

## Determinants of soybean yield-enhancing technology adoption by smallholder soybean farmers in Northern and Upper East regions of Ghana

Selase Kwaku Dotse<sup>1,3</sup>  
Francis K. Obeng<sup>2</sup>  
Theresa Ampadu-Boakye<sup>3</sup>  
Samuel Allotey<sup>4</sup>  
Samuel Adjei-Nsiah<sup>3,5</sup>

<sup>1,3</sup>selasekwaku@gmail.com

<sup>1,2</sup>University for Development Studies, <sup>1,3,5</sup>International Institute of Tropical Agriculture, <sup>4</sup>University for Development Studies, <sup>5</sup>University of Ghana, <sup>1,2,3,4,5</sup> Ghana

<https://doi.org/10.51867/ajernet.7.1.92>

### ABSTRACT

This study analyzed determinants of soybean yield-enhancing technology adoption among smallholder farmers in Ghana's Northern and Upper East Regions, focusing on innovations promoted under the IITA-led N2Africa (2014–2018) and SSPiNG (2021–2024) projects. This study was guided by the adoption theory, which offers a micro-level perspective on change, focusing on individual units within a system, and the diffusion theory, which examines how innovations spread across populations, highlighting the roles of time, social influence, and collective adaptation. This study employed a descriptive cross-sectional research design. Using a multi-stage sampling design, data were collected from 620 farmers, sampled from 35607 farmers, from four districts, using surveys through semi-structured questionnaires and key informant interviews. Data, analyzed with SPSS v28.0 using descriptive statistics and a Probit regression model, revealed that farm size strongly and significantly correlated with the adoption of certified seeds ( $r = 0.318$ ), fertilizer ( $r = 0.378$ ), inoculants ( $r = 0.241$ ), mechanized planters ( $r = 0.498$ ), and Good Agricultural Practices ( $r = 0.498$ ) at  $p < 0.05$ . Education, age, extension access, and support systems were also significant predictors. The results concluded that access to credit showed a negative but insignificant effect, suggesting that financial resources alone are insufficient without complementary knowledge, support, and infrastructure. The findings underscore the need for integrated government, research, non-governmental organization (NGO), and private-sector interventions to enhance dissemination, farmer capacity, and access to quality inputs, thereby boosting adoption rates and soybean productivity.

**Keywords:** Adoption, Communication Channels, Extension Services, Good Agricultural Practices, Yield-Enhancing Technologies

### I. INTRODUCTION

Agriculture remains central to Ghana's economy, employing much of the rural population. While the sector has traditionally been dominated by cash crops such as cocoa, coffee, and timber (Langdon et al., 2018; Diao et al., 2010), recent efforts have focused on diversifying production with non-traditional crops to enhance food security and export earnings. Among these, soybeans emerged as a crop of strategic importance due to their nutritional and economic potential (Abban, 2020; Albishi et al., 2026).

These efforts reflect a strategic policy orientation that positions soybeans as both a commercial and food-security crop. Multiple interventions have supported this agenda. Programmes implemented by the Savannah Accelerated Development Authority (now the Northern Development Authority), the Alliance for a Green Revolution in Africa, the Northern Rural Growth Programme, the Danish International Development Agency, the United States Agency for International Development, and the Youth in Agriculture Programme have promoted soybean cultivation and utilization through input support, capacity building, and market development initiatives (Maïga et al., 2020; Dogbe et al., 2013). Collectively, these interventions underscore soybeans' perceived role in driving inclusive agricultural growth in northern Ghana.

Beyond its economic relevance, soybeans' agronomic and nutritional attributes strengthen their developmental appeal. As a versatile leguminous crop, it serves as a major source of human food, livestock feed, bioenergy, and industrial raw materials (Shea et al., 2020; Wilson, 2015). Often described as a "miracle bean" or "golden bean," the soybean contains approximately 40% high-quality protein and 20% edible vegetable oil, along with a well-balanced amino acid profile (Obasoro et al., 2015; Singh & Montgomery, 1987; El Agroudy et al., 2011; Mohammed et al., 2016). These attributes make it particularly valuable for improving the nutritional status of resource-poor households.

Agronomically, soybeans contribute to the sustainability of intensified cropping systems through biological nitrogen fixation, which enhances soil fertility and supports extended ground cover within crop rotations. In this

regard, soybeans not only function as an income-generating and nutrition-enhancing crop but also as a strategic component of sustainable agricultural systems.

The Northern and Upper East regions of Ghana provide favourable agro-ecological conditions for its cultivation. Recognising this potential, initiatives such as N2Africa (2014–2018) and Sustainable Soybean Production in Northern Ghana (SSPiNG, 2021–2024), led by the International Institute of Tropical Agriculture (IITA), have promoted yield-enhancing technologies including certified seeds, rhizobium inoculants, legume-specific fertilizers, mechanised planters, and Good Agricultural Practices (GAPs).

### 1.1 Statement of the Problem

Despite these interventions, adoption and productivity remain low. National average yields stand at about 1.3 metric tons per hectare, well below the potential yield of 3.0 metric tons per hectare (IDDI, 2024). Constraints include limited access to extension, inadequate knowledge of input use, misconceptions about soybean nutrient requirements, and socioeconomic barriers such as limited credit and mechanisation. Moreover, the effectiveness of dissemination strategies, such as field demonstrations, radio, video shows, and farmer-to-farmer learning, has not been systematically evaluated.

Soybean is increasingly vital to Ghana's agricultural landscape, with potential contributions to nutrition, income, and poverty reduction in northern regions. Yet the persistent gap between innovation dissemination and farmer adoption underscores the need for a deeper understanding of barriers and enablers. While existing literature highlights roles of socioeconomic status, credit, and extension (Feder et al., 1985; Ragasa et al., 2019), few empirical studies have focused explicitly on soybean in Ghana's main production zone.

This study is therefore timely and policy relevant. It provides evidence to guide government, NGOs, and development partners in designing targeted interventions that improve adoption, enhance food security, and promote sustainable rural livelihoods.

### 1.2 Research Objective

This study investigates the factors influencing smallholder farmers' adoption of soybean yield-enhancing technologies in Ghana's Northern and Upper East regions, with particular attention to interventions implemented under N2Africa and SSPiNG. Specifically, the study examines:

- i) The socioeconomic and institutional factors shaping adoption decisions; and
- ii) The relative effectiveness of different dissemination approaches influencing uptake.

## II. LITERATURE REVIEW

### 2.1 Theoretical Review

#### 2.1.1 Adoption Theory

Adoption Theory, developed by Everett M. Rogers in 1962, explains the process through which innovations are disseminated and the factors that shape individuals' decisions to adopt or reject them. The theory is relevant to the present study because it offers a systematic framework for examining the determinants of adoption behavior and for understanding patterns of acceptance within the target population. Agricultural innovation unfolds within functioning organisational structures and inclusive policy environments that bring together diverse rural actors with varying interests and perspectives. Within such integrated systems, the quality of networks and the continuous exchange of information are critical. Communication is not merely supportive but central, serving as a driving force for dialogue, coordinated intervention, and institutional harmonisation (Marzia et al, 2011).

According to Bonabana-Wabbi (2002), adoption is a mental process through which an individual moves from initial awareness of an innovation to its eventual use. Within this framework, adoption is analysed along two dimensions: the rate of adoption, referring to the speed at which farmers accept a technology over time, and the intensity of adoption, denoting the extent or level of its use at a given point.

