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Adoption of Sustainable Intensification Practices among Smallholder Rice Farmers in Northern Ghana: A Case Study of the Savelugu Municipality

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ABSTRACT

Sustainable agricultural intensification is essential for climate change adaptation among smallholder farmers. This study examined factors influencing the adoption of sustainable agricultural intensification practices (SIPs) among smallholder rainfed rice farmers in the Savelugu Municipality. The Municipality is a dominant rice production hub in northern Ghana under rain-fed rice production systems. A total of 241 farmers were interviewed in three rice-growing communities, and the Generalised Poisson Count Regression model was employed to analyse the data. The results revealed that mechanised ploughing, chemical fertilisers and herbicide application account for more than 90% of all SIPs in the study area. The point of sale of farm produce, access to extension services, accessibility of the farming community, and agricultural credit positively affected the number of SIPs adopted. In contrast, farming experiences, membership of farmer-based organization, distance to the nearest market, input subsidy, livestock ownership, seasonal migration, and rice farm income negatively affected the number of SIPs adopted by farmers. The study draws attention to the insightful contextual meaning of factors that influence the adoption of SIPs, including the role of social capital (FBO membership), policy (access to subsidy) and resource endowment (livestock ownership). Using a broad conceptualisation of SIP with an emphasis on social, economic, and institutional variables that are likely to result in trade-offs and synergies within the smallholder rice-growing farming production system, this study contributes to the growing literature on smallholder farmer adoption behaviour in a constrained environment and sheds light on farmers' understanding and conception of SIP practices in the context of climate variability.

Keywords: *sustainable agricultural intensification, climate change, rice, technology adoption, Ghana*

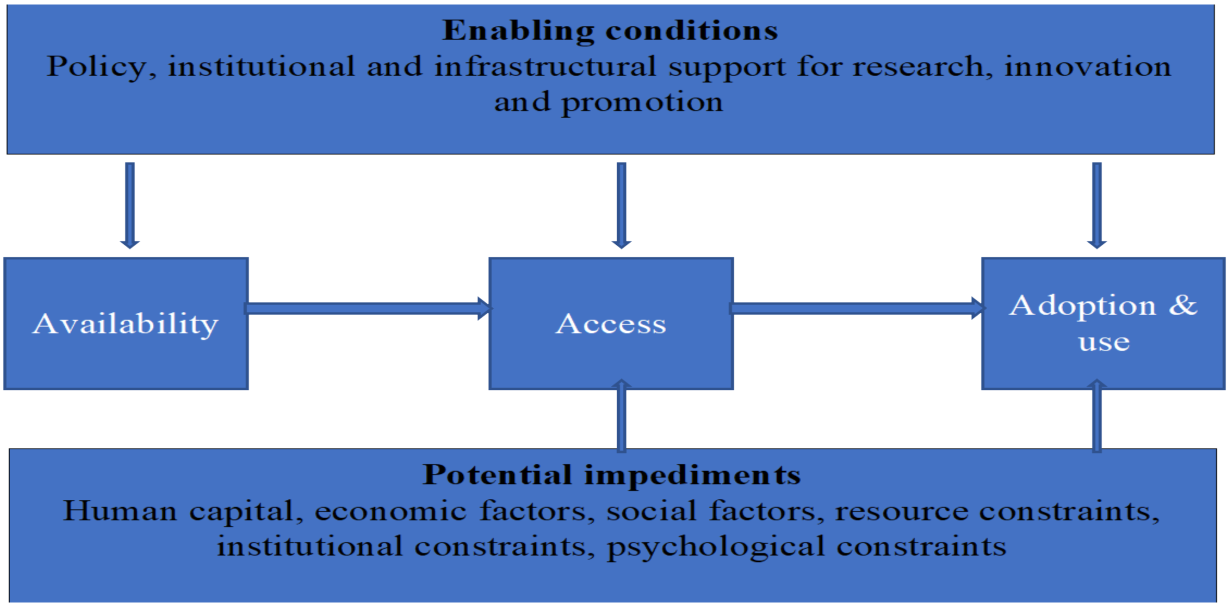
INTRODUCTION

Agricultural intensification in Africa derives its foundations from the Asian Green Revolution (Estudillo et al., 2023). This approach is primarily centred on the extensive use of seeds and fertilisers. However, it is essential to note that unlike in Asia, where the Green Revolution had a significant impact, the results have been less noticeable in Africa. For instance Schutt & Giller (2020) argue that only a small fraction of farmers will adopt fertilizer technology in Africa due to risks associated with unfavourable market conditions and yield uncertainties. Ajayi et al. (2018) suggest that the poor pace of agricultural technology in Africa is due to the lack of consideration of other factors required for sustained technology adoption. Consequently, introducing business models based on contextual considerations is key to sustained technology adoption (Birhanu & Jensen (2023).

Consequently, sustainable agricultural intensification has been suggested as a more responsive approach to increasing the productivity and resilience of agricultural systems, especially in the Global South (Jones-Garcia & Krishna, 2021). This has occasioned a paradigm shift in the discourse on agricultural intensification in Africa (Jones-Garcia & Krishna, 2021). Sustainable agricultural intensification is "a process or system where agricultural yields are increased without adverse environmental impact and the conversion of additional non-agricultural land" (Pretty & Bharucha, 2014). In practice, sustainable agricultural intensification involves using multiple technologies in agricultural production (Haile et al., 2017). In reality, smallholder farmers in Africa often adopt multiple farming practices to maximise their outputs and minimise risks, unlike the monoculture practised by their Asian counterparts (Moda et al., 2023). The adoption and use of multiple farming technologies have become even more crucial due to the growing uncertainty of rain-fed agriculture due to climate change.

Musumba et al. (2017) suggest that concept of sustainable intensification (SIP) emphasises a set of changes in management practices or technologies that leads to varying environmental and socioeconomic trade-offs and synergies across and within domains rather than a unique set of agricultural practices. Therefore, there can be multiple pathways to sustainable agricultural intensification that will vary by location and scale subject to the agro-ecological conditions, farming system, cultural preferences of farmers, institutions and policies (Helfenstein et al., 2020). Subsequently, Nelson et al. (2020) showcase SIP as 'a diverse set of agricultural system actors, who are bounded by rules and structures and influenced by varied drivers at different scales, make decisions on agricultural and land use trade-offs'.

