFCS in 2017, implying that the diversity of food intake may not necessarily be explained by increases in the access dimension of food security in terms of food and total household expenditures. However, the increase in food access and stability as well as the decrease in food utilization as shown in Table 4.2 does not take into account both observed and unobserved factors.

The descriptive statistics on household socioeconomic, community and institutional factors are presented in Table 4.3.

Table 4.3: T-Statistic Mean Differences Between Subsidy and Non-Subsidy Households

Variable	Subsidy Households: Mean	Non-subsidy Households: Mean	Difference
Sex	0.906	0.858	-.049***
Farm_size	1.359	1.201	-0.158
Agri_Equipment	0.773	0.625	-.148***
Adult ES	4.331	4.435	0.104
Agri_equip*Adult_ES	3.429	2.906	0.523***
Non-farm_enterprise	0.366	0.312	-.054**
TLU	2.736	2.135	-.601**
Age	47.168	47.583	-0.415
Mech_use	0.48	0.406	0.074***
Insecticide_use	0.449	0.404	0.045**
Weedicides_use	0.58	0.675	-0.95***
Irrigation	0.152	0.108	0.043**
Age_sg	2462.12	2498.29	-0.36.16
Extension	0.89	0.80	-0.09***
Year_2017	0.258	0.477	-0.22***
Educ_Years*Aid_scheme	4.024	2.807	1.21***
Farm_size_sq	0.206	0.290	-0.085***
Extension*2017	0.206	0.290	-0.085***

Source: Authors' calculations using GLSS 6 and 7 data

The table presents the statistics by making a distinction among households based on the status of their participation in the GFSP. It can be observed from Table 4.3 that there are differences between households that benefited from GFSP (subsidy households) and those that did not benefit (non-subsidy households), as shown by the t-statistic of the mean difference. The implication is that self-selection into GFSP would have been possible since beneficiaries might have been systematically different from non-beneficiaries.

Regarding the food security outcomes, it can be observed from Table 4.4 that the t-statistic mean differences showed differences between subsidy and non-subsidy households in terms of food availability and stability dimensions. The output from maize among subsidy households was significantly higher than that of non-subsidy households by 264Kg (equivalent to 2.5 maxi bags) as shown in Table 4.4. Food and total household expenditures among subsidy households as measurements of food access were also significantly higher than that of the non-subsidy households by GHS169.54 (US$34.34[1]) and GHS179.00 (US$36.16), respectively. However, there was no systematic difference between subsidy and non-subsidy households in terms of food utilization and stability dimensions, as shown in Table 4.4.

The implication is that the increase in food availability among the beneficiaries of GFSP did not translate into diversity of foods consumed and the stability of their food systems in times of shock such as food price hikes. Effect of other farm household characteristics not accounted for by the t-statistic mean differences may still confound the impact of household participation in the GFSP on household dimensions of food security. The propensity score matching technique is able to control for selection bias due to self-selection as a result of systematic differences between subsidy and non-subsidy households.

The inclusion of variables in Table 4.1 as noted before, into the propensity score matching techniques are those that influenced both assignment into the GFSP and food security outcomes but not influenced by participation in the GFSP (Caliendo and Kopeinig, 2008). This allows the food security outcomes to be attributed to the effect of participation in the GFSP (Faltermeier and Abdulai, 2009). The covariates employed in the PSM satisfied the balancing property as shown before in Table 4.1. A visual comparison is contained in Figure 4.1, indicating the before and after matching. It confirms the findings in Table 4.1 that the propensity score matching was able to produce very similar subsidy and non-subsidy households. From Figure 4.1, the differences in distribution before matching (column 1) disappear upon executing the matching procedure (column 2).

Table 4.4: Difference in Food Security Outcomes Between Subsidy and Non-Subsidy Maize Growing Households

Food security outcomes	Subsidy households	Non-subsidy households	Difference
Availability dimension (maize yield /kg)	1622.41	1358.37	264.04***
Food access dimension (consumption expenditure/ AES in GHS[1])	1363.64	1194.10	169.54***
Food access and household welfare (total expenditure/ AES in GHS)	2214.97	2035.89	179.1***
Food utilization (HFCS)	52.031	51.333	0.69
Stability dimension (maize grain stock in Kg)	474.64	464.81	9.83
Stability dimension (Total household assets in GHS/ AES)	26.75	23.85	2.91

[1]GHS4.95 is to US$1.00, using the Bank of Ghana Inter Bank Exchange Rate – End period for January 2019 (Bank of Ghana, 2023). AES: Adult Equivalent Scale. **Source:** Authors' calculations using GLSS 6 and 7 data

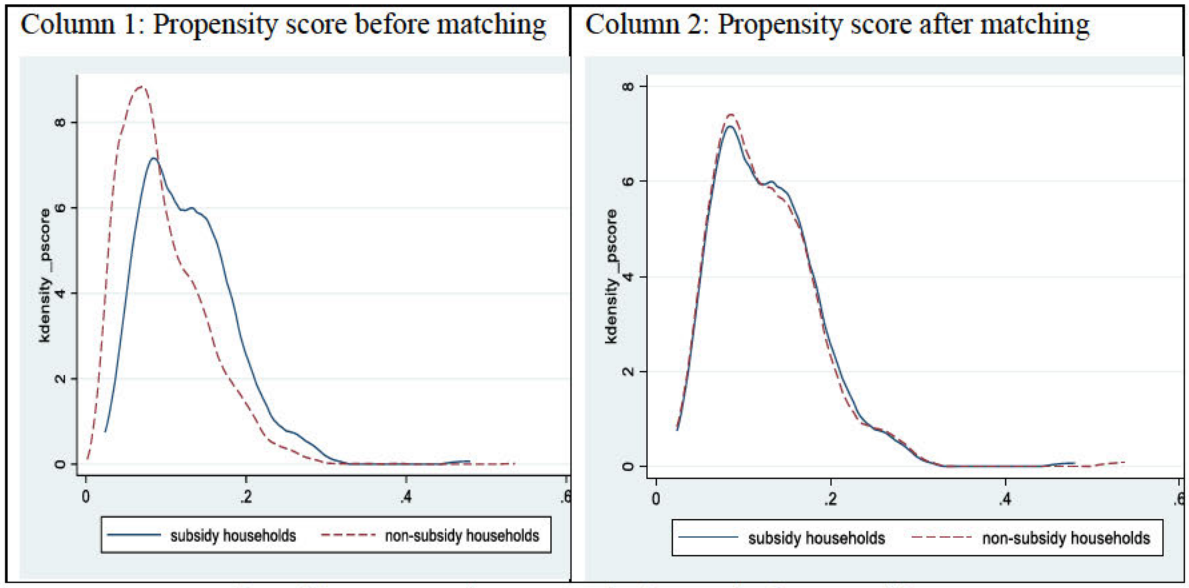
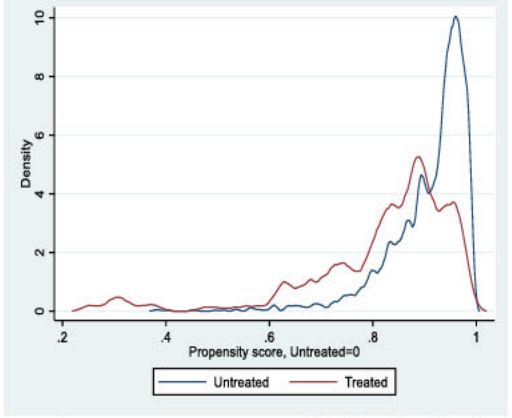


Figure 4. 1: Density of the Propensity Scores before and after Matching

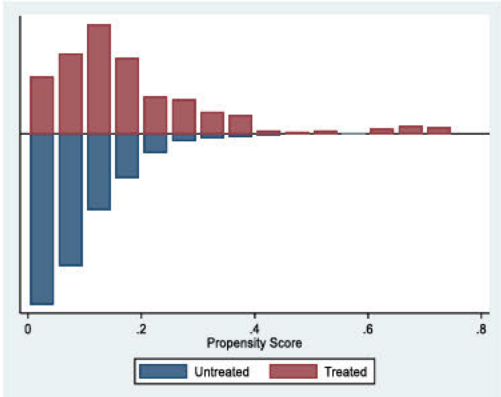
Source: Authors' calculations using GLSS 6 and 7 data

4.3.2 Empirical Results and Discussion

It is recommended to present results on average treatment effects from matching estimators using different approaches (Busso et al., 2014) as it is the case in this study. This requires rigorous testing of the overlap assumption using different techniques that validate one another in obtaining quality matches. After the balancing property test (Figure 4.1), propensity scores were estimated from the logit model by matching subsidy and non-subsidy households. Figure 4.2, panel A, shows the estimated density distribution of the predicted probabilities of subsidy and non-subsidy households, indicating the absence of probability mass near zero or one (using the Stata command "teffects overlap"). The respective masses of estimated densities for the two groups mostly occur in regions where they overlap with each other. This implies that the overlap assumption was not violated, and sufficient common support exists between the two different groups of farm households. The overlap assumption is tested further to ensure the quality matches (using the Stata command "psgraph"), as contained in panel B of Figure 4.2. It also indicates good quality matches between subsidy and non-subsidy households.



Panel A: Common support density distribution for the propensity score, using "teffects overlap".



Panel B: Propensity score distribution and region of common support, using "psgraph".

Figure 4.2: Propensity Score Common Support Distributions

Source: Authors' calculations using GLSS 6 and 7 data

There is also a balance in the covariates employed in the estimated model from the *tebalance overid command* (a chi-squared test of the balance) at $p = 0.5651$, following Austin (2009) and Imai and Ratkovic (2014). It implies that the null hypothesis that the specified treatment model balances the covariates is accepted. Following Lee (2008) and Faltermeier and Abdulai (2009), increased number of covariates including interaction terms as can be observed in Table 4.5 was used to reduce any likelihood of bias due to unobservable factors remaining after the matching procedure. The maximum

likelihood estimates of determinants of a household's participation in GFSP from the logit model are contained in Table 4.5. The results showed that value of agricultural equipment owned by a

Table 4.5: Logit Estimates of Determinants of Participation in Ghana's Fertilizer Subsidy Program

Variable	Coefficient	Standard Error	Marginal effect
Sex	0.210	0.216	0.014
Farm_size	0.162***	0.046	0.011***
Agri_Equipment	0.709**	0.326	0.0477**
Adult ES	-0.118	0.072	-0.01*
Agri_equip*Adult_ES	0.075	0.077	0.01
Non-farm_Enterprise	0.371***	0.132	0.025***
TLU	0.004	0.011	0.000
Age	0.013	0.028	0.001
Mech_Use	0.361***	0.13	0.024***
Insecticide_use	0.356**	0.169	0.024**
Weedicides_Use	0.223	0.227	0.015
Irrigation	0.176	0.188	0.012
Age_sg	0.000	0.000	0.000
Extension	1.904***	0.459	0.128***
Year_2017	-3.683***	0.499	-0.248***
Educ_Years*Aid_scheme	0.011	0.014	0.001
Farm_size_sq	-0.002**	0.001	-0.001*
Extension*2017	2.772***	0.516	0.186***
Constant	-0.49	0.813	-

Source: Authors' calculations using GLSS 6 and 7 data

household, engaging in non-farm income, access to extension in 2017, farm size, use of mechanization and insecticides as well as year of implementation of the subsidy program tended to predict the probability of household participation in the GFSP. The finding that farm size predicts the probability of benefitting from GFSP supports that of Prah et al. (2023) who found similar results for the same program in a smaller survey in Sekyere Kumawu district in the Ashanti Region of Ghana.

But the remaining question is: "If increasing farm size is positively correlated with GFSP participation, then wont its targeting policy of 2Ha or less of farm land under cultivation be defeated?" The study found the contrary since farm size square had negative correlation with the probability of participation in the GFSP, as shown in Table 4.5. As farm size increases beyond a certain threshold, owners of such farms do not get the opportunity to participate in the GFSP. Pest outbreaks such as the Fall army worm, which was first confirmed in 2016 (Williams et al., 2023), have become a major constraint to maize production in Ghana across all the maize growing ecologies (Shaiba et al., 2019; Safo et al., 2023). It, therefore, meets a *prior expectation* that farmers who used insecticides would want subsidized fertilizer to possibly reduce cost of production. The restructuring of the GFSP in 2017 reduced the level of participation as the year 2017 variable had a negative effect on GFSP as shown in Table 4.5. However, the interaction term of the year 2017 and access to extension was positive, implying that the restructuring improved access to extension delivery in 2017, and possibly the quality of the extension service delivered in 2017 as well. The positive and statistically significant relationship between participation in the GFSP on one hand and non-farm income on the other hand, demonstrates a synergy between the two in promoting rural development. From Table 4.5, the positive effect of the value agricultural equipment owned by a household and use of mechanization services by those who do not own equipment among GFSP beneficiaries may imply increasing intensification of agricultural practices in Ghana. This finding may also imply that resourceful smallholder farmers who may have 2Ha or less of farmland under cultivation but can afford the full cost of fertilizer are benefitting from the subsidy program. This could be considered as one of the unintended negative effects of the program.

The results from Table 4.6 show the estimates of the average treatment effects using the different matching methods to explain the impact of participation in GFSP on the multiple dimensions of food security. The nearness neighbour inverse variance-weighting matrix (IVWM) is used as the benchmark estimation. The study reports on IPW and IPWRA as robustness checks. The logarithm of the outcome variables is used in the estimation so the results are interpreted in terms of percentage difference. The results show that the overall average treatment effect of the GFSP is statistically significant across the food security outcomes from the various matching methods.

Results from the IVWM implies that participation in the GFSP in the sample significantly increases household food availability by 19%. The ATET result shows 32 percent increase in food availability among beneficiaries of the program. The IVWM uses four (4) matches since it offers the benefit of relying on sufficient information by including observations that are very similar, following Abadie et al. (2004). Matching on two or more continuous covariates may render NN matching estimators

inconsistent. A bias-corrected estimator that is consistent was, therefore, employed (Abadie et al., 2004; Abadie and Imbens, 2011). It adjusts the difference within the matches for the differences in their covariate values (Abadie et al., 2004). The results indicate that employing the bias adjustment (referred to as ATET adjusted in Table 4.6) significantly decreases the coefficient of the estimated ATET to 29%. It is not surprising that the ATET coefficient is still higher than that of the ATE since it focuses narrowly on GFSP beneficiaries.

There is stability in the findings of positive impact of GFSP on food availability when consideration is given to the other matching algorithms. For example, the ATE coefficients from the NN Mahalonobis and propensity score matching estimators are almost the same as that of the benchmark estimator. However, the ATET coefficients from the NN Mahalonobis and propensity score matching estimators are slightly higher than the ATE and ATET coefficients from the benchmark estimators. The same can be said about the IPW and IPWRA estimators. Whereas the increase in food availability due to participation in GFSP on both the sample and beneficiaries from the doubly robust estimators (IPW and IPWRA) was significantly positive, 22% and 31% increase for ATE and ATET, respectively, compared to the benchmark estimates of 19% and 29% for the ATE and ATET adjustment. The consistent finding of positive increase in the availability dimension due to GFSP participation across all the matching algorithms supports the findings of existing literature on the positive impact of GFSP on crop yield in Ghana (Iddrisu et al., 2020; Tsiboe et al., 2021; Pauw, 2022) and fertilizer subsidy programs in sub-Sahara Africa (Ricker-Gilbert and Jayne, 2016).

For the access dimension of food security, participation in the program benefited participants more compared to non-participants in the sample. The estimated IVWM indicates an increase of 58% in household access to food among GFSP participants compared to non-participants in the sample. The estimated IVWM-ATET suggests 38% increase, on average, in household food access among beneficiaries of GFSP. The bias-adjustment ATET gave a value of 37% increase in food access. Also, estimates from propensity score matching, IPW and IPWRA suggest positive impact of GFSP on food access though with relatively slightly higher coefficients compared to that of the benchmark estimator. For example, the propensity score matching estimator suggests an increase in household access to food by 45%. Similarly, both the IPW and IPWRA estimators found 47% increase in household access to food. The NN Mahalonobis also showed similar consistent and relatively slightly higher impact of GFSP on subsidy beneficiaries.