Broader interpretations extend beyond the individual decision to adopt, emphasising how deeply an innovation is integrated within a specific context. In this sense, adoption theory offers a micro-level perspective on change, focusing on individual units within a system.

#### 2.1.2 Diffusion Theory

Formally known as the Diffusion of Innovations Theory, this concept was developed by Everett M. Rogers in 1962 through his seminal work, "Diffusion of Innovations." Rogers provided a systematic explanation of how new ideas, technologies, and practices spread over time within a social system through various communication channels.

The theory is relevant to the present study because it offers a comprehensive framework for understanding how an innovation is introduced, communicated, and adopted within a target population. It clarifies how awareness and acceptance evolve, identifies factors that may facilitate or impede diffusion, enables the classification of individuals

according to their readiness to adopt, and informs the design of effective communication strategies to enhance uptake. Diffusion theory, as discussed by Evan et al. (2009), examines how innovations spread across populations, highlighting the roles of time, social influence, and collective adaptation. The present study can more systematically analyze the processes influencing the spread and acceptance of the innovation under investigation, thereby strengthening its theoretical grounding and analytical rigor.

Across these perspectives, communication emerges as central to effective adoption. Within integrated agricultural innovation systems, it facilitates participatory processes through reciprocal knowledge exchange, strengthens networks, and enables negotiation and coordinated action among stakeholders. Such communicative functions are fundamental to sustaining innovation and advancing rural development (Prajapati et al., 2025; Gustafsson et al., 2013).

## 2.2 Empirical Review

Soybean was introduced into Ghana between 1909 and 1910 during the colonial period, reportedly by the Portuguese, primarily to enhance human nutrition (Rao et al., 1998). Early efforts to promote its cultivation and utilization, including initiatives by the Council for Scientific and Industrial Research Crop Research Institute and the University of Ghana Agricultural Research Station in the late 1960s and early 1970s, achieved limited success Plahar et al. (2006). A more coordinated breeding programme emerged in the 1970s through collaboration between the Ministry of Food and Agriculture (MoFA) and the International Institute of Tropical Agriculture, aimed at revitalizing soybean production.

Over time, soybeans have transitioned from a marginal crop to one of commercial and strategic importance, serving both as a cash and staple food crop. According to IDDI (2024), national production increased markedly from approximately 152,000 metric tons in 2012 to about 255,209 metric tons in 2022. Similarly, output rose from 140,000 metric tons in 2014 to roughly 255,000 metric tons in 2022, reflecting an estimated annual growth rate of 7.5%. This expansion is largely attributed to policy interventions such as the “Planting for Food and Jobs” programme, which improved farmers’ access to certified seeds, fertilizers, technical support, and strengthened value chain coordination (IDDI, 2024).

Cultivated area expanded from about 85,000 hectares in 2012 to 138,000 hectares in 2022, an increase of 38.4%. Average yields improved modestly from 1.78 to 1.84 metric tons per hectare over the same period (IDDI, 2024). Earlier data indicate yield growth from 1.3 to 1.5 metric tons per hectare between 2000 and 2010, surpassing the Sub-Saharan African average of 1.1 metric tons per hectare (IDDI, 2024). Nonetheless, Ghana’s yields remain below global benchmarks. For instance, the United States Department of Agriculture (2015) reports higher average yields in Argentina (2.76 t/ha), the USA (2.96 t/ha), South Korea (1.93 t/ha), and Brazil (2.88 t/ha). While subsistence systems may yield as low as 0.8 t/ha, adoption of improved commercial practices could potentially raise yields to 4.5 t/ha (Coates et al 2015). Even so, Ghana’s current average yield of about 1.8 t/ha remains below the attainable 2.3 t/ha, underscoring persistent productivity gaps (Tetteh et al., 2017).

Despite production gains, the domestic supply estimated at about 255,000 metric tons in 2022 falls short of the national demand of approximately 300,000 metric tons, leaving a deficit of around 45,000 metric tons (IDDI, 2024). Production is concentrated among smallholder farmers in northeastern Ghana (Yussif, 2019). Between 2007 and 2009, participation in soybean farming increased substantially in this region (Owusu-Akuoko, 2016), including in districts such as Chereponi, where both men and women adopted soybean cultivation as an income-generating activity despite initial profitability challenges linked to limited technical knowledge (Dogbe et al., 2013).

These production constraints intersect with broader structural challenges. Agriculture in Sub-Saharan Africa continues to underperform, and poverty levels remain high; in Northern Ghana, approximately half the population lives below the poverty line (Kwao, 2017). In this context, strengthening institutional support mechanisms is critical. Agricultural extension services, as documented by Rickards et al. (2025), play a pivotal role in enhancing farmers’ knowledge, promoting technology adoption, facilitating market access, and supporting sustainable resource management. Empirical evidence from northern Ghana indicates that participation in extension programmes improves farmer welfare and income (Danso-Abbeam et al., 2018), while access to extension services significantly increases adoption of soil fertility technologies such as chemical fertilizers (Donkor & Owusu, 2019).

## 2.3 Conceptual Framework

This study integrates Rogers’ (2003) *Diffusion of Innovations* (DOI) theory with the economic model of agricultural technology adoption developed by Feder et al (1985) to explain smallholder adoption of soybean yield-enhancing technologies.

The DOI theory emphasises that the spread of innovations is influenced by five perceived attributes: relative advantage, compatibility, complexity, trialability, and observability. These characteristics shape farmers’ perceptions and willingness to adopt technologies such as certified seeds, inoculants, mechanized planters, and Good Agricultural Practices (GAPs). GAPs are guidelines designed to render farm practices safe, sustainable, and environmentally

sound. GAPs cover the whole process of agricultural production, from preparation of land and sowing to harvesting and post-harvest handling. The general goals of GAPs are to enhance food safety, safeguard the environment, enhance fair labor practices, and enhance quality agricultural products.

The economic adoption model conceptualises technology uptake as a rational decision made under conditions of risk and imperfect information. Within this framework, farmers are viewed as utility-maximising agents who evaluate the expected benefits and costs of adopting a new technology, considering their individual circumstances. Adoption decisions are therefore shaped not only by the technical attributes of the innovation itself but also by farmer-specific characteristics such as education, risk preferences, and experience, farm-level resource endowments, including land size and access to inputs, and the broader institutional environment, particularly the availability of extension services and credit.

Drawing on foundational empirical contributions from Sub-Saharan Africa, including the work of Adesina and Zinnah (1993), Mwangi and Kariuki (2015), Ndiritu et al. (2014), and Abdoulaye et al. (2018), this study advances a multidimensional conceptualisation of adoption. Rather than treating adoption as a single, isolated choice, it is understood as the outcome of six interrelated domains that collectively structure both opportunity and constraint.

First, farmer characteristics include age, gender, educational attainment, farming experience, and household size, shape managerial capacity, openness to innovation, labour availability, and attitudes toward risk. Second, farm characteristics such as farm size, land tenure status, soil fertility, and access to irrigation condition the technical and economic feasibility of adopting yield-enhancing soybean technologies. Resource endowments influence not only the affordability of improved inputs but also the scale at which potential gains can be realised.

