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Smallholders' perspectives on sustainable agriculture intensification in Northern Ghana

Ebenezer N.K. Boateng [a,b,c,*], Gerald Atampugre [d], Patricia Solis [b,c], Simon Mariwah [a], Ishmael Mensah [e], Christine Furst [f], Benjamin K. Nyarko [a]

[a] Department of Geography and Regional Planning, University of Cape Coast, Ghana
[b] Knowledge Exchange for Resilience, Arizona State University, Tempe AZ, USA
[c] School of Geographical Sciences and Urban Planning, Arizona State University, Tempe AZ, USA
[d] International Water Management Institute-Ghana, PMB CT 112, Cantonments, Accra
[e] Department of Hospitality and Tourism Management, University of Cape Coast, Ghana
[f] Institute of Geoscience and Geography, Martin Luther University, Halle-Wittenberg, Germany

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ABSTRACT

In the quest to improve food security for a growing population with minimal environmental impact, assessing smallholders' perceptions and practices of sustainable agriculture intensification (SAI) is a prerequisite for achieving Sustainable Development Goal (SDG) 2. However, little empirical evidence exists on smallholders' perspectives on SAI, especially in the context of Sub-Saharan Africa, where a majority of smallholders are relatively poor and live under harsh climatic conditions. This research assessed smallholders' perspectives on the practice of SAI in the Guinea Savanna Agro-Ecological Zone. Data was collected from 698 smallholders in the Bongo and Bolgatanga Municipalities based on a cross-sectional design. It was found that smallholders practised moderate SAI and the positive predictors of SAI adoption were age, monthly income, religion, slope, vegetation and water access, while the negative predictors were farm size, land surface temperature, distance to a dam and land tenure. Based on the assessment of perceived external drivers of adoption, it was found that poor groundwater quality, lapses in government policies on agriculture and lack of engagement in group farming hindered the practice of SAI. It is recommended that non-governmental organizations and government agencies for food and agriculture should enhance efforts aimed at reducing barriers and increasing smallholders' awareness of how SAI supports their livelihood and contributes to achieving SDG 2.

1. Introduction

Over the last two decades, the prevalence of food insecurity has intensified, especially in developing countries. According to the FAO [1], food insecurity forced between 691 and 783 million people into hunger. Evidence from the report indicates that food insecurity in Africa increased from 45.4% to 60.9% between 2015 and 2022 [1]. According to the World Bank [2], about 140 million Africans face acute food insecurity. Arguably, at the regional level, there could be an over-generalisation of food insecurity. However, the FAO [1] report further suggests that in Ghana, food insecurity increased from 38.3% to 39.4% between 2016 and 2022. The current incidence of food insecurity in Ghana is considered moderate to severe [3], which has serious implications for malnutrition, poverty, chronic diseases, price fluctuations and mortality.

Research demonstrates that climate change, rising population, rapid urbanisation, water scarcity, changing diets and economic hardship (inflation and poverty) contribute to food insecurity, especially in developing countries [4,5]. A key intervention to address food insecurity is promoting sustainable agriculture intensification (SAI), which is highlighted in SDG 2.4 as a pathway to achieving sustainable food production and resilient agricultural practices [6]. The concept of SAI focuses on generating more products from existing agricultural land with less or no impact on the environment [7,8]. SAI has been perceived as essential to meeting the increasing demand for food, especially in arid and semi-arid regions experiencing low soil fertility and yields and pressure on agricultural land [9]. SAI has gained much attention since the inception of the SDGs in 2000, particularly in developing countries

* Corresponding author.
E-mail address: eboaten4@asu.edu (E.N.K. Boateng).

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to achieve SDG 2 by 2030.

SAI involves the use of a range of techniques and practices to improve the efficiency of agriculture production while reducing negative environmental impacts. These techniques include conservation agriculture, integrated soil fertility management, and agroforestry, among others. The ultimate goal of SAI is to increase yields, improve livelihoods, and enhance food security while protecting and enhancing natural resources such as soil, water and biodiversity [7]. Several dimensions, such as economic, social, environmental, nutrition and productivity, have been proposed to aid in assessing SAI [10,11]. However, the predominantly used dimensions for assessing SAI are economic, social and environmental since they are the main indicators for measuring sustainability [10,12,13].

In Ghana, the discussion and practice of SAI have been topical over the last decade [14–18]. For instance, Mohammed-Nurudeen [17] reported that agricultural yield is dwindling due to unpredictable rainfall seasons and poor soils. The Minister for Food and Agriculture made a call for sustainable agriculture intensification through no-till agriculture while combating food insecurity. This has resulted in the training of both commercial farmers and smallholders by NGOs on the need for SAI. In addition, immediate past government (New Patriotic Party: 2016-2024) implemented policies such as “Planting for Food and Jobs” (PFJ) and “One Village One Dam” (1V1D) to promote SAI. These initiatives aim to enhance agricultural productivity, improve food security, and provide reliable source of employment, especially in rural communities in Northern Ghana [19–22]. The PFJ initiative, launched in 2017, aimed to improve food self-sufficiency by providing farmers with subsidized inputs (such as improved seeds and fertilizers), and extension services [21, 22]. This initiative forms one of the key pillars of SAI. A study by Pauw [22] revealed that PFJ have brought an increase in rice and maize production but there is more room for improvements. Similarly, the 1V1D initiative focused on constructing small-scale irrigation dams in rural communities in northern Ghana to reduce dependence on erratic rainfall and enable year-round farming, which is essential for intensifying production without expanding farmland [19,20]. However, a study by Adams et al.[20] found that there was an increased reliance on dams constructed by 1D1F but during the dry season, most of the dams dried up due their shallowness.

The Guinea Savanna Agro-Ecological Zone in Ghana is one of the regions that has received much attention on the practice of SAI since the area produces a higher proportion of the country’s food but is greatly affected by climate change [23–25]. Also, a higher proportion of households (about 70%) are engaged in smallholder farming [26,27] with the majority (90-95%) having farm sizes of two hectares or less [28, 29]. Regardless, their contribution plays a critical role in combating food insecurity through food production [30] and this necessitates examining their practices in line with SAI.