In this study, SIP adoption connotes the long-term integration of technology into household livelihood activities. It is understandable that smallholder rainfed farmers, whose primary source of livelihood is crop cultivation, will seek to reduce the risk associated with technology adoption by maintaining their time-tested technology while adopting new technology. This is supported by the theory of rational choice, which essentially suggests that economic agents seek to select options that maximise their behaviour when confronted with alternatives (Zhang, 2024). Thus, farmers will compare the benefits of adopting new technology to the benefits derived from current technology and only adopt a new one if they expected net benefit of adopting that technology exceeds the benefits from non-adoption. In this case, the specific contextual conditions within which farmers operate are crucial in informing farmers' adoption decision-making. Consequently, optimal adoption decision-making among smallholder farmers must be supported by sufficient contextual considerations. This must be occasioned by a broader and sufficient analysis that informs a deeper understanding of farmers contextual realities. Indeed, Berg et al. (2018) project SIP as a unifying concept and relatively pragmatic pathway towards agricultural sustainability, with scope for adaptation to specific circumstances within the boundaries of its key environmental sustainability principles. This implies that SI's role as an organising framework for research, in line with the recommendations of much of the SI literature, needs to be sustained through context-specific conceptual framing, metrics and the testing of actual farming practices.



The study focuses on the Savelugu Municipality in Northern Ghana due to its importance for rice production. The area is home to many developed rice valleys, including Yapali, Diare and Nakpanzuo. However, rice yield has declined over time despite extensive promotion of sustainable intensification practices. Data obtained from the Department of Agriculture indicates that rice yield declined from 32.6t/ha to an average of 28.7t/ha from 2014 to 2017 (MoFA, 2025). The area is also characterised by difficult climatic conditions, such as the increasing incidence of dry spells, drought, and flooding, further exacerbating the challenges of rice production. Consequently, the study addresses the following research questions:

1. What is the state of knowledge on sustainable intensification practices among smallholder rice-growing households?
2. What factors shape farmer decision to adoption of sustainable intensification practices?

The study contributes to the growing literature on smallholder farmer adoption behaviour in a constrained environment by focusing on a broad conceptualisation of SIP with an emphasis on social, economic, and institutional variables that are likely to result in trade-offs and synergies within the smallholder rice-growing farming system. It also sheds light on farmers' understanding and conception of SIP practices in the context of climate variability.

Conceptual framework

From its original focus mainly on productivity and environmental concerns, the definition of SI has evolved to include non-environmental dimensions such as social, cultural, economic, and the human condition (Rockström et al., 2017). In a more recent review of literature, Smith et al. (2017) highlight additional domains, including human condition, nutrition and social equity. Dahlin and Rusinamhodzi (2014) have emphasised the role of management strategies that reverse land degradation and reduce yield losses in the context of climate change. The inclusion of these additional dimensions in emerging definitions is important as it helps to balance the environmental, economic, and social objectives of sustainable intensification. Figure 1 illustrates a conceptual framework for the availability, access and adoption of SIPs.

Figure 1: Conceptual framework

The failure of the Asian-style Green Revolution to achieve impact in Africa highlights the need for context-specific approaches to be designed to achieve sustainable impact. Nin-Pratt and Mabride (2014), while conceding the fact that there may be 'valid reasons for a renewed interest in adapting the lessons of the Asian Green Revolution' for Africa, emphasize the need for research to go further in identifying the potentially unique factors driving agricultural intensification within and across African countries. This approach recognizes the importance of creating a supportive and appropriate environment that enables the implementation of sustainable intensification practices (SIPs), along with the necessary infrastructure and institutions for research and innovation. The approach has consequences for the availability, accessibility and adoption of the appropriate mix of SIPs that are contextually suitable. It is important to note that the availability and adoption of SIPs are mediated by access. Access, in turn, is mediated by several factors that also have implications for the actual adoption of SIPs and their eventual usage. These include human capital, economic factors, social factors, resource constraints, institutional constraints and the often neglected psychological and behavioural factors shaped by specific contexts and experiences. The fact that these factors affect access, adoption and sustained use of SIPs are interrelated must be recognized. However, the relative impact of the factors on access to SIPs and the actual adoption must be weighed carefully. This study emphasizes these factors and their impact on the adoption and sustained use of SIPs under the specific context and conditions of rain-fed smallholder farmers in the Savelugu district, climate variability and a long history of exposure to SIPs.

Following Musumba et al. (2017), we highlight the role of variables related to productivity, economic, environment, human condition and social dimensions of SI: human capital, institutional capital, resource endowment, social capital and resource constraint.

Human capital

The OECD defines human capital as 'the stock of knowledge, skills and other personal characteristics embodied in people that helps them to be productive' (Botev et al., 2019). The role of human capital in technology adoption has been examined in technology adoption research (Skare & Blažević, 2021; Danquah & Amankwah-Amoah, 2017). Adoption costs are higher when economic agents must make decisions under conditions of uncertainty and incomplete information. Shibli et al. (2021) shows that household-level human capital is directly and positively related to the adoption of agricultural technology. Huffman (2020) indicates that in a dynamic economic and technical environment, better educated farmers make better technology adoption decisions. In the present study, age, formal education, gender and experience in rice cultivation constituted human capital.

Institutional capital

Garrabé (2007) defines institutional capital as 'the whole of the formal and abstract institutions which constitute the inciting structure organizing the relations between individuals or organizations, within the process of economic and social production'. Thus, institutions may be viewed as constraints or incentives for human action. Sulaiman (Sulaiman et al., 2021) notes that the institutional environment plays a crucial role in technology adoption by providing the enabling environment. Jones-Garcia and Krishna (2021) emphasize the need to incorporate the socio-institutional context to develop better research strategies for adoption studies. Various studies have explored the effect of institutional factors on technology adoption. Ishola and Arumugam (2019) demonstrate the effect of institutional factors on technology adoption in Nigeria. According to Tanti et al. (2022), institutional support is crucial to enable resource-poor farmers to overcome financial and knowledge constraints in adopting climate-smart agricultural practices. This study considers institutions as constraints or opportunities for farmers' adoption of SIPs. The following institutional factors were considered: year-round accessibility to a farming community, access to extension, point of sale of farm produce, subsidy and distance to the nearest market.