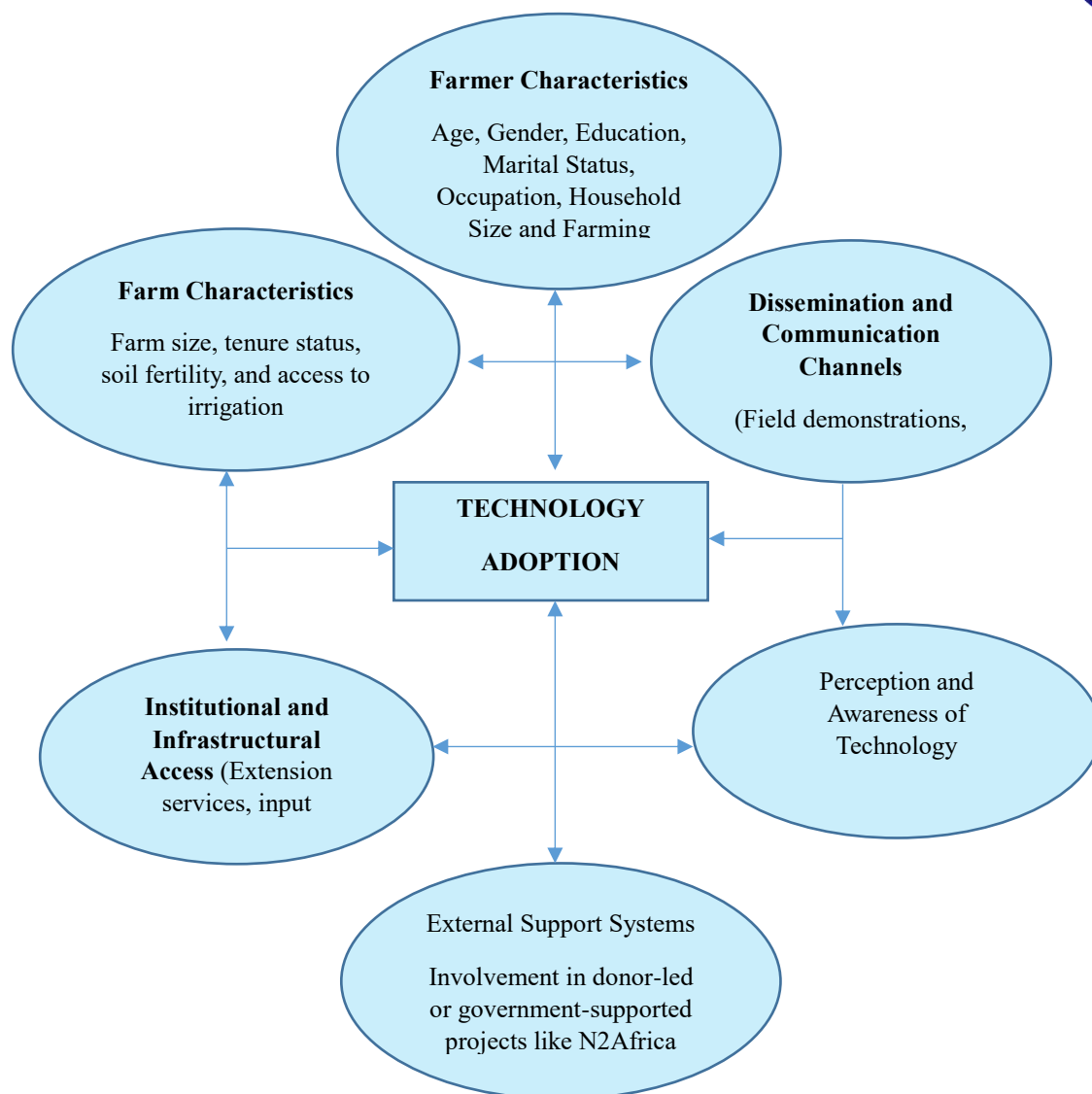
Third, institutional and infrastructural access play a pivotal role. The availability and quality of extension services, proximity to input and output markets, access to credit facilities, and mechanisation services reduce information asymmetries, liquidity constraints, and transaction costs that often impede adoption. Fourth, farmers' perceptions and awareness of the technology, particularly their understanding of its benefits and risks, as well as its compatibility with existing farming practices, mediate the translation of information into action. Even where resources are adequate, negative perceptions or uncertainty may deter uptake.

Fifth, dissemination and communication channels influence both awareness and confidence. Field demonstrations, radio programming, farmer-to-farmer networks, and video-based training platforms shape how knowledge is transmitted, interpreted, and validated within farming communities. Social learning processes embedded in these channels can either accelerate or inhibit diffusion. Finally, external support systems such as participation in donor-led or government-supported initiatives, including N2Africa and SSPiNG, provide complementary inputs, technical backstopping, and institutional coordination that can lower barriers to experimentation and early adoption.

These six domains are analytically distinct but empirically intertwined. Their interaction determines both the capacity of farmers to adopt yield-enhancing soybean technologies through access to resources, knowledge, and institutional support and their willingness to do so, as shaped by expectations, perceived risk, and social context. Adoption, in this view, emerges not as a binary or purely individual choice, but as the outcome of a dynamic interplay between economic rationality, structural conditions, and socially mediated learning processes

Constraints in any domain, such as weak extension services, low capital, or ineffective communication, can significantly inhibit adoption, even when technologies are technically sound and economically viable.

The researcher has developed a conceptual diagram below (Figure 1) for Determinants of Soybean Yield-Enhancing Technology Adoption by Smallholder Soybean Farmers in Northern and Upper East Regions of Ghana.



**Figure 1**  
*A Conceptual Diagram for Soybean Yield-Enhancing Technology Communication and Dissemination*

### III. METHODOLOGY

#### 3.1 Research Design

This study employed a descriptive cross-sectional research design. Such surveys typically rely on a carefully selected sample intended to represent a larger population. Findings derived from the sample are then used to draw inferences about the broader group. Considering the scope of the study area and the characteristics of the target respondents, a survey approach was appropriate and effective for describing individual attributes in this research.

#### 3.2 Study Area

The research was conducted in Ghana’s Northern and Upper East regions, major soybean-producing zones within the Guinea savannah. Four districts were purposively selected Savelugu and Yendi (Northern Region), Bawku Municipal and Bawku West (Upper East), because of their involvement in soybean technology dissemination through the N2Africa and Sustainable Soybean Production in Northern Ghana (SSPiNG) projects. These districts are predominantly agrarian, relying on rain-fed agriculture, with soybean production increasingly promoted as a livelihood and food security crop (Amegashie, 2023)

#### 3.3 Target Population

The target population comprised smallholder soybean farmers exposed to yield-enhancing technologies under N2Africa and SSPiNG. This group was considered most relevant for assessing adoption drivers and constraints, consistent with prior adoption studies focusing on farmer groups engaged in donor-led agricultural interventions (Martey et al., 2014; Doss, 2006).

### 3.4 Sampling Methods and Sample Size

A mixed methods integrated quantitative and qualitative approaches to enhance validity through triangulation (Tonkin-Crine et al, 2015). Sampling followed a multi-stage procedure: first, the Northern and Upper East regions were purposively selected; second, two districts per region were chosen based on farmer concentration and project presence; third, 18 communities were randomly sampled; and finally, 620 farmers were proportionally selected through simple random sampling from 35,607 farmers (Table 1). This approach ensured representativeness, in line with similar technology adoption studies in Sub-Saharan Africa (Asfaw et al., 2012; Kassie et al., 2015).

Determination by Calderon and Berlind (2019), which is  $n = \frac{N}{1+Ne^2}$

The total population for 4 districts = 35,607

$$n = \frac{35607}{1+35,607(0.05)^2} = 399.9796964621085$$

**n = 400 approx.**

Over-sampling refers to initially selecting a larger sample than needed, anticipating that not all individuals will respond (Kalton, 2009). The situation aligns with the use of oversampling, where the study initially targeted a sample of 400 respondents but received 620 responses. This occurs due to high engagement and response rate and better-than-expected response patterns.