There are several studies on SAI in terms of developing indicators for the three sustainability dimensions (economic, environmental and social) [31,32], the relationship between drivers and indicators of SAI [33, 34] and a framework for empirical assessment of SAI [10,11]. Yet, there is little empirical evidence about smallholders’ perspectives on the practice of SAI in Sub-Saharan Africa while combating food insecurity. It is against this background that we sought to assess smallholders’ perspectives on the practice of SAI in the Guinea Savanna Agro-Ecological Zone, particularly in the Bolgatanga Municipality and Bongo District. Specifically, we examined the practice of SAI among smallholders, determined factors that influence SAI practice and assessed the drivers of SAI in the Bolgatanga Municipality and Bongo District.

This study provides an understanding smallholders’ perspectives on sustainable agriculture intensification (SAI) in Sub-Saharan Africa, a region characterized by vulnerable agricultural practices and poorer farmer communities [30,35]. This study also provides valuable insights such as smallholders’ local knowledge systems of SAI that can inform policies and practices to enhance agricultural sustainability and farmer livelihoods in similar contexts. The rest of the study focuses on the theoretical perspective of SAI, materials and methods, results, discussion and conclusion.

2. Literature review

2.1. Theoretical perspective of sustainable agriculture intensification (SAI)

Sustainable agriculture intensification (SAI) is a concept that requires the interplay of social, economic and environmental elements. A review of the literature reveals how SAI is informed by several theoretical perspectives, three of which are considered dominant and relevant to this study. One such key theoretical perspective is the Ecological Systems Theory. The Ecological Systems Theory explains that the development of a phenomenon depends on the interrelationship of different elements [36]. According to this theory, SAI can be considered an ecological system that is shaped by interactions among various elements, including the biophysical environment, social and human agency and economic systems. The theory emphasizes the need to manage these interactions in a way that maintains and enhances the resilience and sustainability of the agricultural system.

Another important theoretical perspective that informs SAI is the Agroecological Approach. This approach recognizes agriculture as an integral part of the broader ecological and social systems and emphasizes the need to manage agriculture in a way that enhances ecosystem services, such as soil fertility, water availability, and biodiversity [37, 38]. The agroecological approach promotes the use of diverse and resilient agroecosystems that are adapted to local conditions and can support sustainable agriculture intensification.

In addition, SAI is informed by the Sustainable Development paradigm. This paradigm emphasizes the need to balance economic, social, and environmental considerations in the pursuit of sustainable development [39,40]. In the context of agriculture, this means that SAI should be guided by a triple-bottom-line approach that seeks to improve economic viability, social equity, and environmental sustainability [10,41]. The Sustainable Development paradigm, with its focus on balancing economic viability, social equity, and environmental sustainability (triple-bottom-line), complements both the Ecological Systems Theory and the Agroecological Approach. While Ecological Systems Theory offers a broad framework for understanding the interrelationship of social, economic, and environmental systems, the Agroecological Approach focuses more on environmental sustainability and promoting resilient, locally adapted agroecosystems. The Sustainable Development paradigm enhances these theories by emphasizing a clear balance across all three dimensions, providing a global perspective through measurable targets like the Sustainable Development Goals (SDGs), and highlighting the importance of both social and economic considerations alongside environmental sustainability.

Across each of these three theoretical perspectives, SAI is underpinned by systems thinking, which recognizes that agriculture is a complex system that is influenced by a range of factors, including biophysical, social, and economic factors, and that interventions in one part of the system can have unintended consequences in other parts of the system [10]. Therefore, SAI requires a holistic and systemic approach that takes into account the interactions among different elements of the agricultural system and their impacts on sustainability.

Taken together, these perspectives provide a conceptual framework for this study as it seeks to understand and guide sustainable agriculture intensification. They emphasize the importance of managing agriculture in a way that enhances ecological, social, and economic sustainability while promoting resilience and adaptability in the face of changing climatic/environmental conditions.

Economic Viability: The economic dimension of SAI explains the importance of agriculture as a source of income and livelihood for many people, particularly in developing countries [31]. To promote economic viability in SAI, interventions should aim to improve productivity, increase incomes, and reduce poverty [10]. This can be achieved through various strategies, such as the adoption of improved technologies, the development of value chains, and the provision of access to finance and markets.

Social Equity: The social dimension of SAI emphasizes the importance of social equity and inclusion in the pursuit of sustainable development. In the context of agriculture, this means that interventions should be designed in a way that promotes social equity, including gender equity, and ensures that marginalized and vulnerable groups have access to the benefits of SAI [10,31]. This can be achieved through strategies such as community-based approaches, participatory decision-making processes, and the provision of social safety nets.

Environmental Sustainability: The environmental dimension of SAI recognizes the importance of managing natural resources in a way that ensures their sustainability and resilience for future generations. In the context of agriculture, this means that interventions should be designed in a way that minimizes negative impacts on the environment, enhances ecosystem services, and promotes biodiversity conservation [10,31]. This can be achieved through various strategies, such as the adoption of conservation agriculture practices, the promotion of agroforestry, and the use of integrated pest management.

These theoretical perspectives collectively provide a useful framework for SAI because they emphasize how agriculture is a complex system that is influenced by economic, social, and environmental factors. SAI interventions that are guided by this paradigm are more likely to be successful because they take into account the interactions among these factors and their impacts on sustainability. Moreover, this study's framework provides a basis for collaboration and dialogue between different stakeholders, including farmers, policymakers, and civil society, in the pursuit of sustainable agriculture intensification.

2.2. *Predictors of sustainable agriculture intensification (SAI)*

While the concept of SAI is traditionally anchored in the interplay of economic viability, social equity, and environmental sustainability, recent literature highlights the critical role of demographic, farming, and ecological factors in shaping the adoption and effectiveness of SAI practices (Fig. 1). Demographic characteristics such as age, gender, education, and household size significantly influence farmers' decisions to adopt SAI. Younger farmers are generally more open to innovation and technology adoption compared to older ones, who may be more risk-averse [42–45]. Education plays a particularly important role, as it enhances farmers' capacity to understand and implement sustainable practices, access extension services, and make informed decisions [42,46]. Gender is another important dimension, as men and women often have unequal access to land, credit, training, and decision-making authority, which can lead to disparities in SAI adoption [47]. Additionally, larger household sizes may provide labor advantages but also exert pressure on land and food, influencing the intensity and type of agricultural practices adopted.