Resource endowment

From the demand perspective, economic factors play an essential role in technology adoption by enabling the acquisition of external resources, especially when adopting new technology requires external input. Household resource endowment is important in determining agricultural technology adoption since it affects a household's ability to acquire technology and manage the risk of investing limited household resources in new technology. Household resource endowment or wealth has been noted to influence SIP adoption (Theriault et al., 2017; Oyetunde-Usmanm, 2021). Guo et al. (2020) argue that income is crucial to the adoption of SIPs. Household resource endowments considered determinants of SIP adoption are livestock ownership, seasonal migration by a farmer, permanent migration of a household member, off-farm employment, the primary source of household income and household size.

Resource constraint

Resource constraints define the opportunity set for farmers in a given context, and farmers will seek to minimize these constraints to maximize their gains from farm investment. Like every economic agent, farmers will carefully assess the resource constraints encountered in a given context and their implications before choosing a technology. Mellon-Bedi et al. (2020) demonstrated that resource constraints limit SIP adoption in northern Ghana. Grabowski and Kerr (2014) show that capital and labour constraints limit technology adoption among smallholder farmers in Burkina Faso. Thus, resource-poor farmers are financially constrained from adopting climate-smart agriculture (Tanti et al., 2022). Factors constraining farmers' successful adoption of SIPs in the study area include land ownership, land tenure security, access to credit, access to hired labour, natural disaster incidence and access to suitable land for farm expansion.

Social capital

Social capital is crucial to SIP adoption (Sulaiman et al., 2021). Social capital 'encompasses the 'norms and networks facilitating collective actions for mutual benefits' (Biresaw, 2019). Farmers are intricately related through their social networks, which generally influence their behaviour by fostering collective actions, reducing transaction costs, relaxing supply-side constraints and disseminating information (Husen et al., 2017; Hunecke et al., 2017; Cordaro & Desdoigts, 2021). Mellon-Bedi et al. (2020) indicate that a lack of social support impedes the adoption of SIPs among farmers in northern Ghana. This study considers membership in Farmer-based Organizations and trust under social capital.

MATERIALS AND METHODS

The Study area

The Savelugu municipality is in the Northern Region of Ghana. It shares boundaries with West Mamprusi to the North, Karaga and Nanton to the East, Kumbungu to the West and Tamale Metropolitan Assembly to the South. The

Municipality has a population density of 68.9 persons per sq. km., making it one of the most densely populated districts in the northern region. According to the 2021 population and housing census, the population of the Municipality is 122,888, comprising 60,390 (49.1%) males and 62,498 (50.9%) females. About 62.9% of the population is urban. However, agriculture is the primary source of livelihood for the people, employing 74.1% of the economically active population in the Municipality. Like most rural areas in Ghana, the district has a high illiteracy rate of 59.8%. The Municipality is within the savannah ecological zone with an average annual rainfall of 800mm, high temperatures ranging from 16^0C to 42^0C, and an average temperature of 34^0C. The land in the Municipality is generally flat with gentle undulating low relief throughout, with the altitude ranging from 400-800 ft. above sea level. The northern part of the Municipality is characterised by gentle slopes, while the southern part has scattered hills. The area is drained mainly by the White Volta and its tributaries, rendering the northern part of the Municipality, including the study area, prone to periodic flooding during the wet season, thus making them suitable for rice cultivation. The Municipality is home to major rice-growing valleys, notably Diare, Nakpanzuo, and Yipalsi. The vegetation consists mainly of the Savannah woodland with scattered drought and fire-resistant trees such as Parkia bigloboza, Vitellaria paradoxa and Diospyros sp.

Figure 1: Map of Savelugu Municipality source: DNRGS, UDS

Sampling and methods of data collection

A population of 1,278 smallholder rainfed rice-growing households, namely Diare, Nankpanzoo and Yapalsi communities, was obtained from the Department of Agriculture. These communities were purposively selected because they are notable rice-growing hubs. A sample of 241 smallholders was obtained using Krejcie and Morgan's (1970) formula for sample size determination at a 95% confidence level and an estimated population proportion of 50%. A list of smallholder rice farming households was obtained for each community, and the sample of approximately 80 households was drawn by lottery. Questionnaires were administered to participating farmers within households to obtain quantitative data through household surveys using trained and experienced enumerators with knowledge of the local language. Respondents were typically the household head. In some cases, the household head nominated a household member to represent the household. Enumerators ensured that household representatives were familiar with the household's rice production and other socio-economic activities.

Estimation procedure

By its nature, the adoption of SIPs involves multiple choices and a choice problem. Therefore, the Poisson regression model is employed to analyse farmers' decisions to adopt SIPs. Previous studies have used the ordered probit model to analyse the adoption of multiple SIPs (Kotu et al., 2017; Haile et al., 2017; Oyetunde-Usman et al., 2021; Weltin et al., 2018). However, Weltin et al. (2018) noted that farmers adopt multiple SIPs simultaneously, and therefore, the number of technologies adopted is not categorical. Thus, the Poisson count model offers a more robust approach to measuring SIP adoption. The Poisson count model's central assumption is that the dependent variable Y has a Poisson distribution. For a univariate Poisson distribution, the average number of occurrences of an event is denoted by a single variable μ, which is a non-negative real number (i.e., μ>0). Following Donkor et al. (2018), a variable y which follows a Poisson distribution and takes values equal to or greater than zero with parameter μ denotes the number of SI strategies adopted by a farmer in a given cropping season and is represented by a probability mass function as follows:

$$\Pr(Yi = y) = \frac{e^{-\mu}\mu^{y}}{y!}, y = 0,1,2,\dots,k \quad (1)$$

Where Yi denotes the dependent variable for the i[th] observation, y is an occurrence of an event or count, and μ is the intensity of occurrence or rate of an event. A key requirement of the Poisson probability distribution is the equidispersion which says that the mean and variance of the dependent variable must be equal

i.e., $E(Yi) = Var(Yi) = \mu$).