**Table 1**

*Number of Respondents per Municipal/District*

District	Smallholder Farmers Population	Sample Size
Savelugu Municipal	2,678	120
Yendi	14,242	200
Bawku Municipal	11,562	200
Bawku West	7,125	100
<b>TOTAL</b>	<b>35,607</b>	<b>620</b>

### 3.5 Data Collection

Primary data were collected through structured questionnaires, key informant interviews, and focus group discussions (FGDs). The questionnaire captured demographic and adoption-related variables, while interviews targeted extension agents, project staff, and community leaders. FGDs provided qualitative insights into shared experiences and constraints. Instruments were pre-tested in non-sample communities to ensure clarity and cultural appropriateness. Similar triangulation approaches have been widely applied in rural technology adoption research (Feder et al., 1985; Ragasa et al., 2019).

### 3.6 Data Analysis

Quantitative data were analysed using SPSS v28. Descriptive statistics summarised farmer characteristics and adoption trends. Probit regression was applied to identify determinants of adoption, following Random Utility Theory (RUT), which posits that farmers adopt technologies when the perceived utility exceeds that of non-adoption (Shakya & Flinn, 1985; Adesina & Zinnah, 1993). Consistent with Marenya and Barrett (2007) and Nkamleu and Adesina (2000), utility was modelled as comprising a deterministic component (farmer and technology attributes) and a stochastic component (unobserved factors).

Given the categorical nature of adoption, a linear probability model (LPM) was also estimated:

$$\Pr(\text{Adoption}) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_n X_n + \varepsilon$$

Where:

$\Pr(\text{Adoption})$  denotes the probability of adopting soybean technologies,  $\beta_0$  is the intercept,  $\beta_i$  are coefficients of explanatory variables, and  $\varepsilon$  the error term. Chi-square tests were used to examine associations between categorical variables.

### 3.7 Ethical Considerations

This study was reviewed and approved by the University for Development Studies Research Ethics Committee. Surveys and interviews were conducted in accordance with the university's ethical guidelines.

The description, measurement, and a priori expectations of the variables influencing adoption of the soybean technologies are presented in Table 2 below.

**Table 2***Description, Measurement, and Hypothesized Signs of Variables used in the Probit Regression Model*

Variable	Description	Measurement	Hypothesized sign
<b>Dependent Variable</b>			
Adoption		dummy; 1 = Yes; no = 0	+/-
<b>Independent Variables</b>			
X <sub>1</sub>	Age of respondent	Years	+
X <sub>2</sub>	Sex of respondent	Dummy: 1= Male, 0= Female	+/-
X <sub>3</sub>	Education	No. of years in school	+
X <sub>4</sub>	Farm size	No. of acres	+
X <sub>5</sub>	Experience in farming	No. of years in farming	+
X <sub>6</sub>	Credit access	Dummy: Yes =1, No = 0	+/-
X <sub>7</sub>	Farm ownership	Dummy: Yes =1, No = 0	+/-
X <sub>8</sub>	Labour availability,	Dummy: Yes =1, No = 0	+
X <sub>9</sub>	Household size,	Number of people	+
X <sub>10</sub>	Access to market	Dummy: Yes =1, No = 0	+
X <sub>11</sub>	Access to extension service	Dummy: Yes =1, No = 0	+/-
X <sub>12</sub>	Group membership	Dummy: Yes =1, No = 0	+
X <sub>13</sub>	Use of demonstration	Dummy: Yes =1, No = 0	+
X <sub>14</sub>	Use of field days	Dummy: Yes =1, No = 0	+/-
X <sub>15</sub>	Use of video shows	Dummy: Yes =1, No = 0	+/-
X <sub>16</sub>	The ease of use of the technologies	Dummy: Yes =1, No = 0	+/-
X <sub>17</sub>	Cost of using the technology	Dummy: High =1, Low = 0	+/-
X <sub>18</sub>	Planting in rows	Dummy: Yes =1, No = 0	+/-

Qualitative data from interviews and FGDs were analysed thematically, involving coding, identification of recurring patterns, and development of themes aligned with the research objectives (Braun & Clarke, 2006).

## IV. FINDINGS & DISCUSSION

### 4.1 Socio-Demographic Characteristics of Respondents

Table 3 summarises the socio-economic and demographic characteristics of respondents from two districts in the Northern Region (Savelugu and Yendi) and two in the Upper East Region (Bawku West and Bawku Municipal). Chi-square tests ( $\chi^2$ ) were used to examine associations between these characteristics and district of residence.

*Gender distribution:* across all districts, females outnumbered males (59.7% vs. 40.3%), with proportions ranging from 55% in Bawku West to 62.5% in Yendi. This predominance of women is consistent with earlier demographic studies in northern Ghana (Aryal et al., 2021). The association between gender and district was not statistically significant ( $\chi^2 = 2.022$ ,  $p = 0.568$ ), suggesting relative uniformity. Age composition varied significantly across districts ( $\chi^2 = 112.928$ ,  $p < 0.001$ ). Savelugu had the youngest profile, with 60.5% aged 18–35 years, while Bawku West and Bawku Municipal showed more aging populations, with over 50% aged 36–50 and 20–30% above 50 years. These patterns reflect migration and labour dynamics highlighted by McGuire & Sperling (2016), Ronner et al. (2016), and Ricker-Gilbert (2020).

Educational attainment differed significantly ( $\chi^2 = 118.626$ ,  $p < 0.001$ ). Respondents in Yendi (78%) and Savelugu (54.6%) were most likely to have no formal education, compared to 35.8% in Bawku Municipal and 56% in Bawku West. Primary education was most common in Bawku Municipal (51.2%), while higher education was negligible across all sites (<8%). These disparities underscore persistent regional inequalities shaped by access, cost, and socio-cultural factors (Rehman & Alharthi, 2016; Ndiritu et al., 2014).

*Marital status:* marriage dominated across districts (92.5% overall), with divorce, widowhood, and singleness rarely reported (<5%). The association with the district was not significant ( $\chi^2 = 16.860$ ,  $p = 0.155$ ), suggesting cultural uniformity. These findings echo wider rural Ghanaian patterns where marriage remains the normative status (Shilomboleni et al., 2023).

*Occupation:* Farming was the primary occupation (95.6% overall), especially in Savelugu and Yendi (>99%). In Bawku West and Bawku Municipal, small proportions of respondents engaged in trading (6.5% in Bawku Municipal), civil service, or entrepreneurship. The district occupation association was significant ( $\chi^2 = 36.865$ ,  $p < 0.001$ ), reflecting modest occupational diversification alongside agricultural dominance (Johnson et al., 2024; Sims & Kienzle, 2017).

Religious affiliation varied significantly across districts ( $\chi^2 = 243.108$ ,  $p < 0.001$ ). Savelugu was almost entirely Muslim (99%), while Yendi and Bawku Municipal showed pluralities of Muslims (79% and 87%, respectively) alongside Christian minorities. In contrast, Bawku West was predominantly Christian (64%) with notable ATR representation (16%). These variations mirror broader regional religious geographies (Sennuga et al., 2020; Marty et al., 2017; Kwapong et al., 2024). Ethnic composition also varied markedly ( $\chi^2 = 662.652$ ,  $p < 0.001$ ). Savelugu and Yendi were dominated by Dagombas (98% and 74%, respectively, with Konkombas forming 24% in Yendi), while Bawku West and Bawku Municipal were overwhelmingly Kusasi (>95%). These findings align with historical settlement patterns and ethnographic studies of the area (Dzanku & Sarpong, 2014; Eric et al., 2014).