Farming characteristics, including farm size, type of crops grown, access to inputs, and experience, also determine the likelihood of adopting SAI. While smallholders may intensify production due to land scarcity, larger farms often have the resources to invest in mechanization and diversified practices [44]. Access to inputs such as quality seeds, fertilizers, and irrigation systems, as well as regular interactions with extension agents, significantly improves the uptake of sustainable practices [46,48]. Farming experience also influences both openness to innovation and reliance on traditional methods, with mixed outcomes depending on the context [42]. Also, ecological indicators such as soil quality, slope, rainfall variability, and agroecological zone are equally critical to predicting SAI. Poor soil fertility often necessitates the adoption of SAI techniques to maintain or boost productivity, especially in resource-constrained environments. Similarly, exposure to erratic rainfall or prolonged dry seasons encourages farmers to adopt water-efficient practices such as conservation agriculture or supplemental irrigation [49]. The agroecological context such as being located in a savannah versus a forest zone affects both the suitability and expected outcomes of specific SAI strategies [50].

Collectively, the dimensions of SAI and these predictors (Fig. 1) provide a multidimensional understanding of the factors that influence SAI uptake, emphasizing that beyond economic and environmental considerations, local socio-demographic and ecological realities must be accounted for when designing sustainable agriculture policies and interventions.

3. Materials and methods

3.1. *Study area*

The study was conducted in two districts in Ghana's Upper East Region: Bolgatanga Municipality and Bongo District (Fig. 2). These neighboring areas lie within the semi-arid Guinea and Sudan Savannah Agroecological Zones, known for their prolong dry seasons and unpredictable rainfall [26,27]. Bolgatanga Municipality, located in the heart of the region, covers about 334 km^2, while Bongo District, just to its

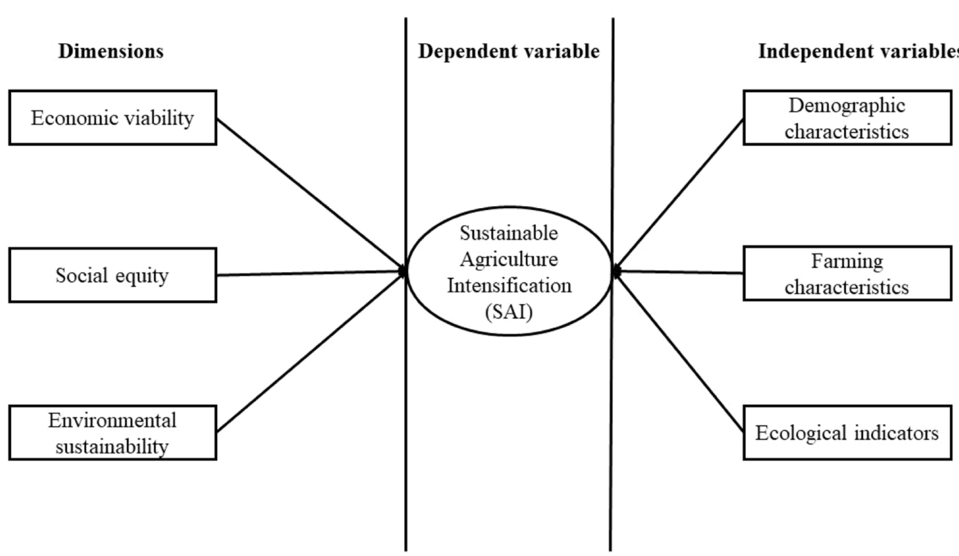

Fig. 1. Conceptual framework.

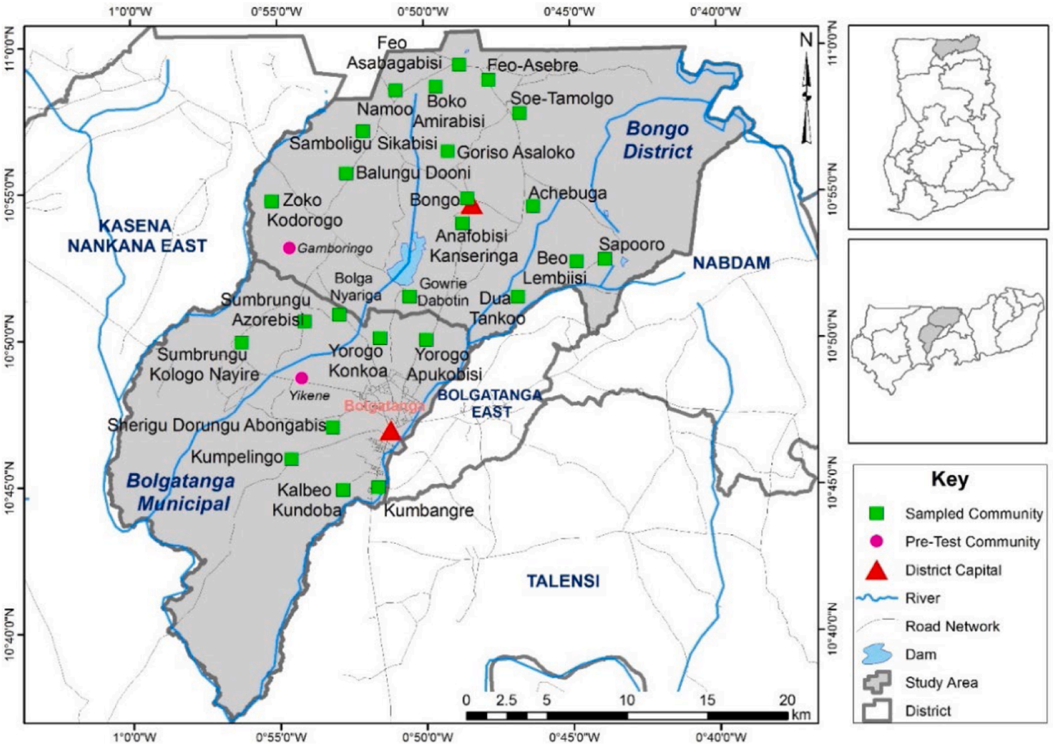

Fig. 2. A map of the study area.
Source: Boateng et al. [54].

north, spans 425 km^2 [51]. The two districts are not only close geographically but share important resources including the Vea Dam, which serves as a vital source if water for both drinking and farming. However, during the dry season, water becomes scarce as rivers and streams dry up, vegetation fades and farming grinds to a halt. Rainfall in the area ranges between 700 and 1010 mm, with a peak occurring in late August or early September [26,52]. Daytime temperatures rises above 35°C, while nights can be surprisingly cool, dropping to about 14°C [26]. The landscape is shaped by gently sloping soils such as lixisol, leptosol, and luvisol, which influence the kinds of crops that can be grown [53].