To ensure that the mean is non-negative and non-zero ($i.e., \mu > 0$), μ is expressed as:

$$\mu = \exp(X'\beta) \quad (2)$$

Where X represents a vector of explanatory variables and β is the parameter to be estimated.

Given a set of explanatory variables, equation (2) can be expressed as:

$$E(Y_i) = exp^{(\beta 1X1i)} exp^{(\beta 2X2i)} exp^{(\beta 3X3i)} \dots\dots\dots exp^{(\beta kXki)} \quad (3)$$

$$= exp^{(\beta jXji)}\text{Cj}$$

$$(i = 1, \dots\dots, n) \quad (3)$$

Where j can take any value from 1 to k and is associated with a specific explanatory variable, and Cj represents the product of the remaining exponential terms in (3) and is a constant. Since the Poisson model is non-linear, maximum likelihood estimation (MLE) is employed to obtain parameters and is expressed as follows:

$lnL(\beta) = ln\left[\frac{e^{-\mu}\mu^{y}}{y!}\right] = -\mu + y_i \ln(\mu) - \ln(y_i!)$
$= -\exp(x'_i\beta) + y_i(x'_i\beta) - \ln(y_i!)$ 4

The marginal effect of a variable on the average number of events is stated as follows:

$$\frac{dE\left(y_i/x_i\right)}{dx_j} = \beta_j \exp(X'_i\beta) \quad 5$$

Thus, a unit increase in X_i will result in an increase or decrease in the average number of the dependent variable, in this case, the number of SI strategies adopted by a farmer, by the marginal effect. It is important to note that the assumption of equi-dispersion is unrealistic, especially in a developing country context, due to challenges with data quality (Agula et al., 2018; Greene, 2008).

The Generalized Poisson regression model

The appropriateness of the Poisson regression model for data analysis is examined. The dependent variable is not normally distributed and discrete. The distribution indicates relatively high counts for lower values for lower levels of adoption of SIPs (the dependent variable) and fewer counts for higher levels of adoption. Thus, the dependent variable is skewed to the right, justifying using the Poisson regression model to analyse the data. Another important criterion is the assumption that the mean of the dependent variable is equal to the variance (equi-dispersion). The mean of the dependent variable is 5.1 while the variance is 4.7, indicating that the data is under-dispersed, thus violating the equi-dispersion assumption. Although under-dispersion is not common in survey data, the phenomenon is real and possible compared to over-dispersion. Modelling under-dispersed count data using inappropriate models is misleading as it results in overestimated standard errors and unrealistic inference (Harris et al., 2012). In such a case, Winkelmann and Zimmermann (1994) proposed the Generalized Poisson regression model (GP) to address the under-dispersion problem

Following Harris et al., (2012), a given under-dispersed count data represented by Y, a regression model based on the GP distribution, assuming a response variableY_i has the following probability mass function as follows:

$$f(y_{i;}\theta_i, \delta) = \frac{\theta_i(\theta_i+\delta y_i)^{y_i-1}e^{-\theta_i-\delta y_i}}{y_i!}, y_i = 0,1,2, \dots\dots \quad (6)$$

where $\theta_i > 0$ and $\max(-1, -\theta_i/4) < \delta < 1$

The mean and variance of the GP random variable Y_i are given as:

$$\mu_i = E(Y_i) = \frac{\theta_i}{1-\delta}, Var(Y_i) = \frac{\theta_i}{1-\partial^3} = \frac{\theta_i}{1-\partial^2}E(Y_i) = \emptyset E(Y_i) \quad (7)$$

Where the term $\emptyset = \frac{\theta_i}{1-\partial^2}$ is a dispersion factor. Depending on the value of ∂ a variable may be equi-dispersed ($\partial = 0$), overdispersed ($\partial > 0$) and under dispersed ($\partial < 0$). In the case of under-dispersion, as it is with the data under consideration, the associated log likelihood L is given by

$$L = \sum_{i=1}^{n} L(\theta_i, \delta; y_i) = \sum_{i=1}^{n} lnL(\theta_i, \delta; y_i)$$
$$= \sum_{i=1}^{n}\{ln\theta_i + (y_i - 1)\ln(\theta_i + \delta y_i) - (\theta_i + \delta y_i) - lny_i!\} \quad (8)$$

Consequently, the following relationship which allows for the introduction of covariates into a regression

$$log\frac{\theta_i}{1-\delta} = \sum_{r=1}^{p} x_{ir}\beta_r \quad (9)$$

where x_{ir} is the ith observation of the rth covariate, p is the number of covariates in the model, and B_r is the rth regression parameter.

Empirically, the number of SIP strategies adopted by a farmer is assumed to be a function of human capital (H), institutional factors (I), economic factors (E), social factors (S) and resource constraints (R). The variables were categorised to allow a deeper and a more focused discussion.

$$SI_i = f(H, I, E, S, R) \quad 10$$

Thus, the intensity of SI adopted is expressed as the combined effect of human capital, institutional factors, economic factors, social factors and natural factors and is expressed as below:

$$SI_i = \sum_{J=1}^{J} \alpha_J H_i + \sum_{j=1}^{J} \beta_j I_i + \sum_{j=1}^{J} \gamma_i E_i + \sum_{j=1}^{J} \delta_i S_i + \sum_{j=1}^{J} \omega_i R_i + \varepsilon_i \quad (11)$$

Variables included in the model

Description of variables and a priori expectations

Indicators have been selected to reflect the context and reality of smallholder rainfed rice-growing households in the Savelugu Municipality

Dependent variable: No. of SIPs adopted by a farmer (Fertilizer, pesticides, weedicides, improved varieties, row-planting, dibbling, crop insurance, bunding, mechanization, harvester, early planting, late planting, improved seed).