**Table 3**  
*Socio-Demographic Characteristics of Respondents*

Attributes	Northern Region		Upper East region		Total Respondent	X <sup>2</sup>	df	P
	Savelugu N=120	Yendi N=200	Bawku West N=100	Bawku Munici. N=200				
<b>Gender: (%)</b>						2.022	3	0.568
Female	61.3	62.5	55.0	57.7	59.7			
Male	38.7	37.5	45.0	42.3	40.3			
<b>Total</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>			
<b>Age of resp:(%)</b>						112.928	9	0.000
18-35 years	60.5	41.5	29.0	15.4	35.8			
36-50 years	36.1	52.0	50.0	51.2	48.5			
51-65 years	3.4	6.5	19.0	31.8	13.9			
above 65	0.0	0.0	2.0	1.5	1.8			
<b>Total</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>			
<b>Education: (%)</b>						118.626	12	0.000
No formal	54.6	78.0	56.0	35.8	57.1			
Primary	19.3	9.0	33.0	51.2	24.3			
JHS/MSLC	16.8	7.0	4.0	7.5	9.5			
SHS	7.6	5.0	4.0	2.5	4.7			
Tertiary	1.7	1.0	3.0	3.0	2.3			
<b>Total</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>			
<b>Marital Status: (%)</b>						16.860	12	0.155
Divorced	0.8	0.5	2.0	0.5	0.9			
Married	95.8	89.0	95.0	91.5	92.5			
Separated	0.0	0.5	0.0	0.5	0.3			
Single	3.4	4.0	3.0	2.5	3.2			
Widowed	0.0	6.0	0.0	5.0	3.1			
<b>Total</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>			
<b>Occup. : (%)</b>						36.865	9	0.000
Civil/Public Serv.	0.0	0.0	2.0	2.5	0.9			
Entrepreneur	0.0	0.5	1.0	0.5	0.5			
Farmer	100.0	99.5	97.0	90.5	95.6			
Trader	0.0	0.0	0.0	6.5	3.0			
<b>Total</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>			
<b>Religion: (%)</b>						243.108	9	0.000
ATR	0.0	0.0	16.0	2.0	4.8			
Christian	0.8	21.0	64.0	10.9	19.8			
Muslim	99.2	79.0	20.0	87.1	75.4			
<b>Total</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>			
<b>Ethnicity:(%)</b>						662.652	15	0.000
Dagomba	98.3	73.5	4.0	0.0	37.7			
Frafra	0.0	0.5	0.0	0.0	0.2			
Konkomba	0.0	24.0	0.0	0.0	7.7			
Kusasis	0.0	1.0	96.0	98.0	50.3			
Mamprusis	0.8	0.0	0.0	0.0	0.2			
Other (Specify)	0.8	1.0	0.0	2.0	1.0			
<b>Total</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>			

## 4.2 Factors Influencing the Adoption of Soybean Yield-enhancing Technologies among the Smallholder Soybean Farmers in the Northern and Upper East Regions of Ghana

Adoption of soybean technologies such as certified seeds, fertilizers, inoculants, mechanized planters, and Good Agricultural Practices (GAPs) was shaped by farmer characteristics, resource endowments, and institutional factors.

*Farmer characteristics:* Age showed a curvilinear effect, with middle-aged farmers more likely to adopt certified seeds and fertilizer, consistent with Rogers' *Diffusion of Innovations* (2003), which suggests adoption peaks when experience and capacity align. Gender also mattered: male-headed households were more likely to adopt mechanized planters and fertilizer, while female-headed households were more inclined toward GAPs, reflecting gendered resource constraints (Doss, 2001; Ragasa et al., 2019). Education was strongly positive across all technologies, echoing findings that higher education enhances the ability to process information and interact with extension services (Asfaw et al., 2012; Feder et al., 1985).

*Credit access:* Although access to credit is commonly assumed to promote the adoption of yield-enhancing inputs, the results indicate a significantly negative relationship between credit access and the use of certified seed and fertilizer. This finding highlights persistent challenges in rural credit markets and the complexities of farmers' decision-making processes. Formal credit arrangements often involve strict conditions and rigid repayment schedules, which may not align with agricultural production cycles. In addition, farmers may divert borrowed funds to meet immediate household needs rather than invest in agricultural inputs. Risk aversion and uncertainty regarding expected returns can further discourage the use of credit for purchasing variable inputs. As noted by Alene et al. (2008), both demand-side behavioral factors and supply-side constraints play critical roles in determining whether credit access translates into increased input adoption.

*Farm and household resources:* Larger farm size consistently promoted adoption across all technologies, confirming earlier evidence that scale reduces risk and increases innovation capacity (Feder et al., 1985; Rogers, 2003). Farming experience also increased adoption, in line with Kitole, (2023) and Fadnavis et al. (2018), who showed that experienced farmers better evaluate innovation benefits. Household size was positive for most technologies but insignificant for GAPs, echoing Zeweld et al. (2019) that labour capacity interacts with technology type. Labour availability raised adoption of certified seeds and fertilizer but reduced uptake of inoculants, mechanized planters, and GAPs, suggesting substitution between labour and mechanization (Wang et al., 2024).

*Market and institutional factors:* Market access encouraged adoption of certified seeds and fertilizer, consistent with evidence that stronger markets incentivize investment in inputs Mawia et al. (2025). In contrast, it did not significantly affect inoculants, mechanized planters, or GAPs, supporting Mahama (2019) that some technologies rely more on knowledge than market incentives. Group membership significantly promoted adoption across all technologies by improving access to information and collective resources (Alene et al., 2008; Ronner et al., 2016; Ndeke, 2021). Demonstration activities and video-based extension also had strong positive impacts, particularly for mechanized planters and GAPs, confirming earlier findings on experiential learning and visual media in reducing uncertainty Capretti (2023).

*Technology attributes:* Ease of use significantly influenced adoption, especially for certified seeds and fertilizers, supporting Rogers (2003) and Doss (2006) that user-friendly innovations spread more easily. Cost effects varied: certified seeds and fertilizers were highly price-sensitive, aligning with Mawia et al. (2025), while mechanized planters and GAPs were less affected by cost, as adoption depends more on expectations of long-term benefits and labour savings Abate et al., (2016). Overall, adoption reflects a mix of farmer characteristics, farm resources, institutional support, and perceived technology traits. While affordability and farm capacity remain central, knowledge access, peer networks, and user-friendliness are equally critical in enabling uptake (Diagne, 2006; Doss, 2006).