Life in these districts varies in pace and structure. Bolgatanga is more urban and serving as the administrative capital of the region, and about 64% of its households live in urban settings [26]. In contrast, Bongo remains largely rural, with only 6% of households in urban areas [51]. Across both districts, females slightly outnumber males, and the population is young with about 42% being youth. A typical household has about five members, nearly half of the adult population are married, and over half can read and write. Agriculture remains the backbone of the economy. More than 70% of the population is economically active, and many people, especially in Bongo (over 70%), engaged in smallholder farming. Most families grow crops and raise livestock not just for income, but as a way of life shaped by the rhythms of the seasons and the land [26,27].

3.2. Study design

This study employed a cross-sectional design to assess smallholder farmers' perspectives on SAI. This study design involves collecting data from a sample of individuals at a specific point in time, and it is useful for exploring the relationship between variables. The target population was household heads who were smallholders. Using the Survey Monkey sample size calculator, 391 and 307 smallholders were sampled for Bongo District and Bolgatanga Municipality, respectively. Based on a multistage sampling procedure, a simple random approach was used to select 9 and 16 communities from Bongo District and Bolgatanga Municipality, respectively. The next level of the multistage sampling was a systematic technique to select smallholder farmers. The purpose of utilizing a multistage sampling technique was to enhance representativeness by systematically selecting respondents in multiple stages, allowing for efficient data collection, reducing operational costs, and ensuring a diverse yet manageable sample from a large and heterogeneous population.

The main data collection instrument for this study was a questionnaire, which had four sections. The first section focused on the demographic characteristics such as sex, age and monthly income of the respondents. The second section gathered data on the farming characteristics such as farming experience, farm size and land tenure of the respondents. The third was based on the items measuring SAI and the final section looked at the drivers of SAI. There were 15 items developed from SAI indicators by Zhen and Routray [31] and Fallah-Alipour et al. [10]. These indicators were transformed into items and measured on a five-point scale where 1 was strongly disagree and 5 being strongly agree. Similarly, ten items were developed to measure drivers of SAI from empirical studies and these items were on a five-point scale. A five-point Likert scale was used for its simplicity, ease of understanding, and suitability for capturing perceptions and attitudes where respondents may have varying levels of perspectives of the phenomenon being studied [55]. A five point Likert scale facilitates statistical reliability and validity in both descriptive and inferential analyses [56]. Prior to the actual data collection, a pre-test was conducted to check the consistency, convergence, and clarity of questionnaire, especially the items on SAI. The results from the pre-test showed consistency and convergence of the items used. However, some of the items were rewarded to ensure more clarity of the questionnaire.

Ethical clearance was received from the Institutional Review Board of the University of Cape Coast (UCCIRB/CHLS/2020/45). In according with the ethical clearance, the researchers and the field assistants adhered to ethical protocols such as informed consent, anonymity and confidentiality to protect all respondents for the study. Using a survey coupled with a computer-assisted personal interview (KoBo Toolbox), a 100% response rate was achieved. The data was collected in March 2021. In addition, we used GIS and remote sensing to estimate some ecological variables such as cost distance to rivers and dams, slope, land surface temperature and others to assess smallholders' perspectives on SAI.

3.3. Statistical analysis

The analysis began with running frequencies for the demographic and farming characteristics and percentage agreement of the 15 items used in measuring SAI using SPSS version 23. A five-point Likert scale of the 15 items was recoded into 0 (comprising strongly disagree, disagree and neutral) and 1 (comprising agree and strongly agree). Cronbach's alpha tool was used to check for the reliability or internal consistency of the 15 items of the three dimensions (Fig. 2). After the Cronbach's alpha test, an exploratory factor analysis (EFA) was conducted and the EFA showed that all items had positive factor loading on the first component, which implies that the first component measured SAI. An index was created from the factor score and recoded based on terciles to represent low, moderate and high using IMB SPSS version 23.

The inferential statistics for SAI assessed the predictors of smallholders' SAI using demographic and farming characteristics and ecological indicators . The dependent variable was SAI (low, moderate and high), whereas the independent variables were demographic (age, gender, educational level, etc) and farming (farm size, land tenure, etc) characteristics and ecological indicators (slope, access to water, etc). These independent variables were selected based on their theoretical and empirical relevance to smallholders' adoption of SAI practices. The analysis used a multinomial-ordered logistic regression tool in Stata version 16. This model is appropriate for dependent variables with more than two ranked categories and allows for the effect of multiple predictors on the likelihood of an observation falling into a particular SAI category [57]. Unlike a binary logistic regression model which collapses the richness of the ordinal SAI data, this multinomial-ordered logistic regression retains the ranking and enhances interpretability. The multivariate analysis was conducted using a stepwise approach to only retain statistically significant variables. Finally, the Kendall Rank Order Coefficient of Concordance was run to examine smallholder farmers' perspectives on the drivers of SAI because it is a robust and suitable tool for assessing the concordance of ranked data among respondents [58].

4. Results

4.1. Socio-demographic and farming characteristics of respondents

Descriptive results (Table 1) of the socio-demographic characteristics revealed that almost two-thirds (64.45%) of the respondents in the Bongo District and seven in ten (70.68%) in the Bolgatanga Municipality identify themselves as male. With regards to the religious affiliation of respondents, both districts had about 50% Christians, while the least was Islamic/Other (7%). However, Bongo District had more Christians (55.2%) compared to the Bolgatanga Municipality (49.5%).

In addition, most of the respondents (85.4%) were married, with Bolgatanga Municipality recording a higher percentage (86.97%) than the Bongo District (84.14%). Also, most of the respondents belonged to the Gruni (99.4%) ethnic group in both districts. Again, most respondents were between the ages of 38- 47 years (30.9%), while the least was found between the ages of 18-27 years (7.3%) in both districts. With the least of the respondents aged between 18-27 years, it is evident that there is relatively lower participation of the youth in agricultural activities. Almost half (46.4%) of the respondents earned between GHC 0-200, whereas only 3% earned GHC 1001+. Specifically, about 50% and 46% of Bongo and Bolgatanga respondents respectively were found to earn between GHC 0-200.