Regarding the impact of GFSP on the additional measure of household food access and general household welfare (total household expenditure per adult equivalent), the study finds positive and consistent results across all the matching estimators. The bias-adjustment ATET suggests that

participation in the GFSP increased household's food access and welfare by 57% higher than households that did not benefit from the program. The positive impacts of GFSP on both food access and household welfare confirm the income effect of input subsidies. Savings made by farm households due to reduced input costs could be spent not only on purchasing more farm inputs (Ricker-Gilbert and Jayne, 2016) but also on food and total household expenses for improved food security and overall household welfare. This finding is consistent with some other studies that have found positive impact of input subsidies on household food expenditure (Iddrisu et al., 2020) and total household expenditure (Wossen et al., 2017). This finding, however, does not indicate the level and diversity of nutrition and food intake, unlike food consumption score.

Participation in the GFSP has negative and significant effect on household food utilization. This is confirmed by the benchmark estimator which is equal to about 6%, as shown in Table 4.6. Thus, participation in the GFSP lowers the probability of a household having to consume foodstuffs from diversified sources by almost 6%. This finding confirms the growing concern that input subsidies in sub-Saharan Africa are concentrating more on mono-cropping systems to the detriment of mixed and intercropping systems (Mason et al., 2013; Levine and Mason, 2014; Ahmad et al., 2023). Smallholder farmers are, therefore, unable to access diversified diet sources since they mostly consume what they grow. The finding of negative impact of GFSP on food utilization is contrary to that of Novignon et al. (2020) who found Malawi's FSP to have increased participating households' dietary diversity, food diversity and micronutrients dietary scores. However, participation in the GFSP positively and significantly increased stability dimension of household food security. The benchmark estimator and the mahalonobis are the only estimators that indicate statistical level of significance. The direction of the coefficients of the other estimators are, however, consistent with that of the benchmark and mahalonabis estimators. The stability dimension of food security is investigated further to see if household food security needs are stable over the long-term, using total household asset value as a proxy. From Table 4.6, the benchmark estimate suggests an increase by 33% among beneficiaries of GFSP compared to those households that did not benefit from the program. When adjusted for bias, the estimated impact reduced to 29%, though still slightly lower compared to the 30% estimates (both ATET and ATET-adjusted) from the mahalonabis estimator. This, to some extent, explains the positive effect of GFSP on improving farm household resilience to vulnerability to food insecurity i.e. during shocks households usually deplete household assets to survive. This finding was, however, weaker in terms of the robustness checks.

Regarding the Rosenbaum sensitivity test as shown in Appendix F, the estimation results from the propensity score matching methods are valid and robust against hidden bias. It can be observed from

the results that the strength of the hidden bias at the various critical values is not sufficient enough even at the lower bounds to question the results of positive and significant effect of participation in GFSP on the dimensions of food security, since all the magnitudes at both the upper bound significance level (sig+) and lower bound significance level (sig-) are not greater than one (Martey et al., 2019).

Table 4.6: Treatment Effects showing Impacts of Participation in the Ghana Fertilizer Subsidy Program (GFSP)

Matching algorithm	Food availability dimension (maize yield /kg)	Food access dimension (consumption expenditure/ AES in GHS[1])	Food access and household welfare (total expenditure/ AES in GHS)	Food utilization dimension (HFCS)	Stability dimension (maize grain stock in Kg)	Stability dimension Total household assets in GHS/ AES)
NN IVW						
ATE	0.187*** (0.056)	0.584*** (0.138)	1.666*** (0.128)	-0.0127 (0.03)	0.175 (0.198)	0.05 (0.127)
ATET	0.321***(.0583)	0.379*** (0.131)	1.626*** (0.116)	-0.055** (0.029)	0.483*** (0.18)	0.33*** (0.115)
ATET adjusted	0.291*** (0.079)	0.373*** (0.131)	1.569*** (0.137)	-0.057** (0.029)	0.342** (0.181)	0.293*** (0.113)
Mahalanobis: Matches (4)						
ATE	0.165*** (0.396)	0.594*** (0.125)	1.648*** (0.064)	0.002 (0.024)	0.217 (0.189)	0.148 (0.112)
ATET	0.319*** (0.056)	0.542*** (0.127)	1.683*** (0.103)	-0.03 (0.03)	0.598*** (0.181)	0.30*** (0.115)
ATET_adjusted	0.319*** (0.056)	0.542*** (0.127)	1.683*** (0.103)	-0.03 (0.03)	0.598*** (0.181)	0.30*** (0.115)
Propensity score matching						
ATE	0.181*** (0.045)	0.759*** (0.142)	1.756*** (0.077)	0.01 (0.027)	0.093 (0.25)	0.095 (0.128)
ATET	0.343*** (0.087)	0.45*** (0.204)	1.428*** (0.227)	-0.01 (0.041)	0.209 (0.226)	0.060 (0.158)
Inverse probability weighting (IPW)						
ATE	0.217*** (0.042)	0.713*** (0.11)	1.749*** (0.066)	-0.019* (0.033)	0.167 (0.241)	0.161*** (0.28)
ATET	0.309*** (0.052)	0.47*** (0.12)	1.494*** (0.084)	-0.04* (0.04)	0.218 (0.174)	0.149 (0.109)
IPWRA						
ATE	0.218*** (0.218)	0.713*** (0.11)	1.749*** (0.066)	-0.019* (0.033)	0.167 (0.241)	0.161 (0.128)
ATET	0.309*** (0.052)	0.47*** (0.12)	1.494*** (0.084)	-0.04* (0.03)	0.218 (0.174)	0.149 (0.109)

Note: ***, ** and * denote statistical significance at levels of 1%, 5% and 10%, respectively. Standard errors are in brackets.

Source: Authors' estimation using GLSS 6 and 7 data

4.4 Summary

This chapter assessed the effect of maize growing household participation in GFSP on the four dimensions of household food security (availability, access, utilization, and stability). The pooled cross-sectional data that this chapter employed was a typical non-experimental one. Hence, the problem of self-selection bias often associated with non-experimental data was addressed using the PSM techniques. The PSM techniques also follow the two-stage equation estimation procedure.

From the logit estimates of the first-stage, value of households' agricultural equipment, engaging in non-farm income by head of a household, access to extension in 2017, farm size and farm size square determined participation in the GFSP. Other determinants were use of mechanization, use of insecticides and year of implementation of the subsidy program. The significant and negative correlation between increasing farm size (farm size square) and participation in the subsidy program indicates a better targeting approach of potential project beneficiaries. It means that farmers with farm sizes greater than 2Ha have not benefitted from the program. However, the positive and significant relationship of the value of agricultural equipment owned by the household and engaging in off-farm enterprise with participation in GFSP, may imply that smallholder farmers who may have 2Ha or less of farmland under cultivation but can afford the full cost of fertilizer are benefitting from the subsidy program. It is therefore important that the subsidy targeting approach is looked at again to consider the value of agricultural equipment owned by households as part of the criteria for selecting GFSP beneficiaries. This will help target most vulnerable farming households and with lesser value of agricultural equipment. Afterall, households with agricultural equipment with higher value such as power tillers and oxen normally rent them out to other farmers to earn extra income which could pay for the full cost of mineral fertilizers.

In addition, the empirical results from the second-stage estimation of the PSM techniques showed a positive effect of GFSP on the availability dimension of food security in terms of yield. Thus, increased output from maize production is attributable to the GFSP among beneficiaries. Increased maize yield increases the probability of higher food consumption at the household as well as the higher income from the sale of surplus maize. Income from the sale of surplus maize can be used to buy what the household does not produce. Consequently, participation in the GFSP has positive effects on household food access and welfare. This positive effect of GFSP on food availability notwithstanding, the finding from the descriptive results indicating maize yield achieved/ Kg is far below the potential yield calls for vigorous promotion of productivity-enhancing technologies by research and policy makers.

In terms of the stability dimension of food security, GFSP increased both maize stock and household total assets value, with higher effect size (intensity) for food stock. Both maize stock and household total assets value were, however, weaker when the robustness checks were done. Maize growing households may have short-term resilience to food security, resulting from food price hikes and weather shocks since the study finds a mean of about 265Kg of maize in stock. However, prolonged weather shocks or other risky events may deplete this limited stock, reducing the stability effect of the GFSP. It is recommended that government put in place policies that promote non-farm income for smallholder farmers which serve as shock absorbers during crop failure at the same time provide extra income for the purchase of farm inputs.

Finally, the negative effect of the GFSP on the utilization dimension of food security, suggests that increased yield and possibly increased income did not translate into households consuming diversified foods. Households depend more on the staples such as maize and other cereals with less calorie intake from diversified food sources, including vegetables and fruits. This could be as a result of the concentration of subsidy programs on sole cropping systems, instead of promoting crop diversification and mixed farming. The study, therefore, recommends agricultural policies that target improving household food nutrition through crop diversification and mixed farming. There is currently no exit strategy for GFSP despite its financial cost. Government together with NGOs and farmer institutions should encourage adoption of climate- smart Integrated Soil Fertility Management (ISFM) technologies as an alternative to GFSP. Considering the fact that adoption of such technologies is still low among farmers despite positive evidence from experimental fields, effective communication is required by all stakeholders based on empirical evidence of the impacts of adoption of ISFM on food security and other welfare indices from household surveys that are nationally representative. The final chapter therefore examines the impacts of the complementarity of Integrated Soil Fertility Management (ISFM) technologies on multiple dimensions of food security in Ghana.

CHAPTER 5: IMPACTS OF THE COMPLEMENTARITY OF INTEGRATED SOIL FERTILITY MANAGEMENT (ISFM) TECHNOLOGIES ON DIMENSIONS OF FOOD SECURITY: EVIDENCE FROM GHANA[3]

5.1 Introduction

Food systems are under increasing pressure to supply food and nutrition that meets the needs of the world's growing population. At the same time, climate change is negatively influencing agricultural productivity, natural resources and rural livelihoods (FAO et al., 2019) and it will continue to slow down progress on the projected decline in hunger in the coming decades (Mason-D'Croz, 2019). Declining soil fertility caused by decades of nutrient mining by smallholder farmers also continues to be a problem (Bekunda et al., 2010; Kugedera et al., 2023; Dunjana et al., 2023). Sub-Saharan African soils are characterized by nutrient deficiency, low clay and organic carbon content, and limited exchange capacity (Bado and Bationo, 2018). For example, in Ghana, rates of depletion in soil nutrients are estimated (on a per hectare basis) at 35 kg N, 4 kg P, and 20 kg K. In all the agro-ecological zones, nutrient depletion is prevalent, with nitrogen and phosphorus being the most deficient. Consequently, agricultural productivity has been declining (Bationo et al., 2018; Chutab, 2023) and food insecurity continues to be a problem with much prevalence among smallholder crop farmers compared to cash crop and vegetable farmers (Kuwornu et al., 2013). A farmer is more likely to be food insecure than a non-farm worker (Bannor et al., 2021), possibly because farmers are mostly smallholders and net-buyers of staple food (Minot and Dewina, 2015; Diao, 2023). Food insecurity is not limited to only rural people but urban dwellers too (Bannor et al., 2021).

To improve food security among people whose livelihoods depend on agriculture, adoption of sustainable agronomic practices and modern inputs, such as improved seeds, fertilizers and other agro-chemicals, is key as they contribute to improving agricultural productivity and household food security (Sheahan and Barrett, 2017; Mujeyi et al., 2021). Recent studies have shown positive impact of modern inputs on some dimensions of household food security such as increased productivity (i.e., availability dimension) as in Martey et al. (2019) and Adzawla et al. (2024) and increased food

[3] This chapter gave rise to the following article both in preprint (DOI:10.21203/rs.3.rs-1758933/v1) and currently under review with Development in Practice: Jinbaani AN and Wale E. Impacts of the complementarity of Integrated Soil Fertility Management (ISFM) technologies on multiple dimensions of food security: evidence from Ghana.

consumption expenditures (i.e., access dimension) (Biru et al., 2020). These studies, among several, do not provide a complete picture to policy makers on the contribution of technology adoption to achieving household food security (FAO, 2008), because their focus is partial. In addition, such studies generally consider the effects of adoption of improved technologies within a single technology framework (i.e., adoption of improved seed or mineral fertilizer), ignoring the interdependence and complementarity of agricultural technologies (Kassie et al., 2018; Biru et al., 2020) with less focus also on sustainable land management practices. The rising cost of chemical fertilizers and the increasing risk of environmental pollution call for the adoption of sustainable farming systems through soil fertility restoring and ameliorating approaches (Fageria, 2007; Kugedera, 2023; Adzawla et al., 2024) such as organic fertilizers. Organic fertilizers are plant nutrient sources from plant and animal by-products (Singh, 2012). Green and animal manure constitute organic fertilizers for this study. The study, therefore, aimed to empirically investigate the impact of the complementarity of Integrated Soil Fertility Management Technologies (ISFM) on multiple dimensions of household food security in Ghana. The choice of ISFM is due to the ever-increasing importance of soil fertility decline and increasing climate variability with the negative consequence on food security and rural livelihoods (Bekunda, 2010; FAO et al., 2019). ISFM is a package of locally adapted soil fertility technologies and better agronomic practices aimed at improving soil fertility and crop yield. The use of improved seeds, organic and mineral fertilizers form the core of ISFM technologies (Lambrecht et al., 2016; Hörner and Wollni, 2021).

Empirical studies on the impact of ISFM practices in improving soil organic carbon has largely been limited to field experiments (Srinivasarao et al., 2012; Vanlauwe et al., 2017; Kugedera, 2023), particularly in Ghana where these experiments are conducted at different locations. It, therefore, becomes difficult to relate a set of ISFM technologies to a particular location in order to understand and monitor their impact (Antwi, 2020). It has also been difficult to relate the impact of ISFM practices to household food security based on the results from agronomic field experiments. There is presently no rigorous study using a nationally representative data on the impact of these technologies on household food security.

In the recent literature on complementary technology adoption, though limited, consideration has been given to the simultaneous adoption of some sustainable land management practices with either improved seed or mineral fertilizer. Examples of such studies include maize legume intercropping and rotations (Kassie et al., 2018), soil conservation practices such as terracing and contour ploughing (Biru et al., 2020) and conservation agriculture (Khonje et al., 2018). However, to the best of the

author's knowledge, there are no studies on the impact of simultaneous adoption of ISFM on the multiple dimensions of food security.

The contribution of this chapter to the existing empirical literature is novel in various ways. First, it analyses and compares the impact of adoption of individual and multiple technologies on all the four dimensions of household food security in Ghana using nationally-representative data. To the best of the author's knowledge, this has not been done before. Secondly, the study employs the multinomial endogenous switching regression (MESR) to a pooled data covering maize growing farm households. Since agricultural technology adoption decisions are interdependent, multivariate models are best suited for analyzing such decisions (Kassie et al., 2018). The MESR accounts for both observed and unobserved factors and employs instrumental variables to obtain efficient and robust estimates (Bourguignon, 2007). With proper empirical evidence on the impact of complementarity of ISFM practices on households' food security, policies could be designed to enhance adoption of the complete package of ISFM practices at the plot level.