**Table 4**

*Factors Influencing the Adoption of Soybean Yield-enhancing Technologies among the Smallholder Soybean Farmers in the Northern and Upper East Regions of Ghana*

Variables	Certified seed		Fertilizer		Inoculant		Mechanized Planters		GAPs	
	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value
Age	0.189	0.001	0.217	0.001	0.128	0.022	0.321	0.001	0.321	0.001
Sex	-0.012	0.878	0.031	0.682	-0.017	0.827	-0.045	0.688	-0.045	0.688
Education	0.392	0.001	0.451	0.001	0.297	0.001	0.621	0.001	0.621	0.001
Farm size	0.318	0.001	0.378	0.001	0.241	0.001	0.498	0.001	0.498	0.001
Experience in farming	0.328	0.001	0.731	0.001	0.481	0.001	0.573	0.001	0.611	0.002
Credit access	-0.148	0.009	-0.198	0.001	0.328	0.001	0.731	0.001	0.731	0.001
Farm ownership	0.031	0.553	0.017	0.805	0.024	0.635	0.041	0.407	0.258	0.004
Labour availability	0.247	0.001	0.292	0.001	-0.159	0.006	-0.289	0.001	-0.289	0.001
Household size	0.135	0.003	0.241	0.001	0.162	0.001	0.192	0.001	0.056	0.390
Access to market	0.442	0.001	0.524	0.001	0.031	0.553	0.017	0.805	0.017	0.805
Access to ext. service	0.365	0.001	0.434	0.001	0.211	0.001	0.405	0.001	0.405	0.001
Group membership	0.277	0.001	0.318	0.001	0.135	0.003	0.241	0.001	0.241	0.001
Use of demos.	0.247	0.001	0.275	0.001	0.382	0.001	0.598	0.001	0.598	0.001
Use of field days	-0.019	0.710	0.002	0.975	0.287	0.001	0.517	0.001	0.517	0.001
Use of video shows	0.366	0.001	0.388	0.001	0.231	0.001	0.412	0.001	0.412	0.001
Ease of technology use	0.431	0.001	0.468	0.001	0.209	0.001	0.378	0.001	0.378	0.001
Cost of technology use	0.332	0.001	0.359	0.001	-0.016	0.759	-0.023	0.758	-0.023	0.758
Planting in rows	-0.049	0.387	-0.062	0.267	0.293	0.001	0.451	0.001	0.451	0.001
Constant	-0.531	0.001	-0.623	0.001	0.348	0.001	0.521	0.001	0.521	0.001
Number of observations	<b>620</b>		<b>620</b>		<b>620</b>		<b>620</b>		<b>620</b>	
LR chi <sup>2</sup> (17)	<b>427.210</b>		<b>498.834</b>		<b>256.409</b>		<b>328.576</b>		328.576	
Prob > chi <sup>2</sup>	<b>0.001</b>		<b>0.001</b>		<b>&lt;0.001</b>		<b>&lt;0.001</b>		<b>&lt;0.001</b>	
Pseudo R <sup>2</sup>	<b>0.688</b>		<b>0.752</b>		<b>0.605</b>		<b>0.652</b>		0.652	
Log pseudo-likelihood	<b>-184.678</b>		<b>-157.421</b>		<b>-172.752</b>		<b>-197.678</b>		-197.678	

## V. CONCLUSION & RECOMMENDATIONS

### 5.1 Conclusion

This study investigated factors influencing smallholder adoption of soybean yield-enhancing technologies in Northern and Upper East Ghana, highlighting how socio-economic, institutional, and structural factors interact to shape uptake. Education, age, extension access, and institutional support collectively enhance both awareness and capacity, creating the conditions necessary for adoption. In contrast, access to credit showed a negative but insignificant effect, suggesting that financial resources alone are insufficient without complementary knowledge, support, and infrastructure.

Structural barriers such as weak extension services, poor weed management, fertilizer challenges, and limited mechanization interact with high costs, land tenure insecurity, supply chain gaps, and inadequate technical knowledge to constrain the use of key technologies, including mechanized planters, inoculants, certified seeds, and fertilizers. Together, these findings underscore that adoption depends on the interplay between affordability, technical capacity, institutional backing, and functional infrastructure, rather than on any single factor in isolation.

### 5.2 Recommendations

The findings indicate that adoption determinants interact in reinforcing ways; therefore, policy responses should be integrated rather than fragmented:

*Adopt an Integrated Extension-Finance-Input Delivery System:* Access to extension services, education, and support mechanisms collectively shape technology adoption. Enhancing extension services through digital advisory platforms, mobile-based tools, and farmer-to-farmer networks should be complemented by bundled inputs, including certified seeds, inoculants, fertilizers, and integrated financial services. By offering technical guidance alongside access to credit and reliable input supply, farmers' perceived risks are reduced, fostering greater confidence to adopt multiple complementary technologies simultaneously.

*Promote Inclusive and Scalable Mechanization Systems:* Farm size is strongly associated with the use of mechanized planters and the adoption of Good Agricultural Practices, indicating the presence of scale effects. Nonetheless, smallholders can also benefit through shared-access models. Policies should support rural mechanization hubs, equipment leasing schemes, and group-based ownership arrangements. These initiatives should be complemented by land tenure reforms and technical training to ensure that mechanization enhances productivity without excluding smaller or resource-constrained farmers.

*Strengthen Input Supply Chains with Institutional Support:* The adoption of certified seeds, fertilizers, and inoculants depends not only on awareness but also on their timely availability and affordability. Investments in rural infrastructure, agro-dealer networks, and last-mile distribution systems should be coordinated with extension services and financial institutions. Well-functioning supply chains reinforce the effectiveness of training and credit interventions.

*Address Financial Barriers Through Risk-Reducing Ecosystems:* Access to finance interacts with factors such as education, extension services, and farm size, influencing adoption decisions. Credit programs are most effective when combined with financial literacy training, crop insurance, savings mobilization, and structured market linkages, as these measures help reduce default risk and improve repayment capacity. Enhancing the capacity of rural financial institutions can foster a supportive ecosystem that sustains adoption beyond the duration of specific projects.

*Design Context-Specific and Systems-Based Interventions:* The influence of determinants on technology adoption is shaped by regional agroecological conditions, socio-cultural norms, and institutional exposure, such as prior project presence. Consequently, policies should adopt a system-oriented approach, designing intervention packages that are tailored to local contexts rather than relying on uniform national strategies. Integrated, regionally adapted bundles that combine extension services, financial support, input, and mechanization are more likely to achieve sustained productivity improvements.

## REFERENCES

- Abate, G. T., Rashid, S., Borzaga, C., & Getnet, K. (2016). Rural finance and agricultural technology adoption in Ethiopia: does the institutional design of lending organizations matter? *World Development*, 84, 235–253.
- Abban, R. (2020). Firm characteristics, business environment, and performance of non-traditional agricultural SME exporters in Ghana. Wageningen University and Research.
- Abdoulaye, T., Wossen, T., & Awotide, B. (2018). Impacts of improved maize varieties in Nigeria: ex-post assessment of productivity and welfare outcomes. *Food Security*, 10(2), 369–379.
- Adesina, A. A., & Zinnah, M. M. (1993). Technology characteristics, farmers' perceptions and adoption decisions: A Tobit model application in Sierra Leone. *Agricultural Economics*, 9(4), 297–311.