Regarding the farming characteristics of respondents (Table 2),

Table 1
Demographic characteristics of smallholders.

Variable	Bongo (N=391)		Bolgatanga (N=307)		Total (N=698)		χ^2 (p-value)
	Freq.	%	Freq.	%	Freq.	%	
Sex							
Female	139	35.55	90	29.32	229	32.81	3.032
Male	252	64.45	217	70.68	469	67.19	(0.082)
Age							
18-27	29	7.42	22	7.17	51	7.31	5. 178
28-37	65	16.62	67	21.82	132	18.91	(0.270)
38-47	124	31.71	92	29.97	216	30.95	
48-57	91	23.27	77	25.08	168	24.07	
58+	82	20.97	49	15.96	131	18.77	
Household size							
1-3	45	11.51	27	8.79	72	10.32	2.788
4-6	188	48.08	162	52.77	350	50.14	(0.426)
7-9	109	27.88	76	24.76	185	26.50	
10+	49	12.53	42	13.68	91	13.04	
Level of education							
No formal edu.	217	55.50	167	54.40	384	55.01	0.771 (0.942)
Basic school	87	22.25	66	21.50	153	21.92	
JHS/JSS	40	10.23	35	11.40	75	10.74	
SHS/Voc	32	8.18	24	7.82	56	8.02	
Tertiary	15	3.84	15	4.89	30	4.30	
Monthly income							
GHC 0-200	197	50.38	127	41.37	324	46.42	10.849
GHC 201-400	112	28.64	101	32.90	213	30.52	(0.054)
GHC 401-600	49	12.53	44	14.33	93	13.32	
GHC 601-800	10	2.56	19	6.19	29	4.15	
GHC 801-1000	12	3.07	6	1.95	18	2.58	
GHC 1001+	11	2.81	10	3.26	21	3.01	
Marital Status							
Never married (Single)	31	7.93	17	5.54	48	6.88	7.336 (0.197)
Married	329	84.14	267	86.97	596	85.39	
Widowed	13	3.32	17	5.54	30	4.30	
Divorced	9	2.30	3	0.98	12	1.72	
Separated	8	2.05	3	0.98	11	1.58	
Co-Habitation	1	0.26	0	0.00	1	0.14	
Religion							
Christianity	216	55.24	152	49.51	368	52.72	2.811
Traditional	145	37.08	133	43.32	278	39.83	(0.245)
Islam/Other	30	7.67	22	7.17	52	7.45	
Ethnicity							
Dagaaba	1	0.26	0	0.00	1	0.14	4.118
Gruni	389	99.49	305	99.35	694	99.43	(0.390)
Kasena	0	0.00	1	0.33	1	0.14	
Kusaal	0	0.00	1	0.33	1	0.14	
Nab	1	0.26	0	0.00	1	0.14	

χ^2 = Chi-Square test results, N= number of observations, Freq.= frequency, %= percent

although most of the respondents (92.7%) had farmlands less than or equal to five separate pieces, the results show that about 11% of the respondents in the Bolgatanga Municipality had six or more farmlands compared to 4% (4%). This difference between the two districts was statistically significant at a 99% confidence level. The urbanised characteristics of the Bolgatanga Municipality are a justification for respondents having more farmlands due to their higher economic status. In addition, the results in Table 2 reveal that about 33% of the respondents had 11-20 years of farming experience, with about 36% and 30%, respectively, from the Bongo District and the Bolgatanga Municipality. Only about 10% had farming experience greater than 40 years, with virtually no significant variation between Bolgatanga Municipality (10%) and the Bongo District (9%).

Notably, in both districts, 85.4% farmed on family lands, with a little

Table 2
Farming characteristics of smallholders.

Variable	Bongo (N=391)		Bolgatanga (N=307)		Total (N=698)		χ^2 (p-value)
	Freq.	%	Freq.	%	Freq.	%	
Number of farmlands							
≥5	374	95.65	273	88.93	647	92.69	11.491
≤6	17	4.35	34	11.07	51	7.31	(0.001)
Farming experience (years)							
≤10	80	20.46	55	17.92	135	19.34	8.059
11-20	140	35.81	92	29.97	232	33.24	(0.089)
21-30	102	26.09	85	27.69	187	26.79	
31-40	33	8.44	44	14.33	77	11.03	
≥41	36	9.21	31	10.10	67	9.60	
Land tenure							
Family	333	85.17	263	85.67	596	85.39	0.113
Other	24	6.14	17	5.54	41	5.87	(0.945)
Owned	34	8.70	27	8.79	61	8.74	
Farm size (acres)							
<1	169	43.2	84	27.4	253	36.25	19.513
2	95	24.30	93	30.29	188	26.93	(0.000)
3	50	12.79	58	18.89	108	15.47	
4+	77	19.69	72	23.45	149	21.35	
Crops cultivated (Multiple responses)							
Maize/corn	143	7.73	220	11.78	363	9.76	
Rice	175	9.45	205	10.98	380	10.22	
Millet	368	19.88	288	15.43	656	17.64	
Guinea corn	250	13.51	262	14.03	512	13.77	
Bambara beans	234	12.64	216	11.57	450	12.1	
Groundnut	319	17.23	276	14.78	595	16	
Beans (Cowpea)	231	12.48	201	10.77	432	11.61	
Other	131	7.08	199	10.66	330	8.9	

χ^2 = Chi-Square test results, N= number of observations, Freq.= frequency, %= percent

above a quarter of the respondents having farm sizes of one and two acres in both districts, with a statistically significant difference between farm size in two districts at a 99% confidence level.

4.2. Smallholders' perspectives on the practice of sustainable agriculture intensification (SAI)

From the review of the literature, three (3) dimensions (economic, social, and environmental) emerged for the assessment of the practice of SAI. These dimensions and their respective indicators were used to develop a five-point Likert scale to measure smallholders' perspectives on SAI. The 15-item Likert scale measuring the three (3) dimensions is shown in Table 3.

Six items were used to measure perspectives on the economic dimension of SAI. In Bolgatanga Municipality, most respondents disagreed with the items measuring the economic dimension of the SAI. The highest (61.56%) and lowest (44.95%) percentages of disagreement came from the items "I have insured my farm" and "I sell some of my produce", respectively. On the other hand, the highest percentage of agreement (25.73%) came from the item "My income is enough to cater for family and farm inputs". Similarly, results from the Bongo District showed that most of the respondents disagreed with the economic items. The item with the highest (50.64%) percentage of disagreement was "I save with some financial institutions for my farm inputs", whereas the item with the lowest percentage of disagreement was "My income is enough to cater for family and farm inputs". It is important to state that quite a higher proportion of the respondents strongly disagreed with the six items measuring the economic dimension of SAI. Notably, the results revealed that most of the respondents in both districts disagreed with all items measuring SAI's economic dimension, indicating the economic dimension is quite low.