Explanatory variables: Twenty-five (25) explanatory variables categorized under human capital, institutional capital, economic endowment, social capital and resource constraints are considered.

Table 1: Variables and a priori expectations

Variable	Definition/Description	Measurement	A priori expectation
A: Dependent variables: A count of fertilizer, pesticides, weedicides, improved varieties, row-planting, dibbling, crop insurance, bunding, tractor, harvester, early planting, late planting, improved seed.			
B: Independent variables			
Human capital			
Age	Age of a farmer	Years	-ve
Education	Access to formal education	No. of years of formal education	+ve
Gender	Sex of a farmer	Male=1, Female=0	+ve
Experience	Experience in rice farming	Number of years in rice farming	-ve
Institutional capital			
Accessibility	Nature of road linking the community to the market	Motorable=1, No= otherwise	+ve
Access to Extension	Regular access to extension services	Yes=1, No=0	+ve

Subsidy	Regular access to input subsidy	Yes=1, No=0	+ve
Point of sale of farm produce	Distance to the point of sale	Distance in km	+ve
Market Distance	Distance to the nearest market	Distance in km	-ve
Resource endowment			
Landholding	Number of rice fields owned by a farmer	Count of individual plots	-ve
Livestock	Number of small ruminants owned by a farmer	Count the number of livestock	+ve
Seasonal migration	Farmer engages in seasonal migration	Yes=1, No=0	-ve
Migration of a HH member	A member of the household has migrated permanently in the past 10 years	Count of the number of HH members	-ve
Off-farm employment	Farmer engages in off-farm employment	Yes=1, No=0	-ve
Rice income	Primary source of household income	Farm = 1, Non-farm = 0	+ve
Household size	No. of persons living in a household	No. of persons directly under the care of a farmer	+ve
Social capital			
FBO membership	The farmer belongs to an FBO	Yes=1, No=0	+ve
Trust	Sustained support for SIP adoption is not assured	Yes=1, No=0	+ve
Resource Constraints			
Land ownership	Farmer has tenure right to rice plot	Yes = 1, No = 0	+ve
Land tenure security	Tenure to rice plot is secure	Yes=1, No=0	+ve
Hired labour	Regular access to hired labour	Yes = 1, No = 0	+ve
Credit	Regular access to credit	Yes=1, No=0	+ve
Land access	Access to land for farm expansion	Yes=1, No=0	+ve
Natural disasters	No. of natural disasters experienced in the past 10 years	Count of no. of natural disasters	+ve

RESULTS

Summary statistics of the variables included in the model

The summary statistics of the respondents are illustrated in Table 3. On average, a farmer adopts and uses 5 SIPs, ranging from one (1) to twelve (12) out of 17 SIPs identified by farmers. The result supports the notion that farmers, generally, are selective in adopting technology and often combine technologies that best serve their needs and expectations. Most farmers are within the economically active age group, with the age of a farmer ranging between 20 and 69 years and an average of 41 years. Rice cultivation is male-dominated, as 84%

of the farmers are male. Some female farmers, however, rely on male household members to cultivate their rice fields raising the possibility more women are involved in rice cultivation than recorded. Educational level tends to be low among rice farmers, with a mean number of years of schooling of 3 years, ranging from 0 to 16 years implying that most rice farmers have only obtained primary education. This is low but unsurprising since literacy levels are relatively low in rural Ghana and among farmers. The average household size is 9 persons and ranges from 1 to 30. Farm and rural households in Northern Ghana are usually large and may consist of one or more families. The average experience in rice cultivation is 10 years and ranges between 5 to 50 years. About 93% of farmers in the study area did not belong to an FBO at the time of the study. Farmers usually form FBOs for self-help or to access external support. The need to access external support largely influences FBO formation in the study area. Thus, FBOs only last if such support exists. Distance to the nearest market reflects market access and enables easier access to input and output markets. While some farmers sell their produce within the communities, others travel up to 11km to access the markets for their produce. On average, however, communities in the study area can easily access markets as a farmer travels 2.9 km to access the market to obtain inputs or sell their produce. Access to agricultural extension is low, with an average of about 2 visits per year. This ranged from 0 to 10 visits in a year. Poor access to extension is not peculiar to the study areas, as access to extension by Ghanaian farmers is generally low. Eighty-three per cent of farmers in the study area have regular access to subsidized inputs. However, despite the subsidy, timely access and rising input costs limit effective input utilization (Table 2).

Table 2: Descriptive statistics of variables

Variable	Minimum	Maximum	Mean	Std. dev.
No. of SIPs adopted	1	12	5.12	2.173
Age	20	69	41.32	11.497
Educational level	0	16	2.70	4.759
Household size	1	30	8.93	5.393
Farming experience	5	50	10.44	8.091
Distance to the nearest market	0	11	2.88	4.247
No. of extension visits	0	10	1.79	1.925
Total size of landholding	1	12	3.64	6.692
No. of Livestock owned	0	117	19.57	23.029
Landuse intensity	20	45	23.5	8.545
No. of climate-related disasters	2	9	5.55	3.529
Percentage of output sold	36.8	93.3	87.2	28.9
Variable	**Measurement**	**%**	**Measurement**	**%**
FBO membership	Yes	6.6	No	93.4
Gender	Female	16.2	Male	83.8
Access to Subsidy	Yes	83.0	No	17.0
Accessibility of Community	Yes	94.6	No	5.4

Access to Credit	Yes	5.8	No	94.2
Tenure Security	Yes	52.2	No	44.8
Off-farm Employment	Yes	30.7	No	69.3
Access to land for expansion	Yes	62.7	No	37.3
Migration of HH members	Yes	10	No	90.0
Rice cultivation as a source of Income	Yes	87.1	No	12.9