- Albishi, T. S., Adaigho, D., Alqahtani, N. K., Sami, R., Uguru, H., Helal, M., ... & Qari, S. H. (2026). In vitro evaluation of bio-fortification effects on the nutritional quality, toxicological safety, and antioxidant of cassava (*Manihot esculenta*) flour, and environmental safety of processing water, using natural additives. *Frontiers in Nutrition*, *12*, 1731737.
- Alene, A. D., Manyong, V. M., Omany, G., Mignouna, H. D., Bokanga, M., & Odhiambo, G. (2008). Smallholder market participation under transactions costs: maize supply and fertilizer demand in Kenya. *Food Policy*, *33*(4), 318–328.
- Amegashie, J. A. (2023). Market segregation in the presence of customer discrimination. *Journal of Behavioral and Experimental Economics*, *105*, 102044.
- Aryal, J. P., Sapkota, T. B., Rahut, D. B., Marennya, P., & Stirling, C. M. (2021). Climate risks and adaptation strategies of farmers in East Africa and South Asia. *Scientific Reports*, *11*(1), 10489.
- Asfaw, S., Kassie, M., Simtowe, F., & Lipper, L. (2012). Poverty reduction effects of agricultural technology adoption: a micro-evidence from rural Tanzania. *Journal of Development Studies*, *48*(9), 1288–1305.
- Balana, B. B., & Oyeyemi, M. A. (2022). Agricultural credit constraints in smallholder farming in developing countries: evidence from Nigeria. *World Development Sustainability*, *1*, 100012.
- Bonabana-Wabbi, J. (2002). Assessing factors affecting adoption of agricultural technologies: The case of integrated pest management (IPM) in Kumi District, Eastern Uganda (Doctoral dissertation, Virginia Tech).
- Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77–101.
- Calderon, V. F., & Berlind, A. A. (2019). Prediction of galaxy halo masses in SDSS DR7 via a machine learning approach. *Monthly Notices of the Royal Astronomical Society*, *490*(2), 2367–2379.
- Capretti, L. (2023). Technology adoption constraints and laser land levelling: evidence from Karnataka, India. Working Papers 1/23, Sapienza University of Rome, DISS.
- Coates, B. S., Poelchau, M., Childers, C., Evans, J. D., Handler, A., Guerrero, F., ... & Shoemaker, D. D. (2015). Arthropod genomics research in the United States Department of Agriculture—Agricultural Research Service: current impacts and future prospects. *Trends Entomol*, *11*(12), 12–27.
- Danso-Abbeam, G., Ehiakpor, D. S., & Aidoo, R. (2018). Agricultural extension and its effects on farm productivity and income: insight from Northern Ghana. *Agriculture & Food Security*, *7*(1), 74.
- Diagne, A. (2006). Diffusion and adoption of NERICA rice varieties in Côte d'Ivoire. *The Developing Economies*, *44*(2), 208–231.
- Diao, X., Hazell, P., & Thurlow, J. (2010). The role of agriculture in African development. *World Development*, *38*(10), 1375–1383.
- Dogbe, W., Etwire, P. M., Etwire, J. C., Baba, I. I. Y., & Siise, A. (2013). Economics of soybean production evidence from Saboba and Chereponi Districts of Northern Region of Ghana. *Journal of Agricultural Science*, *5*, 38–46.
- Donkor, E., & Owusu, V. (2019). Mineral fertiliser adoption and land productivity: implications for securing stable rice production in northern Ghana. *Land*, *8*(4), 59.
- Doss, C. R. (2001). Designing agricultural technology for African women farmers: lessons from 25 years of experience. *World Development*, *29*(12), 2075–2092.
- Doss, C. R. (2006). Analyzing technology adoption using microstudies: limitations, challenges, and opportunities for improvement. *Agricultural Economics*, *34*(3), 207–219.
- Dzanku, F. M., & Sarpong, D. B. (2014). Ghana: household-level farm–nonfarm linkages and household welfare implications. Ghana Micro Report, Institute of Statistical Social & Economic Research, Legon, Ghana.
- El-Agroudy, N., Mokhtar, S., Zaghlol, E. A., & El Gebaly, M. (2011). An economic study of the production of soybean in Egypt. *Agric Biol JN Am*, *2*(2), 221–225.
- Emmanuel, D., Owusu-Sekyere, E., Owusu, V., & Jordaan, H. (2016). Impact of agricultural extension service on adoption of chemical fertilizer: implications for rice productivity and development in Ghana. *NJAS: Wageningen Journal of Life Sciences*, *79*(1), 41–49.
- Eric, O. O., Prince, A. A., & Elfreda, A. N. A. (2014). Effects of education on the agricultural productivity of farmers in the Offinso Municipality. *International Journal of Development Research*, *4*(9), 1951–1960.
- Evan, A. T., Vimont, D. J., Heidinger, A. K., Kossin, J. P., & Bennartz, R. (2009). The role of aerosols in the evolution of tropical North Atlantic Ocean temperature anomalies. *Science*, *324*(5928), 778–781.
- Fadnavis, S., Roy, C., Chattopadhyay, R., Sioris, C. E., Rap, A., Müller, R., ... & Krishnan, R. (2018). Transport of trace gases via eddy shedding from the Asian summer monsoon anticyclone and associated impacts on ozone heating rates. *Atmospheric Chemistry and Physics*, *18*(15), 11493–11506.
- Feder, G., Just, R. E., & Zilberman, D. (1985). Adoption of agricultural innovations in developing countries: a survey. *Economic Development and Cultural Change*, *33*(2), 255–298.
- Gustafsson, J., Cederberg, C., Sonesson, U., & Emanuelsson, A. (2013). The methodology of the FAO study: global food losses and food waste—extent, causes and prevention. FAO.