5.2 Methodology

5.2.1 Materials and Methods

The study conceptualizes the contribution of complementary technology adoption to achieving household food security. This emanates from the premises that the technologies contribute better when combined than each does individually. According to FAO (2008), food security has four dimensions: availability, access, utilization and stability of food. Thus, for households to be food secured, they should have stable access to nutritious food overtime and during shocks such as food price hikes, crop failure due to extreme weather conditions or lack of employment. A household may well be currently food secured but vulnerable to food insecurity in the future (Bogale, 2012; Mthethwa and Wale 2020). Thus, a household's present state of food security may go below socially accepted standards in the future due to idiosyncratic and covariate shocks (Bogale, 2012). Since household characteristics and their exposure to risk in the present will determine how they cope with and manage risks in the future (Capaldo et al., 2010), current analysis of the stability dimension of food security should provide understanding of a household's resilience and vulnerability to food insecurity. Resilience is a household's ability to produce and acquire nutritious and culturally acceptable food over time and space in the face of risky events (Schipanski, 2016), as noted earlier. This establishes a link between household food security and resilience. Thus, the stability dimension of food security has the added advantage of measuring household resilience.

Farmers may choose either improved seed, mineral fertilizers, sustainable land management practices such as organic fertilizer or their combinations based on the expected utility from adoption in meeting all the four dimensions of food security. All four dimensions must be met at the same time in order to achieve food security goals (FAO, 2008). It is anticipated that rational and efficient farmers will adopt complementary ISFM technologies to maximize the expected utility in meeting all the four dimensions of food security (Gebremariam and Tesfaye, 2018). Other recommended practices are necessary for increased productivity such as recommended spacing, knowledge on seed and fertilizer application rates, etc.

However, the study is restricted to the use of ISFM practices. The choice of organic fertilizers is based on the assumption that farmers in coping with the risks of climate variability and declining soil fertility will adopt organic fertilizers to complement mineral fertilizers. Crop yields, in the long-term, tend to decline with increasing use of mineral fertilizers without organic matter or manure (Hui et al., 2017). Cultural practices such as crop rotations and cereal legume intercropping are also sources of organic matter to the soil (Srinivasarao et al., 2012**;** Vanlauwe et al., 2017; Hörner and Wollni, 2021). It is hypothesized that farmers will adopt these technologies in a package because of their favourable agronomic interactive effects (Sheahan and Barrett, 2014). In addition, farmers' decisions regarding adoption of agricultural technologies are interdependent and complementary (Kassie et al., 2018).

A farm household's decision to adopt the package of technologies, however, may be influenced by unobservable factors such as motivation, managerial abilities or expected output. This may cause them to self-select into adopting a particular ISFM technology from the package of technologies. A multinomial endogenous switching regression framework is used. It is an econometric model meant to address selection bias based on the multinomial logit choice (Bourguignon, 2007). The contextual justification of the empirical model estimated is provided in Section 5.5.

Again, in this chapter, food consumption and dietary diversity measures using recall data on foods eaten and their frequency were used to measure the dimensions of food security, following Upton et al. (2016) and Sahu et al. (2017). These include maize yield per hectare as proxy for measuring a household's food availability. Food access was measured using a household's consumption expenditure per adult equivalent. Total household expenditure per adult equivalent was used as an additional measure of food access. It also measures household welfare or overall wellbeing (Tiwari et al., 2013). It is also a consistent measure for household income as observed by Magrini and Vigani (2016). Food utilization was measured using household food consumption score (HFCS). HFCS is calculated as the number of different food groups consumed by the household in the last seven days before the interview, with each group given a weight representing the nutrient density of that food group (WFP, 2008; Tiwari et al., 2013). The seven food groups used in this chapter were the same as

in the previous chapter: “cereals”, “roots and tubers”, “pulses and legumes”, “dairy products, oils and fats”, “meat, fish, and eggs”, “fruits”, and “vegetables”. The availability of food stock at the time of the interview from the previous harvest was used to measure the stability dimension of food security, as in Magrini and Vigani (2016). Food in stock explains a household’s coping against food shortages in the future (Magrini and Vigani, 2016), as noted before. This measurement is important since the pre-occupation of smallholder farmers in Ghana is meeting their family’s food consumption requirements. Again, value of physical assets per adult equivalent was used as an additional measure of the stability dimension of food security. As households may deplete assets to survive during shocks, the expected positive contribution of adoption of ISFM practices to household assets should, therefore, be taken into account.

5.2.2 Theoretical Framework of ISFM Complementarity Adoption

Rural development strategies are driven by changes in farm technology, which should have a significant impact on farm household decision-making (Barnum and Squire, 1979). Though complementarity exists in the use of farm inputs since their joint use contribute to maize output (Kassie et al., 2015; Kassie et al., 2018), empirical analysis of the impact of technology or input use on food security overlooks complementarity and focuses on single effects (Martey et al., 2019; Adzawla et al., 2024). Employing the theoretical frame of Hicks (1970) partial elasticity of complementarity, we specify a production function following Sato and Koizumi (1973) and Lee (1982) as:

$y = f(x_1, \dots, x_n)$,

where y= $output$ and $x_i = factor\ inputs$. The Hicks partial elasticity of complementarity between factors x_i and x_j is defined as:

$$PEC = \frac{ff_{ij}}{f_i f_j},\ i = j \qquad (5.1)$$

where $f_{ij} = \frac{\partial^2 f}{\partial x_i x_j}$. Thus, the partial elasticity of complementarity measures the change in output from the joint contribution of two factor inputs, as the expression involves the cross partial derivative of the production function with respect to x_i and x_j. According to Sato and Koizumi (1973, p.50), if PEC is positive from the joint use of x_i and x_j, then x_i and x_j are complements. On the other hand, if PEC is negative from their joint use (x_i and x_j), then they are substitutes.

From equation (5.1), the determinants of PEC (two bordered Hessian) can be described as:

$$H = \begin{bmatrix} 0 & 1 & \dots & 1 \\ 1 & c_{11} & \dots & c_{1n} \\ 1 & c_{n1} & \dots & c_{nn} \end{bmatrix}$$

As the PEC has been used to classify inputs $(x_1, \dots, x_n)$ into complements and substitutes under a two-factor case, this sort of classification however does not hold in situations where the factor inputs are more than two, except for special types of functions such as Cobb-Douglas and Constant Elasticity of Substitution (CES) (Sato and Koizumi, 1973). Since a linear relationship exists between the partial elasticities of substitution and complementarity, and the market elasticity of derived demand (Hicks, 1970) as observed by Sato and Koizumi (1973, page 52), this monotone relationship can be generalized into a more than two-factor case using the Marshall-Hicks formular, by first defining the following elasticities:

elasticity of demand for the product= $\acute{\eta} = -\frac{dy}{dP} \cdot \frac{P}{y}$

elasticity of derived demand= $\lambda = -\frac{dx_1}{dP_1} \cdot \frac{P_1}{x_1}$

elasticity of supply of other factors $= ¥_i = \frac{dx_i}{dP_i}\frac{P_i}{x_i}$; $(2 \leq i \leq n)$.

After differentiation to obtain systems of $n = equations$ and employing the logarithmic differential of the cost and production functions, Sato and Koizumi (1973, page 54) proved that

$\frac{\partial \lambda}{\partial PEC_{ij}} < 0$ $(1 \leq i, j \leq n;\ \ i \neq j)$,

$\frac{\partial \lambda}{\partial \sigma_{ij}} > 0$ $(1 \leq i, j \leq n;\ \ i \neq j)$.

Thus, the elasticity of derived demand is negatively correlated to the partial elasticities of complementarity and positively correlated to the partial elasticities of substitution (σ_{ij}). This implies that the greater the degree of complementarity between any pair of inputs, the smaller will be the elasticity of derived demand. Conversely, the greater the degree of substitutability of any pair of inputs, the greater the elasticity of derived demand (Sato and Koizumi, 1973).

As it can be observed, the theoretical framework regarding the complementarity of factor inputs focuses on changes in output due to the joint contributions of inputs in a production function (Sato and Koizumi, 1973). However, the consumption behaviour of households must also be accounted for, in addition to the production function. The need for a model that takes into account the integration of production and consumption decisions is therefore imperative (Barnum and Squire, 1979). The

agricultural household model as discussed in Chapter 2 of the thesis is the suitable theoretical model that integrates the consumption and production sides of the farm household and it is applicable with the use of empirical farm households' data (Arthur and van Kooten, 1985). This can be operationalized using the MESR model framework. In our study, the integration of production and consumption decisions allows in the model, ISFM technologies, to determine maize output, food consumption expenditure, total expenditure, total and value of household assets as measurements for the dimensions of food security.

5.2.3 Multinomial Endogenous Switching Regression (MESR) Framework

Estimating the MESR requires a two-stage estimation procedure. For the first stage, a Multinomial logit (MNL) model is estimated. It accounts for unobserved individual heterogeneity and its estimation generates the inverse Mills ratio (Bourguignon, 2007; Biru et al., 2020). According to Dubin and Mcfadden (1984), using the MNL meets the Independence of irrelevant (IIA) assumption. Following Luce (1959), McFadden (1973) and Bourguignon et al. (2007), an outcome model and a household's adoption decision, respectively, can be specified as:

$$Y_i = \beta w_i + u_i$$

$$Y_{ik}^* = \phi_k X_i + \Psi_{ik}, \qquad \text{where } Y_{ik}^* = \begin{cases} 1 \;\; if\; Y_{ik}^* > 0 \\ 0 \;\; otherwise \end{cases} \qquad j = 1 \ldots M \qquad (5.2)$$

where u_i is the disturbance term and $E(u_i|w, X) = 0$ and $V(u_i|w, X) = \sigma^2$. The choice of a maize farm household among M options is described by the categorical variable j, which is dependent on Y_{ik}^*, a latent variable explaining the utility derived from adopting the ISFM technology choices K, X_i is the maximum set of control variables for all M, w_i refers to all the determinants of Y_i, and Ψ_{ik} is the error term.

From equation (5.2), It is assumed that a rational farm household i has an objective of maximizing the gains in attaining food security Y by comparing benefits derived from adopting m alternative combinations of the complementary technologies. The rational farm household will choose k over any alternative technology package m if the expected net gain is positive. This implies that $\Delta Y_{ik} = Y_{im} - Y_{ik} > 0,\ m \neq k$.

Following the assumption of Bourguignon et al. (2007), the model (equations 5.2) is non-parametrically identified from exclusion from some of the variables in X_i from the variables in w_i. If j is the package consisting of all the ISFM technology choices a farm household can adopt, then:

$$Y\begin{cases} 1\ if\ Y_{i1}^{*} > \max_{m \neq 1}(y_{im}^{*})\ or\ \eta_{i1} < 0 \\ \quad . \\ \quad . \\ \quad . \\ k\ if\ Y_{ik}^{*} > \max_{m \neq J}(y_{im}^{*})\ or\ \eta_{ik} < 0 \end{cases} \quad \text{for all } m \neq j \qquad (5.3)$$

Equation (5.3) explains that a maize farm household will adopt technology package k if and only if k gives the greatest expected utility than any other combination, $m \neq j$. Thus, if $\eta_{ik} = \max(y_{ik}^{*} - y_{im}^{*}) < 0$, (Bourguignon et al., 2007). However, the disturbance term Ψ_{ik} is not independent of all η_is.

Estimating ϕ_i will be problematic as this will introduce some correlation between the disturbance component and the explanatory variables in the outcome equation (Bourguignon et al., 2007). This is because adoption of ISFM may not be random and farmers may self-select and make adoption decisions based on information that is not known to the researcher. Then, when employing conventional econometric techniques (such as least-squares), this would impact both adoption and outcome equations, potentially leading to endogeneity bias and inconsistent parameter estimates linked to unobserved heterogeneity (Kassie et al., 2015). Using least squares will therefore give inconsistent estimates (Bourguignon et al., 2007; Di Falco et al., 2011; Kassie et al., 2015). To address this problem, the study employs selection-bias correction technique based on the multinomial logit model estimated using the *selmlog* Stata command (Bourguignon et al., 2007). It models farmers' choices of ISFM combinations and their effects on food security in a multinomial endogenous switching regression counterfactual framework. This strategy follows that of similar studies in the literature (Kassie et al., 2015; Kassie et al., 2018; Biru et al., 2020).

If the error term (Ψ_{ik}) in equation (5.2) is Gumbel distributed (thus, Independence of Irrelevant Alternatives (IIA) assumption), then the probability that an i^{th} maize farm household will adopt combination k can be specified by a multinomial logit model (McFadden, 1973) as follows:

$$P_{ik} = \Pr(\eta_{ik} < 0 / X_i) = \frac{\exp(X_i B_k)}{\sum_{m=1}^{k} \exp(X\ B_m)} \qquad (5.4)$$

The parameters of the latent variable are estimated using the maximum likelihood procedure and consistent estimates of ϕ_i can easily be obtained (Bourguignon et al., 2007). Bourguignon et al. (2007) demonstrated that, even in cases where the IIA hypothesis is violated, selection bias correction based on the multinomial logit model can still provide adequate correction for the outcome equation. Due to its simplicity, the multinomial logit specification is appealing when selection occurs across a

large number of exclusive alternatives, even if it requires parametric and testable independence assumptions. And in the presence of correlations between alternatives, the multinomial logit-based selection bias correction technique provides good performance (Bourguignon et al., 2007).

In the second stage, the outcome equation (i.e., pay-offs or gains in the dimensions of food security) is estimated for adopters and non-adopters of ISFM technologies separately taking into account the endogeneity of technology adoption decisions (Biru et al., 2020). Thus, the MESR framework models the relationship between the four dimensions of food security and a set of explanatory variables for both adopters and non-adopters of ISFM for each technology choice. From Table 5.1, the base category for the technology choice is represented by $K = 0$ for the non-adoption of ISFM technologies. The joint adoption of ISFM technologies are represented by $K = 1, \dots, n$ where at least one ISFM technology is adopted.

Table 5.1 Adoption of ISFM Technology Choices (%)

ISFM Combinations	F_0	F_1	S_0	S_1	O_0	O_1	2013 (%)	2017 (%)	Pooled sample (%)
$F_0S_0O_0$	✓		✓		✓		36	36	36.2
$F_1S_0O_0$		✓					31	31.1	30.8
$F_0S_1O_0$				✓			7	9	7.9
$F_oS_0O_1$						✓	11	6	9
$F_1S_1O_0$		✓		✓			8	12	9.3
$F_1S_0O_1$		✓				✓	3	2.4	2.6
$F_0S_1O_1$				✓		✓	3	2	2.7
$F_1S_1O_1$		✓		✓		✓	1	1.5	1.2

Note: F, S and O denotes mineral fertilizer, improved maize seed and organic fertilizer, respectively. Each of them is a binary variable: subscript "0" refers to non-adoption and "1" refers to adoption.

The adoption of the three ISFM technologies (improved seed, both mineral and organic fertilizers) and their combinations has eight possible set of choices, as indicated in Table 5.1, for each of the equation outcome.

The outcome equation for each possible regime is specified as:

$$\begin{cases} regime\ \ 0: & Y_{i0} = \beta_0 X_i + v_{i0}, & if\ j = 0 \\ & \vdots & \\ regime\ \ K: & Y_{ik} = \beta_k X_i + v_{ik}, & if\ \ j = 1, \dots, 7 \end{cases} \tag{5.5}$$

where $j = 0$ refers to no adoption for any of the individual ISFM practices or their combinations and $j = 1, \ldots, 7$ represents the adoption of the individual ISFM practices or their combinations as listed in Table 5.1, Y_{ik} and Y_{i0} are the impact of ith maize growing household's adoption or no adoption of ISFM practices, respectively, X_i 's are the vectors of exogenous variables, β 's are the parameters to be estimated, and υ_{i1} and υ_{ik} are random error terms. The distribution and variance of the error terms are $E(\upsilon_{i1} / Z, X) = 0$ and $(\upsilon_{ik} / Z, X) = \sigma^2$, respectively. Y_{ik} 's indicate the food security dimensions for the i^{th} farm household in regime k. The assumption here is that the outcome Y_{ik}, thus any of the food security dimensions, is identified if and only if ISFM combination K is adopted where $Y_{ik}^{*} > \max_{m\neq}(y_{im}^{*})$. If the error terms $(\upsilon_{i1}\ and\ \upsilon_{ik})$ are not independent, to obtain a consistent estimation of β_k necessitates the inclusion of the selection correction terms of the various choices of ISFM in the outcome equation (Bourguignon, 2007; Lu et al., 2021).