Source: Field survey, 2021

Ninety-five per cent of farmers indicated that their communities are accessible year-round as relatively good roads and transport serve them. Year-round accessibility to farming communities ensures that farmers can obtain inputs and essential services and generally improves farmers' welfare. On average, a household in the study area owns about 20 small ruminants. This ranges between 0 to 117. Livestock ownership is an essential source of household income and an indication of wealth. At the individual plot level, rice plots have been cultivated for 20 years to 45 years by the current owners, with an average of about 24 years, indicating a high level of intensification of rice fields. Migration among household members is low, with only 10% migrating during the past 10 years. Seasonal migration offers an alternative source of income for farm households and a risk-mitigating strategy. Household members who have migrated support farm households' farming activities through remittances. Rice cultivation constitutes an important source of income for farm households in the study area, as 87% of farmers indicated that it is a significant source of household income. This is unsurprising since the rural communities derive their livelihood mainly from agriculture. Access to credit is low. Ninety-four per cent (94%) of farmers indicated they need reliable access to input credit. Regarding the tenure of security of rice fields, 52% of farmers indicated that their lands are secure. Farmers outside the communities are usually allocated unused land by the household head, pending when a household member may require such land. The number of climate-related disasters encountered by a farmer over the past ten years averaged about six. This indicates a high incidence of climate-related disasters in communities in the study area, as a natural disaster occurs every two years. Common climate-related disasters encountered in the study area are floods, dry spells, late onset of rains, pests and diseases. Only 31% of households in the study area have at least one member engaged in some form of off-farm employment, confirming that farming is a significant source of income for households. Access to suitable land for farm expansion is not a significant concern among rice farmers, as about 63% indicated they could expand their rice farms when needed. However, this is outside the valleys they are currently cultivating. Farmers sell between 37% and 93% of their rice output, indicating high commercialization among rice farmers in the study area.

Results of the Regression Analysis

The results of the Generalized Poisson Regression model, presented as Incidence Rate Ratios (IRR), are displayed in Table 3. The Goodness-of-Fit Chi^2 indicated the model's robustness as it was not significant.

Table 3: Results of the Generalized Poisson Regression

log-likelihood = -429.0276			
Generalized Poisson regression.	Number of obs.	=	241
	LR chi2 (25).	=	180.64

Dispersion = -0.516076		Prob > chi2. =	0.000
Log-likelihood = -428.0276		Pseudo R2 =	0.1742
No. Practices	**IRR**	**St. Err.**	**p-value**
Age	1.003897	.0023552	.097*
Gender	1.04948	.624182	.417
Education	1.009233	.0049995	.313
Household Size	1.009233	.0053511	.083*
Experience	.9880989	.003996	.003***
Land Ownership	1.088919	.0749157	.216
FBO Membership	.7887244	.09037	.038**
Point of Sale	1.195376	.0813455	.009***
Mkt. Distance	.9440923	.0146878	.000***
No. Extension	1.108518	.0232527	.000***
Extension Access	1.273372	.0860085	.000***
Subsidy	.6683402	.0495579	.000***
Accessibility	1.447189	.1188143	.000***
Landholding	1.001829	.0027343	.503
Livestock	1.003703	.0009556	.000***
Landuse Intensity	.9990915	.0035645	.799
Rice Income	.8439301	.066518	.031**
Credit access	1.323026	.1699645	.029**
Tenure security	1.157926	.0574425	.003***
Migration of farmer	.8557734	.0553238	.016**
Migration of household members	.9568261	.0666983	.527
No. of climate-related disasters	1.00189	.0069284	.785
Off-Farm Employment	1.049764	.0590885	.388
Land Access	1.220411	.0655313	.000***
Trust	1.324011	.1689646	.027**
Constant	1.71114	.7175244	.200
*** *p<.01,*	** *p<.05,*		* *p<.1*

The age of farmer, household size, experience in rice cultivation, membership of a farmer organization, point of sale of farm produce, distance to the nearest market, number of extension visits, access to extension, access to subsidy, accessibility of community, livestock ownership, seasonal migration, rice as primary income source, access to credit, tenure security, trust in the sustained support for the promotion of SIPs and access to land for farm expansion exert significant but varying influences on the number of SIPs adopted by rice farmers. The farmer's age had a positive and marginally significant effect on the number of SIPs adopted by a farmer at the 10% significance level. Thus, an additional year to the age of a farmer increases the probability of the farmer adopting SIPs by 0.39%. The marginal increase in SIP adoption with age appears to be related to farming experience. Experience in rice cultivation significantly but negatively affected the number of SIPs adopted by a farmer at the 1% significance level. For each additional year a farmer cultivates rice, the probability of adopting SIPs decreases by 9.88%. This meets our a priori expectation as older farmers are expected to be more risk-averse and unlikely to adopt additional SIPs. Membership in a farmer-based organization (FBO) negatively influenced the number of SIPs adopted by a farmer and was significant at the 5% significance level. Membership of FBOs decreased the tendency of a farmer to adopt SIPs by about 7.8%. Although contrary to our a priori expectation, it is unsurprising that only 6.6% of farmers in the study area currently belong to an active FBO. The point of sale of a farmer's produce contributed to the positive adoption of SIPs and was significant at the 1% significant level. This meets our a priori expectation as it is expected that farmers who sell their farm produce beyond the farmgate tend to receive higher prices and can afford the costs associated with adopting new technology. Farmers who sell their produce outside the farm gate are 19.5% likely to adopt a SIP. The effect of the distance to the nearest input market on SIP adoption is negative and significant at the 1% significance level. A unit increase in the distance to input markets decreases the likelihood of SIP adoption by about 10%. This meets our a priori expectation as distant markets increase input costs. Access to and the intensity of extension visits positively affected the likelihood of SIP adoption and were significant at the 1% significance level. Both met our a priori expectations. A unit increase in the number of extension visits in a year increased the likelihood of SIP adoption by 10.9%, while access to extension increased the number of SIPs adopted by 27.3%. Input subsidy contributed significantly but negatively to technology adoption at the 1% significance level, contrary to our a priori expectation. Access to input subsidy reduced the number of SIPs adopted by farmers by about 6.7% for every unit increase in subsidy received. The most probable reason is that the government input subsidy programme targets a narrow bundle of SIPs (fertilizers and seeds). Therefore, although fertilizer use has increased due to the subsidy, as evidenced by 95% of farmers using chemical fertilizers, the input subsidy has not resulted in the uptake of other SIPs. Accessibility of the farming community is a major contributor to the number of SIPs adopted by farmers as it is significant and positive at the 1% significance level. A unit increase in year-round access to farming communities increased the probability of SIP adoption by 44.7%. This is not surprising as the study communities are well connected with good roads to the Tamale metropolis, the main commercial hub in the northern region and the regional capital. The number of livestock owned positively affected the number of SIPs adopted by a farmer and is significant at the 1% significance level. However, the increase is marginal as a unit increase in livestock ownership resulted in a 0.37% increase in the number of SIPs adopted by a farmer. Livestock ownership is a source of savings for farm households and is sold as a last resort in times of emergency. Migration by a farmer affected the number of SIPs adopted negatively and is significant at the 5% significant level and meets our a priori expectation. Seasonal migration reduces the number of SIPs adopted by 16.4%. This is probably because migration has become an alternative to farming. Rice cultivation as a household's primary source of income contributed significantly to the number of SIPs adopted by a farmer but negatively. It was significant at the 5% significant level and did not meet our a priori expectation. Rice cultivation as a primary source of household income decreased the likelihood of SIP adoption by 15.7%. This could be because farmers are reducing their investment in rice cultivation in favour of less risky crops like soya beans and spreading their risks by cultivating multiple crops. Access to input credit contributed significantly to the number of SIPs adopted by farmers and is significant at the 5% significant level and met our a priori expectation. For a unit increase in input credit, the number of SIPs adopted by a farmer increased by 32.3%. Most farmers in the study area rely on input credit to finance their input needs. Land tenure security has a positive and significant effect on the number of SIPs adopted at the 1% significant level and, therefore, met our a priori expectation—a unit improvement in tenure security results in a 15.8% increase in the number of SIPs adopted. A secure land tenure assures farmers of long-term benefits from their investments, including SIPs. Access to additional land for farm expansion positively and significantly affects the number of SIPs a farmer adopts. Farmers' trust in the prevailing institutional support for sustained uptake and use of SIPs influenced farmers' adoption decisions positively at the 5% significant level. A percentage improvement in trust in institutional support results in a 32% increase in SIPs adopted.