- IDDI, T. (2024). Evaluation of soybean (*Glycine max* (L.) Merrill) germplasm for improved agronomic traits for potential mechanical harvesting (Doctoral dissertation).
- Johnson, S. R., Bernstein, E. J., Bolster, M. B., Chung, J. H., Danoff, S. K., George, M. D., ... & Ivlev, I. (2024). 2023 American College of Rheumatology (ACR)/American College of Chest Physicians (CHEST) guideline for the treatment of interstitial lung disease in people with systemic autoimmune rheumatic diseases. *Arthritis & Rheumatology*, 76(8), 1182–1200.
- Kalton, G. (2009). Methods for oversampling rare subpopulations in social surveys. *Survey Methodology*, 35(2), 125–141.
- Kassie, M., Teklewold, H., Jaleta, M., Marennya, P., & Erenstein, O. (2015). Understanding the adoption of a portfolio of sustainable intensification practices in eastern and southern Africa. *Land Use Policy*, 42, 400–411.
- Kitole, F. A. (2023). Economics of agricultural development: world food systems and resource use. Routledge.
- Kwao, B. (2017). Sustainable systems in Northern Ghana: assessing the influence of international development. Brock University.
- Kwapong, N. A., Whitfield, S., Ambuko, J., Ankrah, D. A., & Swanepoel, F. (2024). Using participatory videos in understanding farmers experiences with climate smart agricultural practices: reflections from Ghana. *Frontiers in Sustainable Food Systems*, 7, 1282993.
- Langdon, S., Ritter, A. R., & Samy, Y. (2018). African economic development. Routledge.
- Luca, A., Marzia, I., Stefania, C., Di Pietro, C., Sortino, G., Vukadin, A., & Simona, B. (2018). Pasta experience: eating with the five senses—A pilot study. *AIMS Agriculture and Food*, 3(4), 493–520.
- Mahama, A. (2019). Agricultural technology transfer mechanisms and adoption among soybean farmers in Chereponi District of Northern Region of Ghana (Doctoral dissertation, University for Development Studies).
- Maiga, W. H., Porgo, M., Zahonogo, P., Amegnaglo, C. J., Coulibaly, D. A., Flynn, J., ... & Chimwaza, G. (2020). A systematic review of employment outcomes from youth skills training programmes in agriculture in low- and middle-income countries. *Nature Food*, 1(11), 755.
- Marennya, P. P., & Barrett, C. B. (2007). Household-level determinants of adoption of improved natural resources management practices among smallholder farmers in western Kenya. *Food Policy*, 32(4), 515–536.
- Martey, E., Wiredu, A. N., Etwire, P. M., Fosu, M., Buah, S. S. J., Bidzakin, J., ... & Kusi, F. (2014). Fertilizer adoption and use intensity among smallholder farmers in Northern Ghana: a case study of the AGRA soil health project. *Sustainable Agriculture Research*, 3(1), 24–36.
- Marty, R., Kaabinejadian, S., Rossell, D., Slifker, M. J., van de Haar, J., Engin, H. B., ... & Carter, H. (2017). MHC-I genotype restricts the oncogenic mutational landscape. *Cell*, 171(6), 1272–1283.
- Marzia, M., Guaiquil, V., Horne, W. C., Blobel, C. P., Baron, R., & Chiusaroli, R. (2011). Lack of ADAM15 in mice is associated with increased osteoblast function and bone mass. *Biological Chemistry*, 392(10), 877–885.
- Mawia, H., Mburu, J., Chimoita, E., & Rutsaert, P. (2025). Understanding seed selection decisions among small-scale maize farmers in Machakos County, Kenya: the dominance of market leader varieties. *Frontiers in Sustainable Food Systems*, 9, 1563538.
- McGuire, S., & Sperling, L. (2016). Seed systems smallholder farmers use. *Food Security*, 8(1), 179–195.
- Mohammed, M. A., Moles, R. J., & Chen, T. F. (2016). Meta-synthesis of qualitative research: the challenges and opportunities. *International Journal of Clinical Pharmacy*, 38(3), 695–704.
- Mwangi, M., & Kariuki, S. (2015). Factors determining adoption of new agricultural technology by smallholder farmers in developing countries. *Journal of Economics and Sustainable Development*, 6(5), 208–216.
- Ndeke, A. M. (2021). Gender influence on soil fertility and water management technologies uptake among smallholder farmers in Tharaka Nithi County (Doctoral dissertation, University of Embu).
- Ndiritu, S. W., Kassie, M., & Shiferaw, B. (2014). Are there systematic gender differences in the adoption of sustainable agricultural intensification practices? Evidence from Kenya. *Food Policy*, 49, 117–127.
- Nkamleu, G. B., & Adesina, A. A. (2000). Determinants of chemical input use in peri-urban lowland systems: bivariate probit analysis in Cameroon. *Agricultural Systems*, 63(2), 111–121.
- Obasoro, O. A., Iwinlade, A., Popoola, O., & Adeoti, A. I. (2015). Effect of adoption of improved soybean variety on productivity of farm households in Benue State, Nigeria. *Legume Genomics and Genetics*, 6.
- Owusu-Akuoko, O. S. W. A. L. D. (2016). Analysis of constraints for the optimization of nutrient use in soybean production in smallholder agriculture in Northern Ghana (Doctoral dissertation, University of Hohenheim).
- Plahar, M. A., Hung, Y. C., & McWatters, K. H. (2006). Improving the nutritional quality and maintaining consumption quality of akara using curdlan and composite flour. *International Journal of Food Science and Technology*, 41(8), 962–972.
- Prajapati, C. S., Priya, N. K., Bishnoi, S., Vishwakarma, S. K., Buvanewari, K., Shastri, S., ... & Jadhav, A. (2025). The role of participatory approaches in modern agricultural extension: bridging knowledge gaps for sustainable farming practices. *Journal of Experimental Agriculture International*, 47(2), 204–222.

- Ragasa, C., Aberman, N. L., & Mingote, C. A. (2019). Does providing agricultural and nutrition information to both men and women improve household food security? Evidence from Malawi. *Global Food Security*, 20, 45–59.
- Rao, N. K., & Sastry, D. V. S. S. R. (1998). Seed quality considerations in germplasm regeneration. In *Regeneration of seed crops and their wild relatives* (p. 144). Bioversity International.
- Rehman, A. A., & Alharthi, K. (2016). An introduction to research paradigms. *International Journal of Educational Investigations*, 3(8), 51–59.
- Rickards, C., Marenya, P., Chiduwa, M., Eitzinger, A., Fisher, M., & Snapp, S. (2025). Enhancing farmers' agency is a more effective extension paradigm: the case of soil health management in Africa. *Agricultural Systems*, 225, 104267.
- Ricker-Gilbert, J. (2020). Inorganic fertiliser use among smallholder farmers in sub-Saharan Africa: implications for input subsidy policies. In *The role of smallholder farms in food and nutrition security* (pp. 81–98). Springer.
- Rogers, E. (2003). *Diffusion of innovations* (5th ed.). Free Press.
- Ronner, E., Franke, A. C., Vanlauwe, B., Dianda, M., Edeh, E., Ukem, B., ... & Giller, K. V. (2016). Understanding variability in soybean yield and response to P-fertilizer and rhizobium inoculants on farmers' fields in northern Nigeria. *Field Crops Research*, 186, 133–145.
- Sennuga, S. O., Fadiji, T. O., & Thaddeus, H. (2020). Factors influencing adoption of improved agricultural technologies among smallholder farmers in Kaduna State, Nigeria. *International Journal of Agricultural Education and Extension*, 6(2), 382–391.
- Shakya, P. B., & Flinn, J. C. (1985). Adoption of modern varieties and fertilizer use on rice in the Eastern Tarai of Nepal. *Journal of Agricultural Economics*, 36(3), 409–419.
- Shea, B., Knowlton, K., & Shaman, J. (2020). Assessment of climate-health curricula at international health professions schools. *JAMA Network Open*, 3(5), e206609.
- Shilomboleni, H., Recha, J., Radeny, M., & Osumba, J. (2023). Scaling climate resilient seed systems through SMEs in Eastern and Southern Africa: challenges and opportunities. *Climate and Development*, 15(3), 177–187.
- Sims, B., & Kienzle, J. (2017). Sustainable agricultural mechanization for smallholders: what is it and how can we implement it? *Agriculture*, 7(6), 50.
- Singh, H., & Montgomery, C. A. (1987). Corporate acquisition strategies and economic performance. *Strategic Management Journal*, 8(4), 377–386.
- Tetteh, F. M., Quansah, G. W., Frempong, S. O., Nurudeen, A. R., Atakora, W. K., & Opoku, G. (2017). Optimizing fertilizer use within the context of integrated soil fertility management in Ghana. In *Fertilizer use optimization in sub-Saharan Africa* (pp. 67–81). CABI.
- Tonkin-Crine, S., Anthierens, S., Hood, K., Yardley, L., Cals, J. W., Francis, N. A., ... & GRACE INTRO/CHAMP Consortium. (2015). Discrepancies between qualitative and quantitative evaluation of randomized controlled trial results: achieving clarity through mixed methods triangulation. *Implementation Science*, 11(1), 66.
- Wang, W., Yang, Z., Gu, X., Mugeru, A., & Yin, N. (2024). How farm machinery rental services and off-farm work affect household income in China. *Agriculture*, 14(10), 1672.
- Wilson, R. T. (2015). Soya bean *Glycine max* (L.) Merr. genetic resources in Tanzania, 1905–2013. *African Journal of Plant Science*, 9(9), 374–384.
- Yussif, M. M. (2019). Social networks and integrated soil fertility management adoption: effects on maize yields and food security of farmers in Northern Region (Doctoral dissertation).
- Zeweld, W., Van Huylenbroeck, G., Tesfay, G., & Speelman, S. (2019). Impacts of socio-psychological factors on smallholder farmers' risk attitudes: empirical evidence and implications. *Agrekon*, 58(2), 253–279.