With regards to the social dimension of SAI, five items were used where most (62.21%) of the respondents disagreed with "I have access to extension service". However, in the Bolgatanga Municipality, the item with the highest (44.95%) percentage of agreement was "I have not been discriminated against as a farmer due to my economic status". Similar results were found in the Bongo District, where about 50% of the respondents disagreed with having access to extension services. Also, the highest percentage of agreement came from the "I have not been discriminated against as a farmer due to my economic status". The results suggest that the perspectives of respondents on the social dimension of SAI were relatively better than the economic dimension.

The environmental dimension of SAI was assessed based on four items. In the Bolgatanga Municipality, most (49.84%) of the respondents disagreed with the statement "I use more fertilizers/pesticides for farming" and the least (29.64%) percentage of disagreement came from the item "I ensure my farming protects the environment. It is worth highlighting that most of the respondents (43.65%) strongly disagreed with the item "I use irrigation for farming". However, 50.64% of the respondents agreed with ensuring their farming practices protect the environment. Again, it was found that most of the respondents strongly disagreed (48.85%) with the item "I use irrigation for farming". Out of the four items used in assessing the environmental dimension of SAI, the results indicate that there was no clear pattern of agreement or disagreement.

4.3. Factor analysis of sustainable agriculture intensification (SAI)

Prior to the integrative assessment of SAI, the reliability test of the items was conducted using Cronbach's alpha. The Cronbach's alpha value for the 15 items was 0.813, which was above the required threshold of 0.7 [59]. Cronbach's alpha test implies that there is internal consistency among the items measuring SAI and this warranted conducting exploratory factor analysis (EFA) for SAI.

The assessment of the convergence of the item was conducted through EFA using the Principal Component technique. The EFA parameters, KMO=0.819, Bartlett's Test of Sphericity = 3479.202, df = 105, p-value = 0.000, met all the required standards (KMO>0.7 and p-value<0.05). The extracted components explained about 28% of the total variance with an eigenvalue of 4.215 (Table 4). All items having positive factor loading means that they all contribute to the measurement of SAI.

The generated regression estimates were ranked and recoded into three categories (low, moderate, and high) for the inferential statistics. The results in Fig. 3 show that about 36% of the respondents in both districts practised moderate SAI. Also, it was found that a relatively low proportion of the respondents practised low SAI. The proportion of smallholders with low SAI in the Bongo District (31%) was higher than those in Bolgatanga Municipal (28.3%). The chi-square test of SAI practices between the two districts revealed no statistically significant association.

4.4. Predictors of SAI

A multivariate analysis of the predictors of SAI in both districts was conducted using multinomial-ordered logistic regression, based on the outcome variable (SAI), categorised into three (low, moderate and high). The explanatory variables used in this model ranged from demographic and farming characteristics to ecological indicators. The model was fitted using the stepwise approach where all statistically insignificant variables (such as sex, level of education, household size, and number of farmlands among others) were excluded. Prior to the final regression analysis, a collinearity test was conducted using a

Table 3
Smallholder' perspective on the items of Sustainable Agriculture Intensification (SAI).

Item	SD		D		N		A		SA	
	N	(%)	N	(%)	N	(%)	N	(%)	N	(%)
Bolgatanga Municipality										
Economic										
My income is enough to cater for family and farm inputs	57	18.57	157	51.14	14	4.56	79	25.73	0	0.00
My income is enough to get the basic needs for farming	48	15.64	154	50.16	46	14.98	56	18.24	3	0.98
I have insured my farm	100	32.57	189	61.56	14	4.56	4	1.30	0	0.00
I save with some financial institutions for my farm inputs	60	19.54	180	58.63	28	9.12	35	11.40	4	1.30
I produce enough to feed my family throughout the year	47	15.31	154	50.16	46	14.98	54	17.59	6	1.95
I sell some of my produce	79	25.73	138	44.95	4	1.30	72	23.45	14	4.56
Social										
I have not been discriminated against in attempts to acquire some farm inputs	19	6.19	67	21.82	42	13.68	121	39.41	58	18.89
I have not been discriminated against in attempts to acquire land for farming	17	5.54	57	18.57	36	11.73	136	44.30	61	19.87
I have not been discriminated against as a farmer due to my economic status	13	4.23	60	19.54	30	9.77	138	44.95	66	21.50
I am efficient in terms of farming productivity	16	5.21	113	36.81	57	18.57	97	31.60	24	7.82
I have access to extension services	75	24.43	191	62.21	21	6.84	16	5.21	4	1.30
Environmental										
I use irrigation water for farming	134	43.65	123	40.07	21	6.84	23	7.49	6	1.95
I use more fertilizers/pesticides for farming	28	9.12	153	49.84	42	13.68	62	20.20	22	7.17
I ensure my farming practices protect the environment	8	2.61	91	29.64	29	9.45	127	41.37	52	16.94
The fertilizer I use has less impact on the land	11	3.58	96	31.27	61	19.87	81	26.38	58	18.89
Bongo District										
Economic										
My income is enough to cater for family and farm inputs	111	28.39	124	31.71	69	17.65	78	19.95	9	2.30
My income is enough to get the basic needs for farming	105	26.85	137	35.04	72	18.41	66	16.88	11	2.81
I have insured my farm	182	46.55	170	43.48	19	4.86	13	3.32	7	1.79
I save with some financial institutions for my farm inputs	133	34.02	198	50.64	24	6.14	30	7.67	6	1.53
I produce enough to feed my family throughout the year	100	25.58	133	34.02	85	21.74	62	15.86	11	2.81
I sell some of my produce	142	36.32	153	39.13	32	8.18	53	13.55	11	2.81
Social										
I have not been discriminated against in attempts to acquire some farm inputs	36	9.21	78	19.95	58	14.83	151	38.62	68	17.39
I have not been discriminated against in attempts to acquire land for farming	35	8.95	66	16.88	46	11.76	166	42.46	78	19.95
I have not been discriminated against as a farmer due to my economic status	29	7.42	72	18.41	46	11.76	172	43.99	72	18.41
I am efficient in terms of farming productivity	48	12.28	125	31.97	85	21.74	111	28.39	22	5.63
I have access to extension services	96	24.55	196	50.13	65	16.62	25	6.39	9	2.30
Environmental										
I use irrigation water for farming	191	48.85	147	37.60	28	7.16	18	4.60	7	1.79
I use more fertilizers/pesticides for farming	81	20.72	193	49.36	44	11.25	61	15.60	12	3.07
I ensure my farming practices protect the environment	37	9.46	84	21.48	47	12.02	198	50.64	25	6.39
The fertilizer I use has less impact on the land	42	10.74	102	26.09	72	18.41	154	39.39	21	5.37