DISCUSSION

Human capital

Among the factors considered under human capital, age and farming experience influenced the number of SIPs farmers adopt. Similar to findings from this study, Guo et al. (2020) found a positive and significant association between the age of a household head and the number of SIPs adopted by smallholder farmers in southern Africa. Older Farmers tend to adopt higher levels of technology and may abandon these when the benefits are below expectation. However, similar to the findings of this study, Ainembabazi and Mugisha (2014) found that as farmers become experienced, they rely more on their own experience than on adopting new technology. Thus, technology adoption tends to be higher among less experienced farmers. Likewise, Issaka et al. (2021) found a similar relationship between farming experience and technology adoption among vegetable farmers in northern Ghana. In the present study, a farmer's experience in rice cultivation was 10.4 years on average, ranging between 5 and 50 years. Thus, farmers have considerable experience cultivating rice. The high marginal effect of age on the adoption of SIPs as against farming experience, which has a higher counter effect, suggests that farming experience is a more crucial variable to consider in technology adoption efforts. As younger farmers gain more experience in farming, with time, they will tend to drift towards the more cautious and risk-averse approach to technology adoption.

Institutional factors

Institutional factors significantly influencing SIP adoption include access and intensity of extension services, access to inputs and output markets, access to subsidy and accessibility of farming communities related to infrastructure. Adequate accompaniment of farmers ensured by reliable and adequate extension services delivery during and after introducing a technology aids the adoption and usage of technology (Ngango et al., 2022). Other studies have supported the findings of this study by associating the quality and intensity of extension services with higher technology adoption among farmers (Oyetunde-Usman et al., 2021; Haile et al., 2017). Tanti et al. (2022) show that access to extension and subsidies are associated positively with the adoption of climate-smart agricultural practices among farmers in India. Rural smallholder farmers tend to have an appreciable trust in local extension agents. Hence, frequent visits and information dissemination positively impact technology, as demonstrated by the results of this study. Ease of access to input and output markets facilitates easier technology adoption and usage by reducing the associated transaction costs through improved access to information, technologies and related services such as credit providers (Kassie et al., 2015). Access to information is critical for adoption as farmers tend to share experiences among themselves. Easy access to input and output markets is a promising avenue to facilitate such interactions and enhance adoption. Good rural infrastructure, such as road networks, enhances access to village-level input and service delivery, enabling farmers to adopt technology (Kotu et al., 2017). Similar to this study, Acheampong et al. (2021) show that distance to the source of inputs is negatively related to the adoption and intensity of agricultural practices. Thus, farmers can easily access markets to obtain services required to facilitate easier adoption of SIPs.

Resource endowment

Household resource endowments of significance to the adoption of SIPs in the study area include household size, livestock ownership, migration, and primary source of household income. The effect of livestock ownership on the number of SIPs farmers adopt is significant and positive. The results obtained from this study are consistent with those of other studies (Ngango et al., 2022; Hailu et al., 2014; Mutyasira, 2018). Livestock ownership embodies a household's wealth and suggests that households sell their livestock to finance farm activities (Oyetunde-Usman et al., 2021). Livestock ownership also serves as a wealth buffer and guarantor upon which the household can fall in times of need. This serves as a motivating factor for the farmer to take risks associated with adopting new technologies. However, the influence of livestock ownership on the number of SIPs adopted is marginal. Under conditions of uncertainty, farmers prefer to keep livestock to hedge against climate variability. The effect of household size on the number of SIPs adopted is positive and significant. This finding is supported by similar studies (Guo et al., 2020; Oyetunde-Usman et al., 2021; Musafiri et al., 2021). Labour availability has been associated with higher SIP adoption (Mutyasira et al., 2018). Larger household sizes suggest households would have access to family labour (Sodjinou et al., 2015). Access to family labour is essential, especially when hired labour is scarce during peak demand periods such as sowing and harvesting. Rice income significantly and negatively affects the number of SIPs adopted by farmers. It is reasonable to assume that farmers whose primary source of livelihood is crop cultivation will seek to reduce the risk of adopting new technology by adhering to their mix of time-tested technology.