The Dubin and McFadden (1984) approach based on linearity assumption is specified as:

$$E(\delta_{ik} / \varepsilon_{i1} \ldots \varepsilon_{ik}) = \sigma_k \sum_{m\neq k}^{k} r_k (\varepsilon_{im} - E(\varepsilon_{im})) \tag{5.6}$$

There is zero correlation between the two error terms (δ and ε). If this is a valid hypothesis, then the multinomial endogenous switching regression can be stated as:

$$\begin{cases} regime\ 0: \quad Y_{i0} = \beta_0 X_i + \sigma_0 \lambda_0 + \varphi_{i0} \qquad if\ j = 0 \\ \\ regime\ K: \quad Y_{ik} = \beta_k X_i + \sigma_k \lambda_k + \varphi_{ik} \qquad if\ j = k \end{cases} \tag{5.7}$$

where σ_k represents the covariance between the error term of equation (5.2) and υ of equation (5.5); λ_k is the Inverse Mills Ratio (IMR) calculated from the multinomial logit equation (5.3). The IMR (λ_k) is given as:

$$\lambda_k = \sum_{m\neq}^{k} \rho_k \left[\frac{\hat{\rho}_{im} In(\hat{\rho}_{im)}}{1 - \hat{\rho}_{im}} + In(\hat{\rho}_{ik}) \right] \tag{5.8}$$

where ρ_k defines the correlation coefficient of the three error terms, Ψ, ε and φ. The error terms have expected zero value. In generating the regressor (λ_k) for the IMR, heteroscedasticity can occur.

Bootstrapped standard errors were obtained using 100 replications to account for the possibility of occurrence of heteroscedasticity, following Bourguignon (2007).

For the MESR model in equation (5.7) to be identified and to obtain robust estimates, the use of selection instruments is common in the literature (Di Falco et al., 2011; Biru et al., 2020; Kassie et al., 2018). These should include not only the variables that are automatically produced by the ISFM adoption selection model's nonlinearity, but also other variables that have a direct impact on ISFM but not the outcome variable (Di Falco et al., 2011). According to Di Falco et al. (2011), by performing a simple falsification test, the admissibility of these instruments is determined. If a variable is a valid instrument, it will influence the decision to adopt ISFM but will not affect the food security dimensions among farm households that did not adapt.

The following variables were included as instruments in the multinomial logit model (Eq. 5.4) for identification purposes and were excluded from the outcome equation (Eq. 5.7): distance to agriculture office and distance to market. The choice of these instruments follows Kassie et al. (2015) since true instruments are sometimes difficult to find. Their validity was checked using the simple falsification test, following Di Falco et al. (2011). It was confirmed that these instruments jointly affect adoption of ISFM practices ($X^2 = 1677.1, \rho = 0.000$) in the multinomial selection equation but do not affect the outcome (food security dimensions). In addition, as stated earlier, estimating the multinomial logit to account for unobserved individual heterogeneity generates the inverse Mills ratio. It was observed that in some of the outcome equations, the IMR and the instruments were significant. This indicates the presence of sample selection in technology choices (Kassie et al., 2018).

5.2.3.1 Estimation of the Treatment and Counterfactual Effects

Estimating the expected and counterfactual outcomes follows next, after the outcome equation ($Eqn.5.6$) has been estimated. This assesses the direct causal effect of adoption of ISFM on the dimensions of household food security (Khonji et al., 2018; Biru et al., 2020). Following (Teklewold et al., 2013; Khonji et al., 2018; Danso-Abbeam and Baiyegunhi, 2018; Lu et al., 2021), MESR framework is used to estimate the average treatment effects of the treated (ATET) (i.e., adopters) by comparing the expected values of the dimensions of food security of adopters and non-adopters of ISFM technologies under both actual and counterfactual situations as follows:

Actual adoption observed in the sample:

$$\begin{cases} E(Y_{i1}/j=1) = \beta_1 X_{i1} + 1\lambda_1 & 5.9a \\ \quad \vdots \quad \vdots & \\ E(Y_{ik}/j=k) = \beta_k X_{ik} + \sigma_k \lambda_k & 5.9b \end{cases}$$

Adopters had they decided not to adopt (counterfactual outcomes)

$$\begin{cases} E(Y_{i0}|j=1) = \beta_0 X_{i1} + \sigma_0 \lambda_1 & 5.10a \\ \quad \vdots \quad \vdots & \\ E(Y_{i0}|j=k) = \beta_0 X_{ik} + \sigma_0 \lambda_k & 5.10b \end{cases}$$

The unbiased estimates of the ATET is defined as the difference between equations 5.9a and 5.10a or equations 5.9b and 5.10b. For example,

$$ATET = E[Y_{i1}|j=1] - E[Y_{i0}|j=1] = \beta_i(X_1 - X_0) + \lambda_{i1}(\sigma_{11} - \sigma_{i0}) \qquad (5.11)$$

The first term on the right-hand side of equation (5.10) represents the expected change in adopters' average outcomes if their characteristics had equal pay-off as non-adopters. The second term λ_i is the selection term that captures all potential effects of the differences in unobserved variables. Since the interest of this study is estimating the average gain or impact of adoption of ISFM on food security dimensions, the results and discussions are based on the ATET estimates.

5.2.4 Description of Food Security Outcome and Explanatory Variables Used in the Study

The description of the variables used in the study are contained in Table 5.2 The choice of the variables is based on literature (Scheiterle and Birner, 2018; Bidzakin et al., 2023). For example, lack of or inadequate infrastructure and poor access to credit have been found to constraint the adoption of mineral fertilizers (Scheiterle and Birner, 2018). Access to extension services influences adoption of mineral fertilizers (Emmanuel et al., 2016). Adoption of organic fertilizer was shown to be primarily influenced by participation in farmer-based organizations, availability of organic fertilizer, access to extension services, and cost of transportation in Ghana (Bidzakin et al., 2023). Kassie et al. (2015b) found household socio-economic characteristics such as gender and number of years of education of head of household, farm size and tropical livestock units to influence multiple technology adoption.

The use of mineral fertilizer has been found to increase yield (Emmanuel et al., 2016; Martey et al., 2019), farm income (Martey et al., 2019). For example, adoption of mineral fertilizers has been found to increase agricultural income by 30% and yield by 55%, respectively among rice producers in

Table 5.2 Description of Food Security Outcome and Explanatory Variables

Variable	Description
Food security outcome variables:	
Availability dimension	Yield is used as a proxy for the availability dimension, measured as maize output in Kg per hectare
Food access dimension	Consumption expenditure on food and beverages per adult equivalent in Ghana Cedis (GHS) over a 12-month period
Food access and household welfare	Total expenditure per adult equivalent on food and non-food items in GHS over a 12-month period
Food utilization	Composite household food consumption score (HFCS) from specific food groups and their weights in the last seven days before the interview
Food stability	Food stock in terms of maize stored from the last harvest at the time of interview (Kg)
Food stability	The total value of household assets per adult equivalent (in Ghana Cedis)
Explanatory variables	
Sex	1 if head is a male; 0 otherwise
Farm_Size	Size of land allocated to maize (in hectares)
Agri_Equipment	Value of agricultural equipment in working condition (GHS)
Adult_ES	Adult Equivalent Scale
TLUs	Tropical Livestock Units
Education	Number of years spent in formal schooling by household head
Non-farm_Enterprise	1 if head of household engages in non-farm enterprise; 0 otherwise
Marital_Status	1 if head of household is married; 0 otherwise
Ecological_Zone	1 if household is in the southern agro-ecological zone; 0 otherwise
Aid_Scheme	1 if mutual aid schemes found in the community; 0 otherwise
Extension	1 if agricultural extension officers visit farm households; 0 otherwise
Land_Ownership	1 if any household member owns farm land; 0 otherwise
Market	Distance to the nearest big market (Km)
Agri_Office	Distance to the nearest agriculture office (Km)

northern Ghana (Martey et al., 2019). Adoption of organic fertilizer has been found to significantly increase maize yield in northern Ghana by 57%, income by 53%, and gross margins by 63% (Bidzakin et al., 2023). These notwithstanding, Poor soil fertility and low crop yield persist in SSA (Chianu et

al., 2012). One potential technology that can lessen soil infertility is the introduction of integrated soil fertility management (ISFM) practices. Results from two on-farm experiments carried out in the semideciduous forest and coastal savannah agroecological zones of Ghana demonstrated that applying mineral fertilizer alone or in combination with goat manure increased grain yield significantly (Marfo-Ahenkora et al., 2023). A combination of NPK and chicken manure gave superior grain yield of maize from field trials across the transitional and Guinea savanna agro-ecologies of Ghana (Essilfie et al., 2024).

Kassie et al. (2015b) used maize productivity as a proxy for measuring food security since the production of basic staples at the household level plays a critical role in determining food availability and access. Subsequently, this study uses maize output as a proxy for measuring the availability dimension. However, limited empirical studies exist on the combined effects of ISFM not only on yield or farm income, other dimensions of food security and welfare. A study on the impact of ISFM is important as access to information on technology choices is one of the factors that impede adoption (Scheiterle and Birner, 2018).

5.2.5 Study Area and Data

The study uses the same nationally pooled cross-section data from the Ghana Living Standard Survey (GLSS) for survey rounds six and seven as employed in the previous chapters. In this study, the data refers to only farmers growing maize. The GLSS7 is the newest round undertaken between 2016 and 2017. The GLSS6 data was collected between 2012 and 2013. For this study, the pooled sample size for only maize-growing households for GLSS6 and GLSS7 was 10,166. Thus, 5,771 maize growing households for GLSS 6 and 4,395 maize growing households for GLSS 7. The GLSS data are a set of repeated cross-section surveys. The reason for using pooled cross-section data is that statistical reliability of results and accuracy of estimated parameters are achieved with pooled data compared to a single cross-sectional data (Zieman et al., 2002; Gerdtham et al., 1998). In addition, there is low level of adoption of multiple technologies among maize growing households across the survey years. Pooling the data increases the sample size. The Ghana Statistical Service collects the GLSS data with technical assistance from the World Bank. The information covers demographic characteristics, household agricultural production, asset ownership, access to financial services, education and housing conditions, among others. Households are the unit of analysis of GLSS data, as mentioned earlier.

5.3 Results

5.3.1 Descriptive Statistics

The definition of food security outcomes and ISFM technology choices with their respective descriptive statistics are shown in Table 5.1. The complementary adoption of ISFM technologies leads to eight (2^3) combinations of agricultural practices (Table 5.1), from which maize growing households can make adoption choices. From the pooled sample of 10,166 maize growing households, about 36% did not adopt any of the ISFM technologies (Table 5.1). For the adoption of any single component of ISFM technologies, about 31% of farm households adopted mineral fertilizer, about 8% adopted improved seed and 9% adopted organic fertilizer. Regarding the complementarity of adoption of ISFM technologies, about 9% of farm households adopted both mineral fertilizer and improved seed, about 3% adopted both mineral and organic fertilizers and about 3% adopted both improved seed and organic fertilizer. From Table 5.1, only 1.20% of farm households adopted mineral fertilizer, improved seed and organic fertilizer combined (jointly). Regarding the descriptive analysis of the measurements of food security dimensions as indicated in Table 5.3, maize yield was lower in 2017 (1000.8 Kg/ha) than in 2013 (1932.3 Kg/ha) from the sample. However, mean total maize grain stock marginally increased from 318 Kg in 2013 to 362.63 Kg in 2017. The average value of household assets per adult equivalent also increased from GHS15.00[1] (US$3.00) in 2013 to GHS35.00 (US$7.00) in 2017. Total household expenditure per adult equivalent, on average, was GHS2150.00 (US$434.34) in the pooled sample whereas household food expenditure per adult equivalent was GHS1260.00 (US$254.54). On average, there were marginal increases in total household expenditure and household food expenditure from 2013 to 2017, as shown in Table 5.3. However, food consumption score was lower in 2017 compared to 2013. It should be noted that other factors other than adoption of ISFM technologies might have accounted for the variations in these outcome variables. Hence the need to employ the endogenous method to establish causal effects. Descriptive statistics of the explanatory variables employed in the analysis are also presented in Table 5.3. Most of the heads of maize growing households were male (81%). Average farm size was 1.072Ha for the full sample.

Table 5.3: **Descriptive Statistics of Explanatory Variables Used in the Empirical Analysis**

Variable	2013		2017		Pooled sample	
	Mean	**Std. Dev.**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**
Food security Outcome variables:						
Availability dimension	1932.3	101.63	1000.8	173.74	1530.2	775.96
Food access dimension	1205.7	121.16	1331.7	125.93	1260.0	123.4
Food access and household welfare	2000.4	190.86	2347	227.6	2150	208.2
Food utilization	56.6	19.01	46.2	16.6	52.1	18.8
Food stability	318	142.45	363	123.5	377	134.6
Food stability	15	6.66	35	19.71	23.5	13.92
Explanatory variables						
Sex	0.824	0.381	0.813	0.39	0.819	0.385
Farm_Size	1.096	1.432	1.04	1.948	1.072	1.675
Agri_Equipment	178.522	2150.28	290.279	3952.14	226.766	3061.44
Adult_ES	3.987	2.279	4.21	2.453	4.083	2.358
TLUs	1.838	4.79	1.287	4.88	1.6	4.84
Education	7.879	0.629	4.088	0.872	5.616	4.789
Non-farm_Enterprise	0.335	0.072	0.32	0.066	0.328	0.47
Marital_Status	0.717	0.45	0.794	0.405	0.75	0.433
Ecological_Zone	0.422	0.049	0.361	0.048	0.396	0.49
Aid_Scheme	0.555	0.497	0.577	0.494	0.565	0.496
Extension	0.977	0.151	0.588	0.492	0.809	0.393
Land_Ownership	0.67	0.47	0.755	0.43	0.707	0.455
Market	13.029	0.210	8.503	0.242	11.075	5.789
Agri_Office	13.179	3.158	17.385	14.118	14.995	9.799

[1]**Notes**: GHS4.95 is to US$1.00, using the Bank of Ghana Inter Bank Exchange Rate – End period for January 2019 (Bank of Ghana, 2023).

Source: Authors' calculations using GLSS 6 and 7 data

5.3.2 Factors Influencing Adoption of ISFM Technologies

Results from the multinomial logit regression estimates explaining the factors that determined adoption of ISFM are presented in Table 5.3. The base category is non-adoption of ISFM technologies ($F_0S_0O_0$), as noted earlier. The value of the Wald test [$X^2(98) = 1487.42;\ \rho = 0.000$] shows that the coefficient of the covariates is significantly different from zero. Hence, the model has strong explanatory power and fits the data well. For the sake of brevity, we report only on factors that have significant effects on the joint or complete adoption of ISFM choices. From the results, male-headed households were willing to adopt mineral fertilizer and improved seed ($F_1S_1O_0$) jointly. The value of agricultural equipment showed a positive correlation with joint adoption of all the ISFM technology choices. Adult equivalent scale, as proxy for provision of household labour, was found to raise the probability of joint adoption of mineral fertilizer and improved seed ($F_1S_1O_0$), and the complete ISFM technologies ($F_1S_1O_1$). As noted earlier, organic fertilizers in this study refer to green and animal manure. Unlike compost whose preparation requires special skills, such skills are not required in the case of green and animal manure, hence can easily be adopted by smallholder farmers. The results also show a positive relationship between tropical livestock units and joint adoption of mineral and organic fertilizers ($F_1S_0O_1$).