Scale: Strongly disagree (SD); Disagree (D); Neutral (N); Agree (A); Strongly agree (SA), N= number of observations, %= percent

pairwise correlation analysis among the independent variables. The results showed that none of the independent variables correlated to a coefficient greater than 0.7, which falls within the recommended coefficient of <0.8 [60,61].

The results in Table 5, especially the R^2, show that the explanatory variables explain about 18% and 11% of the practice of SAI in the Bolgatanga Municipality and Bongo District, respectively. The results further reveal that age is a significant predictor of the practice of SAI at a 95% confidence level in the Bolgatanga Municipality. Specifically, it was found that respondents aged 38-47 years [OR=3.693, CI=1.060, 12.872] are more likely to practise high SAI compared to those aged 18-27 years. It was also found that respondents with a monthly income greater than GHC 200 were more likely to practise SAI compared to those with a monthly income less than or equal to GHC 200 in both districts. Also, traditionalists [OR=1.858, CI=1.051, 3.285] in Bolgatanga Municipality were found to be more likely to practise SAI compared to Christians at a 95% confidence level.

Respondents with big farm sizes (above 0.5 acres) were [OR=0.440, CI=0.230, 0.812] less likely to practice SAI in Bongo District. For instance, respondents with a farm size of about 1 acre were found to have 0.440 lower odds of practising high SAI than respondents with 0.5 acres farm size. Furthermore, respondents in densely vegetated areas [OR=2.573, CI=1.106, 5.987] in the Bolgatanga Municipality were more likely to practise SAI than those in areas with no vegetation at a confidence level of 95%. On the other hand, respondents in the Bolgatanga Municipality found in areas with high land surface temperature [OR=0.210, CI=0.046, 0.939] were found to be less likely to practise high SAI compared to those in areas with low SAI.

In addition, respondents in Bolgatanga Municipality who owned their farmlands [OR=0.244, CI=0.009, 0.644] were less likely to practise SAI than those who used family lands. Yet respondents whose land tenure was “other” [OR=3.413, CI=1.411, 8.256] were more likely to practise SAI in Bongo District than those who used family land. Apart from land tenure, the results showed that respondents in Bolgatanga Municipality whose farms were on steep slopes [OR=3.734, CI=1.630, 8.557] were more likely to practsce SAI compared to those whose farms were on gentle slopes at a 99% confidence level. In terms of proximity to a dam, it was found that respondents whose farms were far [OR=0.092, CI=0.032, 0.268] or farthest [OR=0.018, CI=0.003, 0.105] from a dam were less likely to practice SAI compared to those whose farms were near the dam in the Bolgatanga Municipality. Concerning water access, the results show that respondents with moderate water access [OR=0.367, CI=0.137, 0.981] have less likelihood of practising high SAI compared to those with low water access in the Bolgatanga Municipality. On the contrary, respondents in Bongo Districts who had moderate [OR=2.085, CI=1.159, 3.753] and high [OR=2.39, CI=1.259, 3.983] water access were found to be more likely to practise high SAI compared to those with low water access.

4.5. *Drivers of SAI*

Although the predictors of SAI have been investigated, it was deemed relevant to examine smallholders' perspectives about the drivers (external factors) of SAI. These drivers could be considered as perceived

Table 4
Factor analysis of sustainable agriculture intensification (SAI).

Factors	Factor loadings	%	Eigenvalue	α
I ensure my farming practices protect the environment (ENVI3)	.660	28.1	4.215	0.813
The fertilizer I use has less impact on the land (ENVI4)	.623			
I have not been discriminated against as a farmer due to my economic status (SOC3)	.622			
My income is enough to cater for family and farm inputs (ECO1)	.611			
I have not been discriminated against in attempts to acquire land for farming (SOC2)	.595			
My income is enough to get the basic needs for farming (ECO2)	.593			
I am efficient in terms of farming productivity (SOC4)	.579			
I have not been discriminated against in attempts to acquire some farm inputs (SOC1)	.578			
I save with some financial institutions for my farm inputs (ECO4)	.567			
I use more fertilizers/pesticides for farming (ENVI2)	.460			
I produce enough to feed my family throughout the year (ECO5)	.441			
I sell some of my produce (ECO6)	.393			
I have access to extension services (SOC5)	.362			
I use irrigation water for farming (ENVI1)	.361			
I have insured my farm (ECO3)	.336			

α= Cronbach's alpha, %= proportion of variance explained

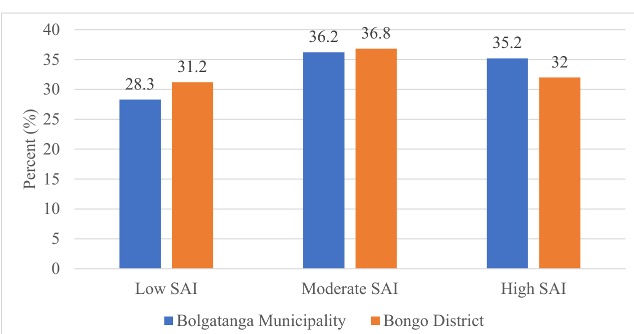

Fig. 3. Descriptive statistics of sustainable agriculture intensification (SAI). Chi-Square test (χ^2) = 1.133, p-value = 0.567.

external variables that influence smallholder farmers in the practice of SAI. Deducing from empirical studies, ten items were developed to examine smallholders' perspectives on drivers of SAI. In the conduct of the inferential statistics, the Kendall rank order analysis was used to examine the drivers of SAI. Results from the Kendall rank order analysis (Table 6) revealed that in Bolgatanga Municipality and Bongo District, the rank order had chi-square values of 656.29 and 430.38 respectively with a statistical significance of less than 0.001. This means that the data fits the model used and justifies that the results explain the reality.