Social capital

Membership of a farmer-based organization (FBO) and trust in the prevailing institutions to sustain support for the adoption and continuous use of SIPs constitute significant social factors determining the number of SIPs adopted by farmers. Current membership of an FBO served as a proxy for a farmer's social network. The effect of FBO membership on the number of SIPs adopted was significant but negative. Contrary to the findings from this study, however, other studies have established a positive and significant relationship between FBO membership and SIP adoption (Awotide et al., 2016; Ngango et al., 2022; Guo et al., 2020; Hamazakaza, 2022). FBO membership, theoretically, influences farmers' technology adoption decisions so long as it enables them to build the required social capital. Most farmers in the study area had become members of FBOs in the past, mainly due to external influence. There is a long history of NGOs and government institutions sponsoring the formation of FBOs in the study area to support farmers without adequately ensuring their sustainability. Bad experiences with FBOs can negatively affect members' mindsets regarding technologies introduced to FBOs in the study area. Thus, FBOs in the study area still need to generate the expected social capital to aid the adoption of SIPs. In the present study, trust in the ability of existing institutions, both formal and informal, to support the adoption and sustained use of SIPs has a positive effect on the number of SIPs adopted by farmers. Under conditions of uncertainty, farmers may fail to follow through with adopted technology if they lack adequate trust in local institutions to support their adoption decisions (Oliva et al., 2020). The significantly high impact of trust on the adoption of SIPs, as shown by the results (32.3%), is a testament to the fact that farmers expect sustained support in the adoption process and that once they are convinced of institutional support, adoption is almost guaranteed. Therefore, a positive perception of institutional support for the adoption and sustained use of technology supports the adoption of SIPs. Trust or perception of the ability of institutions to support innovations constitutes a significant source of social capital adequately and sustainably. Institutional weaknesses, lack of collaborative governance, and conflicting objectives among different actors can constrain climate change adaptation capacity (Eisenack et al., 2014).

Resource constraint

Land tenure security, access to additional land for farm expansion, and access to credit significantly and positively affected the number of SIPs farmers adopt. Findings from other studies support the current findings (Ruzzante et al., 2021; Ngango et al., 2022; Hailu et al., 2014). Secured land tenure safeguards farmers' investment in adopting SIPs and guarantees positive returns. A secured land tenure enhances the adoption of SIPs and ensures that farmers' investments in land are protected. About 60% of farmers in the study area confirmed that land tenure is secured and did not constrain the number of SIPs a farmer adopts because most land is owned and managed by households. Due to high poverty rates, farmers in the study area rely on input credit to finance their farming activity. The adoption of SIPs will always come with additional costs for farmers. Hence, good and reliable access to credit will positively affect adoption. Other studies (Hailu et al., 2014; Guo et al., 2020) have associated access to credit with a higher rate of technology adoption by farmers. Credit becomes critical to technology adoption when technology adoption requires external input. Conclusion and

CONCLUSIONS AND RECOMMENDATIONS

Sustainable intensification options are subject to local conditions. They are largely specific to the cropping systems and are characterized by several trade-offs among different sustainability indicators. Finding suitable options, therefore, requires informed discussions on acceptable solutions and trade-offs involving stakeholders beyond farmers. The study sought to determine the factors influencing the number of sustainable intensification practices adopted by smallholder rain-fed rice farmers. The study, motivated by recent concerns about the impact of climate variability on rice productivity, was conducted in the Savelugu District of the Northern Region of Ghana. In particular, the study sought to determine the effects of human, institutional, economic and social capital on the number of SIPs adopted by rainfed lowland rice farmers. Categorizing individual factors under broader categories offers additional insights into the broader and systemic implications of the results. It adopts the Generalized Poisson Count Regression model, which assumes that sustainable agricultural intensification implies using multiple agricultural strategies to achieve intensification objectives. Indeed, farmers in the study area adopt multiple technologies to achieve their intensification objectives. Of the 17 sustainable intensification practices identified in the study area, mechanized ploughing, fertilizer, and weedicides were consistent. They accounted for 93% of all sustainable intensification strategies employed by farmers. In contrast, the rest accounted for less than 50%. Among the factors influencing the number of SIPs adopted by farmers, the point of sale of farm produce, access and intensity of extension access, accessibility of the farm and credit access had a positive effect. On the other hand, farming experiences, membership of an FBO, distance to the nearest market, access to input subsidy, livestock ownership, seasonal migration, and rice income negatively impacted the number of SIPs adopted by farmers. This confirms the essential role of human capital, the institutional environment, economic factors, social capital and resource endowment in farmers' decisions to adopt SIPs. In particular, the study draws attention to the specific, insightful meaning of factors that impact the adoption of SIPs, including the role of social capital (FBO membership), policy (access to subsidy) and resource endowment (livestock ownership) on the adoption of SIPs. The study also highlights the role of institutional factors in farmers' adoption and continuous use of SIPs. Finally, the study draws attention to the need for adoption studies to consider factors influencing the sustained use of technology after adoption as equally critical. Consequently, the following recommendations are made:

The promotion of sustainable intensification strategies among farmers should be accompanied by the appropriate technology packages that will allow farmers adequate flexibility to choose the mix of technology that suits them.

Adequate and careful attention should be paid to how contextual factors influence technology adoption as these mediate the influence of factors influencing farmers' adoption decisions.

The institutional environment is essential for the successful promotion of SIPs and their sustained use. Consequently, the institutional environment should be considered an integral part of the effort to promote SIPs.

Trust in existing institutions to support the adoption and sustained use of SIPs has been shown to impact the adoption of SIPs significantly. Consequently, technology adoption efforts must be supported by both formal and informal institutions over the long term to ensure continuous use of SIPs and sustain farmers' trust in the process.

In particular, the following factors must be considered in promoting SIPs: the point of sale of farm produce, access and intensity of extension access, accessibility of the farm, and credit access.

Conflict of interest

The authors confirm no conflict of interest.

Data availability

The data used in this study is available on request.

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