The number of years a household head spent in school raises the likelihood of adoption of all the ISFM technology choices. Engaging in off-farm work by the head of a household positively affects the joint adoption of mineral fertilizer and improved seed ($F_1S_1O_0$), mineral and organic fertilizers ($F_1S_0O_1$) and the complementary ISFM technologies ($F_1S_1O_1$). Land size under cultivation positively and significantly affects the probability of adopting mineral and organic fertilizers jointly ($F_1S_0O_1$). Regarding the agro-ecological zone, the probability of adopting mineral fertilizer and improved seed ($F_1S_1O_0$), mineral and organic fertilizers ($F_1S_0O_1$) as well as the complete ISFM technologies ($F_1S_1O_1$) is higher in the northern agro-ecological zone relative to the southern zone. Joint adoption of mineral fertilizer and improved seed ($F_1S_1O_0$), improved seed and organic fertilizer ($F_0S_1O_1$) as well as the complete package of ISFM technologies ($F_1S_1O_1$) is positively related with the presence of mutual aid schemes in a community. Access to extension increases the probability of adopting jointly mineral and organic fertilizers ($F_1S_0O_1$), as well as improved seed and organic fertilizer ($F_0S_1O_1$). Farm households that own farmland under cultivation are more likely to adopt all the single and joint ISFM choices but less likely to adopt jointly

Table 5.4: Multinomial Logit Estimates of Factors Influencing Adoption of ISFM Technologies

Variables	$F_1S_0O_0$		$F_0S_1O_0$		$F_0S_0O_1$		$F_1S_1O_0$		$F_1S_0O_1$		$F_0S_1O_1$		$F_1S_1O_1$	
	ME	**SE**	**ME**	**SE**	**ME**	**SE**	**ME**	**SE**	**ME**	**SE**	**ME**	**SE**	**ME**	**SE**
Sex	0.239**	(0.098)	-0.093	(0.128)	0.426***	(0.163)	0.288***	(0.148)	0.266	(0.301)	0.088	(0.227)	0.557	(0.431)
Agri_ equipment (log)	0.123***	(0.015)	0.129***	(0.021)	0.135***	(0.023)	0.177***	(0.022)	0.173***	(0.036)	0.233	(0.035)	0.251***	(0.046)
Adult_ES	0.056***	(0.016)	0.036	(0.023)	0.018	(0.023)	0.051***	(0.021)	0.053	(0.034)	0.028	(0.035)	0.095**	(0.044)
TLUs	0.007	(0.01)	-0.004	(0.019)	0.001	(0.015)	0.009	(0.013)	0.027*	(0.014)	0.008	(0.019)	0.02	(0.016)
Education	0.031***	(0.008)	0.02*	(0.011)	0.014	(0.012)	0.022**	(0.011)	0.036*	(0.019)	0.048**	(0.019)	0.053**	(0.022)
Non-farm_Enterprise	-0.037	(0.068)	0.135	(0.094)	0.004	(0.007)	0.205**	(0.092)	0.281*	(0.167)	-0.107	(0.157)	0.606***	(0.22)
Farm_size	0.11***	(0.03)	0.002	(0.049)	0.124***	(0.032)	-0.051	(0.044)	0.107***	(0.039)	0.069	(0.08)	0.049	(0.062)
Marital_status	0.083	(0.089)	-0.121	(0.118)	0.176	(0.131)	0.023	(0.131)	-0.389	(0.255)	-0.028	(0.189)	-0.212	(0.32)
Ecological_Zone	-0.54***	(0.089)	0.006	(0.113)	-0.838***	(0.119)	-0.129***	(0.115)	-0.73***	(0.233)	0.232	(0.193)	-0.897***	(0.293)
Aid_Scheme	0.134	(0.083)	-0.005	(0.101)	0.462***	(0.118)	0.394***	(0.115)	0.455**	(0.205)	0.336**	(0.165)	0.389***	(0.307)
Extension	-0.041	(0.015)	0.005	(0.135)	0.593***	(0.16)	-0.113	(0.121)	0.919**	(0.278)	0.967**	(0.261)	0.143	(0.29)
Land_ownership	0.195***	(0.012)	0.279***	(0.097)	0.445***	(0.113)	0.545***	(0.108)	-0.97**	(0.192)	0.38**	(0.168)	0.686**	(0.312)
Year_2017	-0.28***	(0.017)	0.086	(0.127)	-0.089***	(0.139)	0.065	(0.12)	-0.509**	(0.215)	-0.487***	(0.202)	-0.407	(0.315)
Total_asset	-0.023	(0.017)	0.006	(0.023)	0.03	(0.025)	0.002	(0.023)	0.001	(0.044)	0.043	(0.039)	0.076	(0.055)
Market	-0.056***	(0.007)	-0.007	(0.008)	-0.066***	(0.011)	-0.022***	(0.008)	-0.083***	(0.016)	-0.029*	(0.015)	-0.079***	(0.022)
Agri_office	0.005	(0.003)	-0.014***	(0.004)	0.027***	(0.005)	-0.029***	(0.005)	0.007	(0.008)	-0.005	(0.008)	0.037**	(0.016)

Note: ME and SE denote marginal effects and standard errors, respectively. ***, ** and * denote statistical significance at levels of 1%, 5% and 10%, respectively.

Source: Authors' calculations using GLSS 6 and 7 data.

mineral and organic fertilizers ($F_1S_0O_1$). The year dummy negatively influenced the joint adoption of improved seed and organic fertilizer ($F_0S_1O_1$). However, the year dummy influenced positively the joint adoption of mineral fertilizer and improved seed ($F_1S_1O_0$). Distance to market significantly lowers the probability of joint adoption of almost all the ISFM choices, as can be observed from Table 5.4. This can be explained by the fact that increased transaction cost reduces farmers' incentives to produce more marketable surplus as the profit margin would be lower. The likelihood of adopting mineral fertilizer and improved seed ($F_1S_1O_0$) reduces with distance to agriculture office. On the other hand, the propensity to adopt the complete ISFM package ($F_1S_1O_1$) increases with increasing distance to the agriculture office.

5.3.3 Impacts of Adopting ISFM Technologies on Food Security

The multinomial endogenous switching regression (MESR) based causal effects of ISFM technologies on dimensions of food security are presented in Table 5.5. From the unconditional average effect results, adoption of all the combinations of ISFM technologies considered in the study have positive and significant effect on all the food security dimensions. Regarding the availability dimension, the lowest gain is achieved from the adoption of only improved seeds ($F_0S_1O_0$) (237Kg/Ha) as presented in column 2 of Table 5.5. Joint adoption of all the ISFM technologies: mineral fertilizer, improved seed and organic fertilizer ($F_1S_1O_1$) produces for the farm households the highest food availability. Thus, maize yield gain of 2500Kg/Ha. These findings are consistent with those of Kassie et al. (2018), Khonje et al. (2018) and Asante et al. (2024) who found increased maize yield by smallholder farmers due to the joint adoption of multiple ISFM technologies more than the adoption of any single technology. For example, Kassie et al. (2018) found the combined effect of improved maize seeds, mineral fertilizer and legume diversification to have significantly increased maize yield by 1,755.05Kg/ha in Ethiopia. This is however below the finding of 1545.92Kg/ha from the ATET as shown in Table 5.5. Asante et al. (2024) found that adopting all three conservation agricultural technologies together (zero tillage, row planting, and drought-resistant seed) has the largest impact on maize yield in Ghana. These findings explain the importance of the complementarity of ISFM technologies in meeting household food security, in terms of the availability dimension.

The unconditional average effects of combinations of ISFM technologies on food access are presented in column 3 of Table 5.5. Joint adoption of mineral fertilizer, improved seed and organic fertilizer ($F_1S_1O_1$) contributed the highest impact on a household's access to food, by GHS2084.43 (US$493.00), followed by joint adoption of mineral and organic fertilizers ($F_1S_0O_1$). The access

dimension of a household's food security is evaluated further using total household expenditure, as contained in Column 4 of Table 5.5. Again, the complete adoption of ISFM contributed the highest gain on household access to food. Column 5 of Table 5.5 shows the unconditional average effects of the combinations of ISFM technologies on household food utilization. Joint adoption of mineral and organic fertilizers ($F_1S_0O_1$) results in the highest gain in improving household food utilization more than that of joint adoption of the complete package of ISFM practices. This is against *a priori expectation* possibly because the unconditional average effects do not account for 'hidden' biases. Household food utilization gains for the joint adoption of $F_1S_0O_1$ and complete ISFM practices were 20.00 and 19.30 consumption scores, respectively. Column 6 of Table 5.4 shows the unconditional average effects of the joint adoption of ISFM technologies on the stability dimension of food security. Again, joint adoption of mineral fertilizer, improved seed and organic fertilizer ($F_1S_1O_1$) contributed the highest food stability improvement of 917Kg. The stability dimension is evaluated further using value of physical assets as contained in Column 7. The result indicates that households that adopted mineral and organic fertilizers jointly ($F_1S_0O_1$) had the highest pay-off on food stability by GHS240.00 (US$48.48), on average. This was followed by the complete adoption of ISFM ($F_1S_1O_1$) with a gain of GHS93.90 (US$19.00).

The above results from unconditional average effects did not account for both observed and unobserved factors in farm households' decision to adopt ISFM technologies. Such results may be misleading because of selection bias from observed and unobserved factors (Lu, et al., 2021; Khonji et al., 2018). Subsequently, the findings of the average treatment effect on the treated (ATET), our benchmark estimator, are presented below the unconditional average effects of Table 5.4. Similarly, it can be observed that the adoption of all the ISFM choices positively and significantly affect all the dimensions of food security. Joint adoption of mineral fertilizer, improved seed, and organic fertilizer ($F_1S_1O_1$) still gives the highest gain in all the dimensions of food security, except the stability dimension when it was measured in household value of physical assets. From Column 5 of Table 5.4, it is observed that when both observed and unobserved factors are accounted for, complete adoption of ISFM contributed the highest household food utilization score unlike joint adoption of mineral and organic fertilizers under the unconditional effects.

Table 5. 5: Multinomial Endogenous Switching Regression (MESR) based Average Treatment Effects explaining the Impacts of Adoption of ISFM Technologies on the Dimensions of Food Security

Unconditional average effects	Food availability dimension (maize yield /kg) (2)	Food access dimension (consumption expenditure/ AES in GHS[1]) (3)	Food access and household welfare (total expenditure/ AES in GHS) (4)	Food utilization dimension (HFCS) (5)	Stability dimension (Food stock in Kg) (6)	Stability dimension (Total household assets in GHS/ AES) (7)
$F_1S_0O_0$	332.57*** (4.50)	578.31*** (7.18)	738.09*** (9.54)	10.16*** (0.16)	18.95*** (0.77)	1.807*** (0.091)
$F_0S_1O_0$	237.45*** (4.07)	687.35*** (11.02)	506.50*** (19.60)	4.47*** (0.22)	35.37*** (2.55)	2.914*** (0.263)
$F_0S_0O_1$	252.21*** (4.90)	595.86*** (11.40)	589.63*** (13.79)	7.32*** (0.17)	112.12*** (5.90)	3.40*** (0.43)
$F_1S_1O_0$	394.85*** (9.40)	843.99*** (11.45)	1244.10*** (18.32)	13.00*** (0.20)	78.61*** (3.84)	3.37*** (0.10)
$F_1S_0O_1$	589.49*** (16.55)	1117.00*** (22.10)	2917.34*** (58.67)	20.00*** (0.28)	137.68*** (25.29)	240.73*** (7.79)
$F_0S_1O_1$	847*** (20.7)	846.94*** (11.64)	1264.50*** (21.21)	12.33*** (0.17)	305.24*** (28.27)	41.37*** (1.40)
$F_1S_1O_1$	2500*** (22.2)	2084.43*** (60.21)	6192.60*** (309.54)	19.30*** (0.47)	917*** (71.64)	93.90*** (5.34)
Average treatment effects on the treated (ATET)						
$F_1S_0O_0$	241.30*** (5.55)	307.89*** (7.81)	579.72*** (10.79)	6.16*** (0.18)	10.12*** (0.43)	0.79*** (0.35)
$F_0S_1O_0$	221.07*** (8.54)	690.44*** (22.73)	593.84*** (44.61)	3.53*** (0.43)	51.92*** (10.46)	1.47*** (0.46)
$F_0S_0O_1$	306.40*** (18.03)	401.37*** (21.93)	559.94*** (28.98)	6.34*** (0.40)	13.41*** (10.23)	7.40*** (1.79)
$F_1S_1O_0$	302.31*** (20.01)	486.53*** (20.29)	967.61*** (37.46)	10.80*** (0.33)	16.20*** (56.52)	2.40*** (1.82)
$F_1S_0O_1$	488.77*** (69.03)	887.15*** (52.09)	1699.55*** (144.52)	16.24*** (0.87)	387.75*** (144.90)	131.11*** (34.51)
$F_0S_1O_1$	600.17*** (76.84)	823.45*** (32.05)	1295.37*** (73.12)	13.45*** (0.53)	342.39*** (461.95)	49.00*** (4.81)
$F_1S_1O_1$	1545.92*** (80.23)	1551.90*** (174.91)	3576.07*** (266.89)	28.41*** (2.40)	784.19*** (128.26)	51.33*** (6.69)

Note: ***, ** and * denote statistical significance at levels of 1%, 5% and 10%, respectively. Standard errors are in brackets.

$F_0S_0O_0$ is the base category (i.e., non-adoption of ISFM technologies). AES: Adult Equivalent Scale. [1]GHS4.95 is to US$1.00, using the Bank of Ghana Inter Bank Exchange Rate – End period for January 2019 (Bank of Ghana, 2023)

Source: Authors' calculations using GLSS 6 and 7 data

5.3.4 Discussion

Discussion of the results is based on the descriptive statistics, factors explaining adoption of ISFM practices as well as the impacts of adoption of ISFM practices on the dimensions of household food security. The plot level descriptive analysis shows a very low adoption of complementary technologies among maize growing households in Ghana. This finding supports that of Sheahan and Barrett (2014) and Suri and Udry (2022) that there is limited or no complementarity in modern input utilization at the plot level. The multinomial logit model estimates both the coefficients and marginal effects of factors explaining adoption of ISFM technologies (Nguyen-Van et al., 2017; Khonji et al., 2018). The discussion is, however, based only on the marginal effects (Table 5.4) since it is more convenient to interpret them (Nguyen-Van et al., 2017). From the results in Table 5.4, the marginal effects significantly differ across ISFM technology choices. Household socioeconomic, institutional and community factors do have significant effects on the probability of adoption of single and combination of ISFM technologies.

The finding that male-headed households were more willing to adopt ISFM technologies compared to female-headed households highlights the gap in gender roles in technology adoption between men and women where participation of the latter is limited. This finding is consistent with that of Wekesah (2019) who found low adoption of soil conservation practices among women relative to men farmers. The finding that the value of agricultural equipment raises significantly the probability of adopting most of the ISFM choices reinforces the importance of agricultural mechanization in modernizing Ghana's agriculture (Kansanga, 2017; Mohammed et al., 2023). Agricultural mechanization will remove human drudgery currently associated with agriculture as this is evidenced in the study by the significant and positive relationship between adult equivalent scale and combined adoption of mineral fertilizers and improved seed as well the complete ISFM technologies. The probability of adopting mineral and organic fertilizers increases with increasing number of livestock units per household since farmers can sell their livestock to purchase mineral fertilizer and other farm inputs. Farmers also use droppings from livestock as organic fertilizers to complement mineral fertilizers. Education is an important determinant of adoption of ISFM choices in the study. This finding implies that farmers with better education are more likely to understand the benefits associated with adoption of improved technologies such as ISFM (Khonji et al., 2018; Erekalo and Yadda 2023).

The finding that engaging in off-farm work by the head of a household increases the probability of adopting combined ISFM technologies meets *a priori expectation,* particularly when mineral fertilizers and improved seed are costly in Ghana and government had to subsidize for farmers. Income from off-farm work plays the role of credit thereby increasing the adoption of ISFM

technologies. This finding supports that of Maré et al. (2022) that improved access to credit increases the adoption of sustainable agricultural practices. From Table 5.3, the adoption of complementary ISFM technologies ($F_1S_1O_0;\ F_1S_0O_1;\ F_1S_1O_1$) in the north is possibly due to the rapidly declining soil fertility in northern parts of Ghana and the understanding that complementary technologies may give higher returns than adopting single technologies. This finding is consistent with that of Darfour and Rosentrater (2016) that farmers in the north combine both organic and mineral fertilizers at the plot level. Community mutual aid schemes, as proxies for access to credit, promote technology adoption (Martey and Kuwornu, 2021; Erekalo and Yadda 2023). Presence of community mutual aid schemes raises the probability of adopting complementary ISFM choices. The significant and positive relationship between community mutual aid schemes and the adoption of the combined as well as the complete ISFM package means that access to credit is critical to multiple technology adoption among smallholder farmers in Ghana.

There is also evidence of positive and significant relationship between access to extension and single/joint adoption of some of the ISFM technologies ($F_0S_0O_1;\ F_1S_0O_1;\ F_0S_1O_1$) in the study. Access to agricultural extension is endogenous to the adoption of proven technologies such as ISFM practices (Oyetunde-Usman et al., 2021). The finding also highlights that the sustained effort of agricultural extension in promoting organic fertilizers in Ghana is paying-off. Tenure security is often cited in the literature as having positive effect on the adoption of sustainable land management practices (Agula et al., 2018). This is confirmed in the study by the significant and positive correlation between land ownership and ISFM technology choices. However, the negative effect of land ownership on the joint adoption of mineral and organic fertilizers ($F_1S_0O_1$) may imply an increased understanding among non-farmland owners that the productivity of mineral fertilizers is enhanced when complemented with organic fertilizers. They may, therefore, want to optimize productivity quickly through this combination. In this study, the significant and positive influence of the year dummy on adoption of improved seed ($F_0S_1O_0$) and the joint adoption of mineral fertilizer and improved seed ($F_1S_1O_0$) could be explained by renewed efforts by the government in 2017 in promoting the complementary adoption of both mineral fertilizer and improved seed through input subsidies (MoFA, 2017).

Regarding the impacts of adopting ISFM technologies on food security dimensions, in general, the ATET outcomes are smaller than the unconditional average effects given in Table 5.5. This observation regarding lower magnitudes of ATET compared to that of the unconditional average effects is consistent with that of Lu et al. (2021). Across the technology choices, households who adopted ISFM technologies would have obtained lower benefits in achieving food security had they

not adopted. It can also be observed (Table 5.5) that the adoption of a combination of any two ISFM technologies, for example, improved seed and organic fertilizer ($F_0S_1O_1$) or inorganic fertilizer and improved seed ($F_1S_1O_0$), increases a household's food availability than the adoption of any single ISFM technology. This finding reinforces the need to promote ISFM technologies as a package to farmers, since better outcomes are achieved from joint ISFM adoption.

From the average treatment effects results in Table 5.5, it should be observed that adoption of only organic fertilizer ($F_0S_0O_1$) results in a lower gain in the availability dimension of food security (252.21Kg/Ha of maize yield) compared to the single adoption of mineral fertilizer (332.57Kg/Ha). This is because mineral fertilizers are used up quickly in the soil by the plant roots compared to organic fertilizers. The highest gain in food availability (2500Kg/Ha) is achieved in the complete adoption of ISFM technologies ($F_1S_1O_1$). This finding begs the question of why policy makers and extension staff promote the use of improved seeds and mineral fertilizers under declining soil fertility conditions without the complementarity of organic fertilizers. Though declining soil fertility has rather contributed to increased use of mineral fertilizers in sub-Sahara Africa through fertilizer subsidy programs (Martey et al., 2019), there has been relatively less policy consideration and farm household plot level decisions on the complementing role of organic fertilizers in improving soil fertility and land productivity. This is despite the fact that the use of mineral fertilizers is associated with low efficiency and low economic viability in some parts of Ghana (Adzawla et al., 2024). The finding highlights the important role of sustainable soil fertility management practices (such as the use of organic fertilizers) in improving land productivity, as well as achieving food availability. The findings on the highest gains in the other dimensions of food security due to complete adoption of ISFM choices in terms of food access, food utilization and stability call for the promotion and adoption of ISFM as a complete package. The findings on the positive role of ISFM are similar to other studies that have analyzed the impacts of multiple technology adoption on welfare outcomes such as maize yield (Khonji et al., 2018; Kassie et al., 2018), consumption expenditure (Lu et al. 2021; Biru et al., 2020) and food consumption and dietary diversity scores (Bedeke, 2023). The positive relationship between food availability and the other dimensions of food security may imply that income from sale of surplus due to increased food availability is spent on increasing food access (household food consumption), for example. However, this relationship becomes complex when it comes to the utilization and stability dimensions proxied by HFCS and household's assets value, respectively. Though there is a positive relationship, the gain on utilization due to complete adoption of ISFM (a score of 28) is still below the typical threshold of an acceptable food consumption score of thirty five (35) and above, according to the WFP (2008) standardized description of dietary habits. This finding is contrary to that of Teklu et a. (2024) who found higher consumption scores of 42.2

and 38.4 of adopters of sustainable practices such as crop residue management and compost, respectively, in Ethiopia. Household food consumption score of 28 can be described as being within the borderline food consumption. The borderline food consumption is between 21.5 and 35. Between 0-21 is considered poor food consumption habit (WFP 2008). Moreover, a gain in a household's food stability (thus, a household's assets value of GHS51.33 or $11.6 due to adoption of the complete ISFM package was only 0.678% of per capita GDP in 2013, using constant 2015 U.S. dollars (World Bank, 2023). Contrary to *a priori* expectation, the joint adoption of mineral and organic fertilizers ($F_1S_0O_1$) achieves the highest pay-off on the stability dimension of food security upon further evaluation using the value of household physical assets (GHS131.11 or $30.00) than the adoption of the ISFM complete package ($F_1S_1O_1$). This may explain the need to jointly promote the use of mineral fertilizers with organic fertilizers. On the other hand, the use of recycled maize seed is still common among farmers in Ghana and improved maize seeds are sometimes stored under poor conditions. Complete adoption of the ISFM package also results in the highest gain in terms of household income or the general welfare of a household measured by total household consumption.

5.4 Summary

This chapter examined the impacts of the complementarity of Integrated Soil Fertility Management (ISFM) technologies on multiple dimensions of food security. Specific food security dimensions assessed were food availability measured by maize yield/ Ha, access to food by a household measured by both household food consumption expenditure and total household expenditure, household food utilization measured by household food consumption score, as well as food stability measured by both household food stock, and value of household physical assets. The ISFM technologies were both mineral and organic fertilizers and improved seed. The plot level descriptive analysis showed a very low adoption of complementary technologies among maize growing households in Ghana. About 9% of farm households adopted both mineral fertilizer and improved seed, about 3% adopted both mineral and organic fertilizers and about 3% adopted both improved seed and organic fertilizer. Only 1.20% of farm households adopted mineral fertilizer, improved seed and organic fertilizer jointly. The multinomial logit results showed that both household characteristics and institutional factors determined the joint adoption of ISFM technologies. The household characteristics were gender, value of agricultural equipment, adult equivalent, number of years a household spent in school, land ownership and household head engagement in off-farm work. The institutional factors were presence of a mutual aid scheme, access to extension visits and distance to agriculture office. The implication is that increasing the adoption of ISFM practices will require improvements in these households' characteristics and institutional factors as they are a function of adoption. In addition, this finding highlights the fact that promoting multiple technology adoption such as ISFM goes beyond field

experiments showcasing their benefits as that has always been the practice. Such practices have led to the low adoption of ISFM as evidenced in this chapter. Distance to market, however, was found to reduce the likelihood of farmers adopting ISFM technologies jointly. Thus, improved access to market through better road network and other infrastructure as well as better market returns for farm produce will increase adoption of ISFM technologies among smallholder farmers.

The average treatment effect (ATET) assessed the impact of adoption of ISFM on the dimensions of food security. The results showed that all the ISFM choices positively and significantly influenced all the dimensions of food security. As there is growing advocacy for the use of mineral fertilizers in SSA due to fertilizer subsidy programs, it was however found in this chapter that when the use of mineral fertilizers was complemented with organic fertilizers, households achieved higher payoffs in all the dimensions of food security than the adoption of only mineral fertilizers or improved seed. This finding underscores the critical role of soil fertility improvement in meeting household food security. Complete adoption of ISFM gave the highest gain in all the dimensions of food security, except the stability dimension when the value of household physical assets was used as the means of measurement. Under this circumstance, joint adoption of mineral and organic fertilizers resulted in the highest improvement in household food stability. Across the technology choices, households who adopted ISFM technologies would have obtained lower benefits in achieving food security had they not adopted.

The implication of this study is that it extends the findings on the importance of ISFM practices such as organic fertilizers in improving soil fertility and increasing soil organic carbon sequestration from field experiments to the impact of adoption of ISFM practices on household food security using a nationally representative survey data. The implementing agency has to exert the maximum effort possible to ensure the adoption of the complete ISFM package since the adoption of any single ISFM technology or a combination of any two ISFM technologies is associated with lesser benefits. There should be a consistent awareness creation among policy makers and farmers that multiple technology adoption meets the food security needs of farmers better than adoption of any single improved technology. There must also be awareness among policy makers that measuring food security can be complex, since it was found in this chapter that the availability dimension can be met whilst households' food utilization can still fall below acceptable threshold. Taking into account the empirical findings of the three chapters, the following chapter provides a recap of the study, conclusions, recommendations and future research directions.

CHAPTER 6: CONCLUSIONS, RECOMMENDATIONS AND AREAS OF FURTHER RESEARCH

6.1 Recapping the Purpose of the Study

The study made an attempt to evaluate the supply and demand side investments in achieving rural development goals including increased food security. The supply side investment looks at government policy, with the Ghana Fertilizer Subsidy Program (GFSP) in particular, its impacts on improving the adoption of Soil Intensification Practices (SIPs) and gross farm inputs. The choice of SIPs and gross farm inputs is important for two reasons. Firstly, SIPs are climate smart technologies and it is important that a government agricultural policy such as GFSP addresses food security in a sustainable manner. Secondly, purchase of gross farm inputs which are also sustainable practices is a means of measuring if GFSP has contributed to rural development due to the forward and backward linkages between farmers' input purchases and rural economies. The demand side investment primarily takes into account farm level investments through input purchases and multiple adoption of Integrated Soil Fertility Management (ISFM) practices by smallholder maize growing farmers.

Against the background that fertilizer subsidy programs have historically been controversial with *pros* and *cons* arguments leading to current input subsidies being termed as 'smart', such arguments have excluded the empirical contribution of subsidy programs to meeting the smart objectives at the same time contributing to sustainable management practices and food security. Beyond the role of government in meeting the food security needs of the population from the supply-side, the individual and its capacity to meet its food security needs, thus the demand-side is equally important. The empirical objectives of the study were arrived at based on knowledge gaps identified from literature review. The findings of the literature review revealed some benefits associated with the implementation of fertilizer subsidy programs across Sub-Sahara Africa (SSA), including Ghana. These benefits include increased crop output, especially maize. However, the link between participation in fertilizer subsidy programs and the four dimensions of food security, as well as climate smart technologies such as SIPs remains less explored. The findings of the literature also revealed the provisioning of food security has largely been dependent on what governments do through agricultural policies such as fertilizer subsidies. However, the demand-side in terms of farm households' adoption of multiple technologies in meeting the four dimensions of food security remains scanty in the empirical literature.

The study investigated the main knowledge gaps in the literature and arrived at three specific objectives which were to: (i) assess the extent to which Ghana's fertilizer subsidy program affected adoption of agricultural intensification technologies and gross farm inputs; (ii) investigate the impact

of Ghana's fertilizer subsidy program on multiple dimensions of household food security; and (iii) examine the impacts of the complementarity of Integrated Soil Fertility Management (ISFM) technologies on multiple dimensions of food security. The study employed theoretical and conceptual frameworks as well as econometric models to address these objectives.

Firstly, the two-stage least squares with instrumental variables (2SLS-IV) and endogenous switching regression approaches were employed in chapter three to assess the extent to which Ghana's fertilizer subsidy program affected adoption of SIPs and gross farm inputs. These models also made it possible to identify socio-economic characteristics of maize growing households, institutional and community factors that influenced participation in the GFSP. These two models have the advantages of controlling for endogeneity and sample selection bias. Farmers' decision to participate in the GFSP and invest in SIPs may be affected by both observed and unobserved factors. The use of the ordinary least squares to estimate the effect of GFSP on adoption intensity of SIPs may therefore lead to sample selection bias. The two models were used after observing the presence of selection bias in the participation of the GFSP, which was corrected in the second stage estimation process for each of the models. The underlying assumption of this objective in chapter three was that conceptual approaches adopted by the existing literature in evaluating fertilizer subsidy programs are largely limited to program's effects on crop yield and increased use of mineral fertilizers. However, program's enduring effects even after exit, such as adoption of SIPs and other climate-smart technologies by smallholder farmers is largely not taken into account. In addition, access to agricultural input and output markets remains a major constraint facing farmers. The household's demand for SIPs and gross farm inputs was, therefore, modeled as a utility maximization constraint.

Secondly, the study employed propensity score matching techniques, and two doubly robust estimators (inverse probability weighting, and inverse probability weighted regression adjustment) as robustness checks in chapter four, to investigate the impact of GFSP on multiple dimensions of household food security. In addition, the methods of standardized means and variance ratios were used. They assessed the extent to which the PSM achieved balance in the distribution of the covariates between GFSP participants and non-participants. The econometric estimation methods mentioned also provided two stage estimation procedure. Consequently, the first stage estimation also evaluated factors that influenced participation in the GFSP. Results from the estimates of determinants of participation in chapter four were found to be consistent with those found in chapter three for the same variables. The choice of the use of propensity scores methods was because they are appropriate when selection bias owing to non-random treatment assignment is a possibility. When estimating average treatment effects of program beneficiaries is the parameter of interest, such as GFSP's impact

on household food security using observational data in this case, propensity scores methods are again appropriate. The propensity scores matching techniques have the advantage of controlling for bias and model misspecification. The "doubly robust" estimators also have the advantage of obtaining consistent estimators even under circumstances where only one of the models is specified correctly. The study relied on three assumptions (Conditional Independence Assumption (CIA), also known as unconfoundedness assumption; the overlap or matching assumption; and the conditional mean independence assumption) to obtain consistent estimates of the treatment effects. These assumptions in chapter four permitted identification of causal effects between the food security outcomes of subsidy and non-subsidy households.

Finally, the MESR was used in chapter five to assess the impacts of the complementarity of ISFM technologies on multiple dimensions of food security. The assumption was that adoption of ISFM technologies by smallholder farmers could equally improve their food security dimensions without GFSP. However, effective communication based on empirical evidence explaining the pay-offs of ISFM on food security may increase its adoption since adoption of ISFM technologies continue to be low among smallholder farmers in SSA. The novelty of the MESR is that it analyses and compares the impact of adoption of individual and multiple technologies. The MESR also accounts for both observed and unobserved factors. It employs instrumental variables to obtain efficient and robust estimates. The findings in chapter five are important for policy since the decisions to adopt agricultural technologies are interdependent. Such decisions are best analyzed by multivariate models such as MESR.

6.2 Conclusions

6.2.1 Determinants of Participation in the GFSP and its Impact on Adoption of SIPs and Gross Farm Inputs

The main empirical finding was that GFSP had a positive impact on SIPs and gross farm inputs. This implies that the GFSP meets the 'smart' subsidy objective as it contributes in crowding-in private farm investments in the agro-input market. The input purchases of beneficiaries of GFSP also demonstrates the program's contribution to the growth of rural economies since there is forward-backward linkages between input purchases from farmers and the local input markets. The positive correlation between GFSP and SIPs as well as gross farm inputs indicates the contribution of GFSP to the adoption of climate risks mitigating measures by smallholder maize growing farmers in Ghana. This finding presents a positive outlook on how subsidized mineral fertilizers to farmers can help them adopt coping strategies against climate change and variability. Against increasing vulnerabilities

to climate change, other factors that also influenced adoption of SIPs and gross farm inputs should be mainstreamed in research and development practice for enhanced decision making in formulating policies that capacitate smallholder farmers' resilience towards the negative impacts of climate change.

The value of agricultural equipment, number of years of education, engagement in non-farm enterprises, access to extension, presence of irrigation and mutual aid schemes in a community were the socio-economic, community and institutional factors that determined participation in the GFSP. However, the access to extension in 2017 only mirrored extension access in 2017, unlike the previous definition of extension that looked broadly at whether an extension officer visited a household. The finding of negative correlation between access to extension in 2017 and participation in GFSP meant that government's restructuring efforts of the program in 2017 were largely successful. The decreasing effect of farm size square variable also confirms a positive effect of the restructuring in that a maize growing household with farm size under cultivation beyond a certain threshold (above 2Ha) did not benefit from the program. However, the finding that households with higher value of agricultural equipment as well those engaged in off-farm income sources who possibly could pay for the full cost of fertilizer still benefited from the GFSP still raises questions about the success of the targeting procedure.

6.2.2 Impact of Participation in the GFSP on Dimensions of Food Security

The main empirical finding was that the overall average treatment effect of the GFSP was statistically significant across the food security dimensions from the matching methods. For example, increased output from maize production among program beneficiaries was attributable to the GFSP. Conversely, there was a positive correlation between participation in the GFSP and households' access to food as well as household welfare. This sheds light on the influence of increased crop output in making food available to the population and improvements in households' total food consumption. In addition, the finding that households' food stability also increased due to participation in the GFSP adds to the importance of increased maize productivity among smallholders. With increased maize productivity, smallholder farmers do not only sell the surplus but also store some against shocks in order to smoothen consumption all-year round. However, the utilization dimension of food security rather decreased due to participation in the GFSP. These findings highlight the complexity of measuring food security and the need for policy and research to emphasize on measuring all the dimensions of food security and to move away from discrete measures of food security.

6.2.3 Factors Influencing Adoption of ISFM Technologies, and Impacts of Adopting ISFM Technologies on Food Security

The study found that all the ISFM choices positively and significantly influenced all the dimensions of food security. When the use of mineral fertilizers was complemented with organic fertilizers, households achieved higher payoffs in all the dimensions of food security than the adoption of only mineral fertilizers or improved seed. Adoption of the full complement of ISFM gave the highest gain in all the dimensions of food security, except the stability dimension when the value of household physical assets was used as the means of measurement. Households that adopted ISFM technologies would have obtained lower benefits in achieving food security had they not adopted across the technology choices. This means that the persistence of food insecurity among smallholder farmers in Ghana could be explained by the low level of adoption of complementary technologies at the plot level. This calls for policy makers, Non-Governmental Organizations (NGOs) and agricultural extension to intensify education on the importance of adoption of complementary technologies among smallholder farmers. The same explanation can be given to the poor household resilience in times of shocks considering the weak food stability dimension experienced by maize growing households in the study. Investment in education, good road network to make markets accessible and improved capacity and number of agricultural extension staff are, therefore, necessary for adoption of the complete ISFM technologies. Government should implement rural development policies that promote off-farm work and mutual aid schemes. Similar input subsidy programs implemented across SSA should include organic fertilizers to optimize program impacts on all the four dimensions of food security. There is the need for the implementation of national policies that promote the use of organic fertilizers at the farm level. Farmers' technical skills also need to be built by the Ministry of Food Agriculture that enable farmers to convert organic matter from plant and animal sources into compost. Local government agencies and district assemblies need to support in this regard. To achieve increased adoption of ISFM technologies, household endowments have a critical role to play. This is because factors such as value of agricultural equipment, adult equivalent, number of years a household spent in school, land ownership and household head engagement in off-farm work were found in chapter five to positively and significantly increased the likelihood of joint adoption of all the ISFM technologies.

6.3 Policy Recommendations

To address the problems of poor targeting and absence of an exit strategy associated with the GFSP, below-potential yield of maize, and at the same time help GFSP achieve its objectives of increasing

agricultural productivity, improving food security and developing the private sector input markets, this study recommends a holistic approach that addresses the supply-side as well as the demand side of agricultural investments. Thus, whilst researchers should find innovative ways for implementation by policy makers in ensuring that GFSP is well targeted at those who truly cannot afford mineral fertilizers at full market price, at the same time, policy makers should create the enabling environment that crowds-in private investment from smallholder farmers in the adoption of climate-smart and sustainable intensification practices for increased food security and overall rural development. Specifically, the study recommends the following:

a. *Streamline the objectives of the GFSP*

Since the GFSP has been found to play a positive role in promoting private input market development and a disincentive for crop diversification (part of the findings of specific objectives 1 and 2 of the study, respectively), the study recommends that the program should continue but should be targeted at rural farming communities that have comparative advantage for cereal and vegetable production. The study also recommends that government should put in place measures that promote crop diversification and mixed farming among beneficiaries of the program. Given that food utilization is low among the program beneficiaries, this will improve access to diversified food and improve household nutrition.

b. Improve the current targeting procedure of the GFSP

The current targeting approach that considers farmers with 2Ha of land under cultivation or less, irrespective of whether owners of such farm lands can afford mineral fertilizers at full market cost should be abolished. This recommendation is in respect of a finding that is consistent in the investigation of both specific objectives 1 and 2 of the study that participation in the GFSP were influenced by value of agricultural equipment owned and engagement in non-farm enterprises by a household head. This means that such a person can still benefit from GFSP as long as he/she has land of 2Ha or less under cultivation though such a person can afford to buy mineral fertilizer at prevailing market price. Instead, the study recommends targeting of households with poor resource endowments, in addition to the geographical targeting of rural farming communities. It is, therefore, important that the subsidy targeting approach considers the value of agricultural equipment owned by households and whether household members are engaged in non-farm income sources as part of the criteria for selecting GFSP beneficiaries.

c. Building viable and sustainable local institutions

The findings of objective 1 in chapter 3 revealed community mutual aid schemes and farmer cooperatives as positively influencing adoption of SIPs and gross farm inputs. Number of years of

education and having non-farm income source by head of household, access to extension, and again, community mutual aid schemes were found to promote joint adoption of ISFM technologies in the assessment of specific objective 3 in chapter 5. The study therefore recommends that government, through the Ministry of Food and Agriculture, should strengthen and resource farmer-based and local institutions such as mutual aid schemes and farmer cooperatives. This will enhance their ability to give credit to constrained households so that they can invest more in SIPs and farm inputs for overall agricultural development. The focus of government should not be solely on GFSP. It is recommended that government put in place policies that promote non-farm income for smallholder farmers which serves as shock absorbers during crop failure at the same time provide extra income for the purchase of farm inputs. Government in partnership with NGOs should invest in education, improve capacity and number of agricultural extension staff. The finding under specific objective 3 that distance to market reduces the probability of farmers adopting ISFM technologies jointly requires that government invests as well to improve the road network to make markets accessible. These are viable options for building sustainable local institutions.

d. *Promote the adoption of climate-smart productivity-enhancing technologies*

The results from specific objective 3 in chapter 5 showed that adoption of ISFM technologies have positive outcomes on the dimensions of food security. The study therefore recommends that government prioritizes policies aimed at creating the enabling environment for the adoption of climate-smart complementary technologies, with organic fertilizer playing a key role. The findings from the assessment of specific objective 3 indicating that maize yield achieved is far below the potential yield calls for vigorous promotion of productivity-enhancing technologies by research and policy makers. As there is currently no exit strategy for GFSP despite its financial cost, the study recommends that government together with NGOs and farmer institutions encourage adoption of climate-smart Integrated Soil Fertility Management (ISFM) technologies as alternatives to GFSP. The private sector should also be supported by government to set up composting plants that process organic waste into organic fertilizers to sell to farmers at affordable prices. The policy mantra of achieving an African green revolution should be realigned with the promotion of the adoption of complementary ISFM technologies.

6.4 Study Limitations and Future Research Directions

Whilst the study is novel in using pooled cross-sectional data that is nationally representative to establish the causality of GFSP on input market development and multiple dimensions of food

security on one hand, and on the other hand, the causality between complementary ISFM technology adoption and multiple dimensions of food security, the study's major limitation is that it did not use panel data. It is, therefore, suggested that the Ghana Statistical Service and other state institutions start undertaking panels surveys so that future research can be conducted using panel data. This will make it possible to better estimate the causal relationships between policy variables such as GFSP and complementarity of technology adoption, and outcomes such as private input market development and multiple dimensions of food security. The changes occurring therein over time can be observed and accurate predictions about future trends can be made for policy formulation on overcoming food insecurity and at the same time promoting rural development.

Another limitation of the study is its focus on only maize-growing households. Typical farming households grow more than one crop in a cropping season, though maize is mostly cultivated in Ghana. Future research could look at the welfare effects of adoption of SIPs or complementary technologies in the multi-cropping systems. The effect of participation in GFSP has also been limited to only both productivity-enhancing climate-smart farm inputs and some few proxies for measuring the dimensions of food security. Since sustainable agricultural production encompasses agro-forestry, future studies be conducted linking participation in GFSP to agroforestry or other land care practices by farmers such as land conservation or tree planting. Regarding food security, future studies can focus on explaining how GFSP has reduced child undernourishment and malnutrition among beneficiaries. Further research is also needed to help understand how to better operationalize the various food security metrics into measuring the availability, access, utilization and stability dimensions of food security. The study has also not investigated ways of improving access to ISFM technologies, especially organic fertilizers. Future research could explore business models for the private sector participation in setting up compost plants that also supply organic fertilizers to farmers at competitive prices. This will go a long way to complement the use of mineral fertilizers or serve as alternative to the use of mineral fertilizers for sustainable and climate-smart agricultural production. Beyond the use of manure and organic matter from crop residues, future research could explore the use of human excreta and other wastes for crop fertilization as well as estimating their long-term environmental benefits. Empirical evidence on the long-term environmental benefits from the use of human excreta and other wastes for crop fertilization may motivate government, NGOs and the private sector to invest in such an endeavor.

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APPENDICES

Appendix A: The Agro-ecological Zones of Ghana and the Formerly Ten Administrative Regions

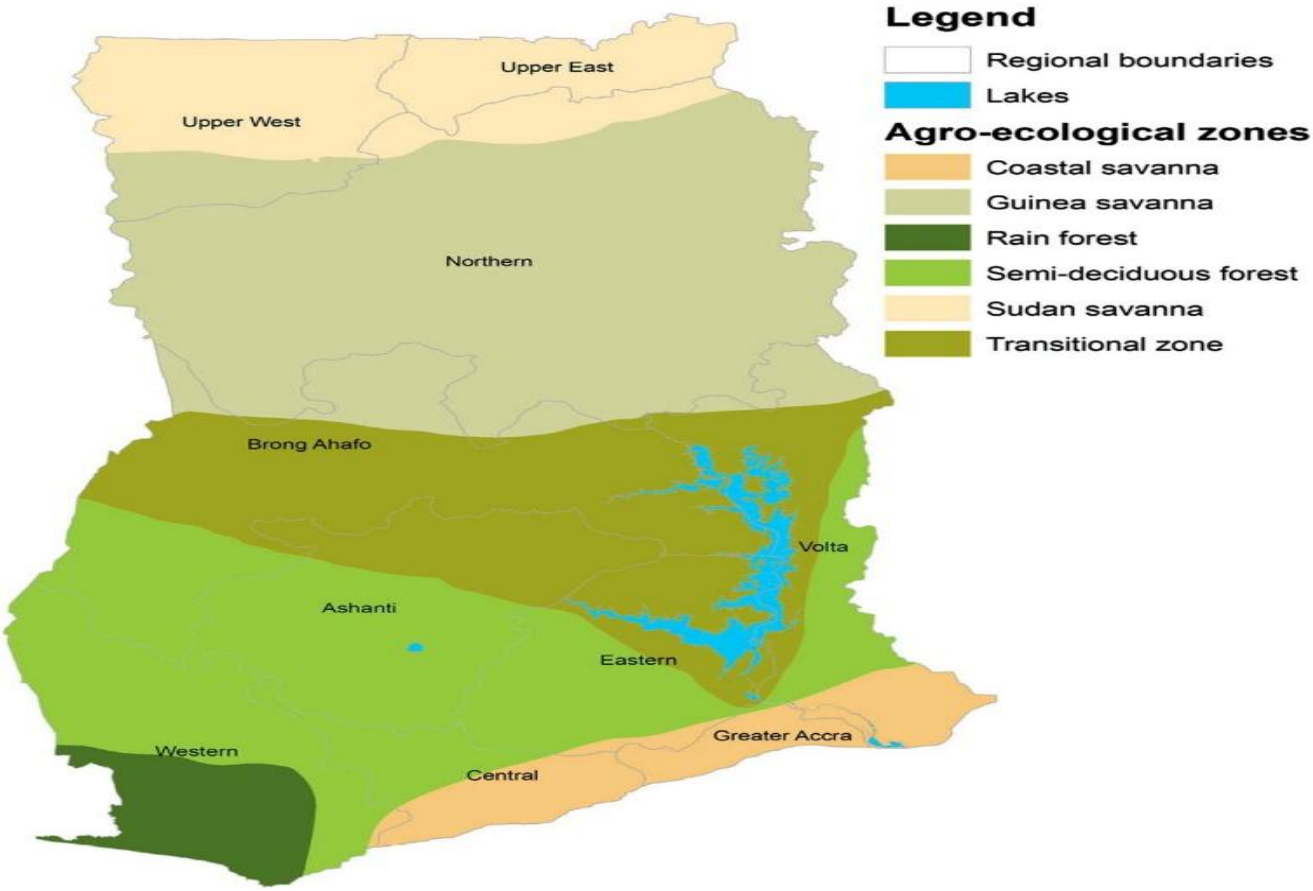

Figure 3: Map of Ghana

Source: Osei and Stein (2017)

APPENDIX B: Harmonization and Generation of Variables

B1. Survey Questionnaire

The Questionnaire for the GLSS consists of three separate questionnaires labeled as Household Questionnaire Part A, Household Questionnaire Part B and Rural Community Questionnaire. Thus, the questionnaire for the household consists of parts A and B. The Rural Community Questionnaire is a focus group discussion at the community level. Both GLSS 6 and GLSS 7 have the same set of questions. The Following are the links to the Questionnaires for GLSS rounds six and seven, respectively: https://www2.statsghana.gov.gh/nada/index.php/catalog/72;

https://www2.statsghana.gov.gh/nada/index.php/catalog/97

B2. The Raw GLSS Data

The raw data for this study consisted of GLSS6 and GLSS7. The data is publicly available at the National Data Archive (NADA) of the Ghana Statistical Service (GSS) at https://www2.statsghana.gov.gh/nada/index.php/home. There is a documentation published alongside. It contains details on the surveys' procedure for sampling and data collection. The harmonized data is limited to only maize growing farmers for this study. GSS generates variables for their use. Some of the already generated variables used for this study were Level of education in years of household's head, Total household's expenditure; Total food expenditure; Adult equivalent scale; Radio owned; and Motorcycle owned. What the study did was to generate variables at the household level for Level of education of household's head, Total household's expenditure; Total food expenditure; Adult equivalent scale; Radio owned; Motorcycle owned for only maize growing households. This was done by using *"generate"* and *"collapse" by household ID* commands in Stata.

B3. Generated Variables

The study adapted the procedure by Tsiboe (2020) on generation and harmonization of GLSS data for different rounds. The variables generated by the study used information collected from the household and community questionnaires. As noted earlier, the household questionnaire is composed of parts A and B. Part A consists of Sections 1 to 7 and Part B consists of Sections 8 to 12. Part A covered information on household members demographics, education and skills training, employment and time use, health, housing, domestic and outbound tourism and migration. Part B included information on household expenditure (food and non-food expenses), household agriculture income, income transfers, credit, assets and use of financial services, as well as migration and remittances. The community questionnaire consists of five sections. Information covered by these sections are demographic information, education, health and agriculture as well as economy and infrastructure. Given the objectives of this study, information on, household food and non-food expenses, agriculture, infrastructure as well as credit and assets were used.

3.1 Generation of variables from the raw data

Households that were into agricultural production were first identified using the household identification of responsibility in Section 6; farm land details in Section 8B; and harvest and disposal of crops in Section 8C. Finally, farm households that cultivated maize were then extracted from the data set using the Stata command: *keep varlist==19*, where 19 was the code for maize crop. The different data sets were then merged by using Identifiers such as household ID, region, district and cluster from both Parts A and B and another set of identifiers (region cluster community number and

community name) from the community questionnaire. The following variables were generated for the study:

Ecological zone: Information for the ecological zone is recorded in the Survey Information Section for both Parts A and B of the household Questionnaire. The variable for Ecological zone was coded 1 for all the ecological zones in southern Ghana, and 0 for Ecological zones in northern Ghana.

Urban residence: This variable was generated based on the information provided in the Survey Information Section for both Parts A and B of the household Questionnaire. It was coded 1 if household was resident in urban, 0 if household was resident in rural.

Farm household demographic characteristics: Household roster in Section 1 of the Part A Questionnaire contains the demographic characteristics of all household members. Head of household was coded 1 and male gender code was 1 and female code was 2. Female was recoded as 0 in the study. Marital status was coded 1 if head of household was married and the rest of the options were recoded as 0. Head of household's age in years was taken as recorded in the household roaster (Section 1).

Access to extension: Across the two surveys, information on whether agricultural extension officers visit households in a community was recorded in Section 5 of the Community Questionnaire. It was coded 1 if yes, 0 otherwise.

Participation in farmer cooperatives: The information on participation in agricultural cooperatives by farmers was recorded in Section 5 of the Community Questionnaire. It was coded 1 if yes, 0 otherwise

Distance to Agricultural extension office: Information on how far an agricultural extension office from a particular community in Km was recorded in Section 5 in the Community Questionnaire question.

Presence mutual aid scheme: Information on a mutual aid's presence in a community for farmers was recorded in Section 5 of the Community Questionnaire.

Irrigation: Information on whether a community has irrigation was recorded in Section 5 of the Community Questionnaire.

Non-farm enterprise: Information on engagement in non-farm enterprises was recorded in Section 4 of Part A. At least, any member of a maize growing household who was a paid employee or engaged in non-agricultural related jobs was coded 1, and 0 for otherwise.

Connection to national grid: Information on main lighting source for a household is recorded in Section 7D of Questionnaire Part A. If the source of electricity was the national grid, a generator or solar energy, it was coded as 1. If neither of these, it was coded as 0.

Use mobile phone: Information on the use of mobile phone is contained in Section 7E of Part A of the Questionnaire.

Farmland ownership: Information on whether any member of a household owns land for agricultural purposes is provided for in Section 8A of Part B Questionnaire. If yes, it was coded 1, 0 otherwise.

Tropical Livestock unit: This variable was constructed based on information recorded in Section 8A on ownership of livestock by a household. First, total number of a particular livestock was calculated per a household. Secondly, the total number of each livestock was then multiplied by its predetermined weight to obtain the tropical unit. For example, sheep and goats have a weight of 0.1, pigs have 0.2 and cattle have 0.7, among others. The sum total of the livestock units was computed for each household and the household ID was used to identify maize growing households.

Value of agricultural equipment: Information on the ownership and value of agricultural equipment are recorded in Section 8A. The total sum of the value for all equipment owned by a household was calculated. The calculation however excluded fishing gears such as outboard motor, canoe and fishing net since the focus of this study was on maize production.

Farmland size and yield: the variable for farmland size was constructed based on the information recorded in Section 8C1. The units of farmland size were converted to hectares by multiplying those recorded in acres, poles, ropes, and other by 0.404686, 0.404686, 0.044965, and 0.01, respectively, following Tsiboe (2020). For yield, information on specific crops output is recorded in Section 8C1 in varying units of measurement (e.g., Kg, ton, bag (mini, maxi), pounds, etc. Only the output for maize was considered for this study. When the stated unit of measurement for maize output was in Kg in the GLSS data set, it was taken as recorded. All other units of measurement recorded for maize output were converted to Kg using the appropriate conversion factors from MoFA. The yield for maize (Kg/Ha) was then computed for each household based on the total maize output divided by the farm size under maize cultivation.

Food (Maize) stock: Information on the quantity of food in store for key staples at the time of GLSS data collection is recorded in Section 8D of Part B. The units of measurement were in different forms. Just as in the case of yield, when the stated unit of measurement for maize quantity was in Kg in the GLSS data set, it was taken as recorded. All other units of measurement recorded for maize quantity in store were converted to Kg using the appropriate conversion factors from MoFA.

Participation in Subsidy: This variable was generated using information on sources of inputs purchased recorded in Section 8F. Households that purchased inorganic fertilizer from MoFA was deemed to have taken part in the GFSP. Households that purchased fertilizer from the private sector (i.e., open market), NGOs and others were considered non-participating farm households.

Expenses on SIPs: This variable was generated using information recorded in Section 8F on purchases on mechanization, irrigation, organic fertilizer, pesticides, improved seed, and mineral fertilizer. Total

amount obtained for each household was divided by the farm size under maize cultivation to obtain expenses of SIPs per hectare in GHS.

Gross farm input Expenses: Information on all the cost of inputs as recorded in Section 8F was used to generate this variable. Total amount spent on all the inputs which are variable inputs was computed and divided by farm size for maize in GHS.

Adoption of mineral (inorganic) and organic fertilizers and improved seed: Information for the purchase of these inputs is recorded in Section 8F in Part B of the Household Questionnaire. If any of these inputs was purchased by at least a member of a household, that particular household was considered to have adopted that particular input (technology). Households that did not purchase were coded 0 and those that purchased were coded 1

Agricultural loan received: Information on the total amount of loan received if at least any member of the household had applied for a loan was recorded in Section 12A. The agricultural loan variable was constructed if the purpose of the loan received was for agricultural purposes.

Household's Asset Value per Adult Equivalent: Information on the assets owned by a household is recorded in Section 12B. Total sum of the value of all assets for a household that cultivated maize was taken and divided by the value of the Adult equivalent scale for that particular household.

Appendix C: Mean Differences Between Subsidy and Non-Subsidy Households

Variable	**Subsidy households: Mean**	**Non-subsidy households: Mean**	**Difference**
SIPs_Expenses	5.875	5.934	0.059
Gross_Expenses	6.067	6.098	0.032
Sex	0.906	0.858	-0.049***
Agri_equipment (log)	0.773	0.626	-0.148***
Adult ES	4.331	4.434	0.104
Education	6.836	4.928	-1.907***
Non-farm enterprise	0.366	0.312	-0.054**
Land size	1.359	1.201	-0.158
Marital status	0.83	0.801	-0.029
Ecological zone	0.249	0.227	-0.023
Urban residence	0.073	0.080	0.007
TLUs	2.736	2.135	-0.601**

Aid_scheme	0.648	0.628	-0.021
Irrigation	0.152	0.108	-0.043***
Access to extension	0.89	0.80	-0.09***
Radio owned	0.659	0.582	-0.077***
Motorcycle owned	0.229	0.214	-.015
Land_ownership	0.765	0.784	0.019
Use mobile phone	0.514	0.514	-0.192***
National_Grid	0.393	0.409	0.016
Membership_Cooperative	0.464	0.707	0.107***
Age	47.168	47.583	0.415
Agric_loan	10.665	22.717	12.052***
Market	10.223	11.558	-1.335***
Agric_Office	15.199	14.473	-0.726
Total_assets (log)	2.62	2.621	0.001

Source: GLSS data (2012/13 and 2016/2017)

Appendix D: Factors Influencing GFSP Participation and Its Effect on the Adoption of SIPS from Endogenous Switching Regression (n = 4,365)

Variables		**Log of SIPs adoption intensity**	
	Selection (Subsidy)	**Subsidy households**	**Non-subsidy households**
Sex	-0.039 (0.138)	0.188 (0.256)	0.336*** (0.065)
Agri_Equipment	0.032** (0.015)	0.105*** (0.095)	0.099*** (0.009)
Adult_ES	-0.022* (0.016)	0.028** (0.106)	0.024*** (0.009)
Education	0.016* (0.009)	-0.017** (0.080)	-0.012** (0.005)
Non-Farm Enterprise	0.13 (0.100)	-0.061** (0.526)	-0.074** (0.039)
Farm Size	0.01 (0.016)	0.149* (0.078)	0.060 (0.050)
Marital Status	0.16 (0.106)	0.483 (0.853)	0.046 (0.056)
Ecological Zone	0.040 (0.099)	0.409** (0.168)	0.348*** (0.054)
Urban Residence	0.148 (0.117)	-0.017 (0.251)	0.127 (0.062)
TLUs	0.004 (0.006)	0.022 (0.028)	0.007** (0.003)
Aid Scheme	0.208 (0.225)	0.253 (0.194)	0.171*** (0.043)
Irrigation	0.273 (0.207)	-0.028** (0.858)	-0.200*** (0.077)
Access to. Extension	0.285* (0.165)	0.546 (0.944)	-0.051 (0.049)
Radio owned	0.069 (0.087)	0.320** (0.156)	0.111*** (0.039)

Motorcycle owned	-0.034 (0.130)	0.048** (0.547)	0.322*** (0.050)
Land Ownership	-0.068 (0.082)	0.104** (0.582)	0.176** (0.047)
Use_mobile phone	0.109 (0.101)	0.108 (0.235)	0.087* (0.052)
National Grid	-0.042 (0.105)	0.021** (0.313)	0.145** (0.039)
Membership_Cooperative	-0.166 (0.078)	0.092 (0.785)	0.117*** (0.045)
Age	0.001 (0.003)	-0.005 (0.014)	-0.003** (0.001)
Agri_Loan	-0.045 (0.032)	0.066*** (0.075)	0.041** (0.014)
Total assets	0.047 (0.029)	0.085** (0.182)	0.018 (0.011)
Year 2017	-0.505*** (0.119)	0.314 (1.705)	0.536 (0.071)
Market	-0.010 (0.010)	-	-
Agri_Office	0.012 (0.022)	-	-
Constant	1.888 (0.509)	1.678** (9.685)	4.448*** (0.122)
Wald $\chi^2(23)$	141.72***		
/lns1	0.311 (2.395)		
/lns2	-0.077*** (0.021)		
/r1	1.190 (4.946)		
/r2	-0.123 (0.336)		
Sigma_1	1.365** (3.269)		
Sigma 2	0.926 (0.020)		
rho_1	0.831*** (1.534)		
rho_2	0.122*** (0.331)		
Log Likelihood	-495.14		
Likelihood ratio test of joint independence of equations $\chi^2(1)$	2.02***		

Notes: Standard errors in parenthesis; *, ** and *** significant at 10%, 5% and 1% levels, respectively. **Source**: GLSS Data (2012/13 and 2016/2017)

Appendix E: Factors Influencing GFSP Participation and Its Effect on the Adoption of Gross Farm Inputs from Endogenous Switching Regression (n = 4,365)

Variables	**Selection** **Subsidy**	**Log of gross farm adoption intensity**

		Subsidy households	**Non-subsidy households**
Sex	-0.028 (0.184)	0.064* (0.326)	0.331*** (0.061)
Agri_Equipment	0.032* (0.018)	0.095 (0.083)	0.097*** (0.009)
Adult_ES	-0.023 (0.016)	0.036** (0.086)	0.030*** (0.009)
Education	0.015 (0.011)	0.026 (0.109)	-0.009* (0.005)
Non-Farm Enterprise	0.134 (0.107)	0.074 (0.572)	-0.067 (0.042)
Farm Size	0.016 (0.033)	0.164*** (0.063)	0.056 (0.049)
Marital Status	0.161 (0.102)	0.47 (0.833)	0.013 (0.057)
Ecological Zone	0.147 (0.116)	0.350* (0.313)	0.368 (0.049)
Urban Residence	0.147 (0.116)	0.030* (0.317)	0.151** (0.063)
TLUs	0.003 (0.007)	0.022 (0.033)	0.010*** (0.003)
Aid_Scheme	0.204 (0.286)	0.281* (0.160)	0.187*** (0.042)
Irrigation	0.256 (0.236)	0.155 (1.194)	-0.196** (0.081)
Access to. Extension	0.295* (0.160)	0.530 (1.222)	-0.040 (0.058)
Radio owned	0.071 (0.087)	0.373** (0.160)	0.100** (0.037)
Motorcycle owned	-0.033 (0.149)	0.102** (0.657)	0.38** (0.050)
Land Ownership	-0.066 (0.081)	0.112** (0.828)	0.170*** (0.046)
Use_mobile phone	0.105 (0.146)	0.130 (0.423)	0.073 (0.050)
National_Grid	-0.039 (0.117)	0.049** (0.443)	0.143*** (0.037)
Membership_Cooperative	-0.153 (0.081)	0.030 (0.937)	0.118** (0.052)
Age	0.002 (0.002)	-0.002 (0.012)	-0.004*** (0.001)
Agri_Loan	-0.047 (0.038)	0.061* (0.055)	0.047*** (0.016)
Total_assets	0.049 (0.036)	0.122 (0.148)	0.016 (0.013)
Year_2017	-0.504*** (0.164)	0.144** (1.857)	0.470 (0.101)
Market	-0.011 (0.010)	-	-
Agri_Office	0.012 (0.025)	-	-
Constant	1.899***(0.350)	1.299** (0.159)	1.653***(0.133)
Wald $\chi^2(23)$	112.17***		
/lns1	0.415*** (2.600)		

/lns2	-0.128*** (0.030)
/r1	1.487 (5.908)
/r2	-0.113 (0.725)
Sigma_1	1.515*** (3.938)
Sigma_2	0.880 (0.027)
rho_1	0.903** (1.092)
rho_2	0.113** (0.716)
Log Likelihood	-480.75
Likelihood ratio test of joint independence of equations $\chi^2(1)$	0.61***

Notes: Standard errors in parenthesis; *, ** and *** significant at 10%, 5% and 1% levels, respectively. **Source**: GLSS Data (2012/13 and 2016/2017)

Appendix F: Rosenbaum Bounds Sensitivity Test Against Hidden Bias for All the Measurements of Food Security Dimensions

Food security dimensions	Critical value of hidden bias (Γ)	Sig +	Sig-
Availability dimension (maize yield)	1 2 3	0.000 0.024 0.759	0.000 0.000 0.000
Food access (Food consumption expenditure)	1 2 3	0.000 0.756 0.999	0.000 0.000 0.000
Food access and household welfare (Total household expenditure)	1 2 3	0.000 0.009 0.616	0.000 0.000 0.000
Food utilization (Food consumption score)	1 2 3	0.384 1.000 1.000	0.384 0.000 0.000
Stability dimension (Maize stock)	1 2 3	0.063 0.999 1.000	0.063 0.000 0.000
Stability dimension (Total household assets value)	1 2 3	0.356 0.000 0.000	0.356 0.000 0.000

Notes: Sig+ refers to upper bound significance level. Sig- refers to lower bound significance level.