From the results (Table 6), the mean rank score ranged from 3.57 to 7.34 in Bolgatanga Municipality. Considering the highly ranked item with a mean score of 7.34, smallholders in the Bolgatanga Municipality indicated that poor groundwater quality hinders the practice of SAI. Apart from poor groundwater quality hindering the practice of SAI in the Bolgatanga Municipality, respondents ranked the level of education (m=7.21) and government policies on agriculture (m=6.01) to be the

Table 5
Multinomial ordered logistic regression on the predictors of smallholders' sustainable agriculture intensification (SAI).

Independent variable	Bolgatanga Municipality OR [95% CI]	Bongo District OR [95% CI]
Age (Ref. 18-27)		
28-37	2.109 [0.550, 8.085]	1.710 [0.644, 4.535]
38-47	3.693* [1.060, 12.872]	2.109 [0.814, 5.462]
48-57	2.497 [0.680, 9.166]	2.055 [0.794, 5.319]
58+	3.545 [0.872, 14.416]	1.353 [0.504, 3.635]
Monthly Income (Ref. GHC 0-200)		
GHC 201-400	3.353** [1.902, 5.911]	2.174** [1.346, 3.510]
GHC 401-600	3.935** [1.959, 7.905]	2.636** [1.277, 5.440]
GHC 601-800	4.188* [1.123, 15.618]	2.684 [0.516, 13.973]
GHC 801-1000	2.683 [0.256, 28.122]	2.732 [0.561, 13.308]
GHC 1001+	15.288** [2.470, 94.639]	3.533 [0.934, 13.361]
Religion (Ref. Christianity)		
Traditional	1.858* [1.051, 3.285]	1.022 [0.641, 1.630]
Islam/Other	2.531 [0.830, 7.713]	1.911 [0.878, 4.158]
Farm size (Ref. 0.5)		
1	0.676 [0.300, 1.524]	0.440** [0.238, 0.812]
2	1.132 [0.513,2.500]	0.773 [0.394, 1.520]
3	1.208 [0.480, 3.037]	0.603 [0.249, 1.459]
4+	0.810 [0.341, 1.927]	0.264 [0.124, 0.562]
Land tenure (Ref. Family)		
Others	0.731 [0.237, 2.251]	3.413** [1.411, 8.256]
Owned	0.244** [0.009, 0.644]	0.642 [0.300, 1.373]
Slope (Ref. Low)		
Moderate	1.573 [0.931, 2.656]	1.127 [0.702, 1.809]
High	3.734** [1.630, 8.557]	0.956 [0.452, 2.022]
NDVI (Ref. No vegetation)		
Sparse vegetation	1.684 [0.857, 3.309]	0.992 [0.540, 1.823]
Dense vegetation	2.573* [1.106, 5.987]	1.057 [0.498, 2.243]
Distance to Dam (Ref. Near)		
Far	0.092** [0.032, 0.268]	0.895 [0.562, 1.424]
Farthest	0.018** [0.003, 0.105]	1.057 [0.498, 2.0220]
Water Access (Ref. Low)		
Moderate	0.367* [0.137, 0.981]	2.085* [1.159, 3.753]
High	0.785 [0.299, 2.061]	2.39** [1.259, 3.983]
Land surface temperature (Ref. Low)		
Moderate	0.232 [0.053, 1.015]	1.731 [0.882, 3.394]
High	0.210* [0.047, 0.939]	1.190 [0.601, 2.356]
Cut (Low)	-1.295 [-3.300, 0.709]	0.213 [-0.909, 1.336]
Cut (Moderate)	0.780 [-1.190, 2.751]	2.090 [0.948, 3.233]
N	307	391

(continued on next page)

Table 5 (*continued*)

Independent variable	Bolgatanga Municipality OR [95% CI]	Bongo District OR [95% CI]
Wald chi^2	93.93	101.86
Prob > chi^2	0	0
R^2	0.183	0.115

**=p<0.001; *=p<0.05, OR= odds ratio, CI= Confidence Level

Table 6
Rank order analysis of drivers of sustainable agriculture intensification (SAI).

Item Bolgatanga Municipality	Mean Rank	Item Bongo District	Mean Rank
Poor groundwater quality	7.34	Level of education	6.62
Level of education	7.21	Poor groundwater quality	6.42
Government's policy on agriculture	6.01	Engagement in farming groups	6.29
Urban growth	5.77	Urban growth	6.2
Population growth	5.1	Government's policy on agriculture	5.93
Farm size	4.99	Population growth	5.51
Limited access to the use of modern technology	4.69	Limited access to the use of modern technology	4.86
Engagement in farming groups	4.49	Farm size	4.61
Low soil nutrient content	3.83	Low soil nutrient content	4.44
Inadequate capital	3.57	Inadequate capital	4.13
N	307	N	391
Kendall's W[a]	0.24	Kendall's W[a]	0.12
Chi-square	656.29	Chi-square	430.38
df	9	df	9
p-value	<0.001	p-value	<0.001

df= degree of freedom, N= number of observations

second and third highest drivers of SAI respectively. The least ranked driver of SAI in the Bolgatanga Municipality was inadequate capital (3.57).

Within Bongo District, smallholders revealed a slightly different order of ranking of the drivers of SAI compared to those in the Bolgatanga Municipality. The ranking ranged from 4.13 to 6.62. The highest-ranked driver of SAI was level of education (m=6.62), while the least ranked was inadequate capital (m=4.13). The second and third-ranked drivers were poor groundwater quality (m=6.42) and engagement in farming groups (m=6.29), respectively.

5. Discussion

This study sought to assess smallholders' perspectives on the practice of SAI in the Guinea Savanna Agro-Ecological Zone (semi-arid), particularly in the Bolgatanga Municipality and Bongo District. Specifically, we sought to examine the practice of SAI among smallholders, determine factors that influence SAI and assess the drivers of SAI in the Bolgatanga Municipality and Bongo District.

5.1. Smallholder perspectives on SAI practices

Generally, there were varied perspectives on the items used in measuring smallholders' practice of SAI. In terms of the economic dimension of SAI for Bolgatanga Municipality and Bongo District, most respondents disagreed with all the items adapted. The results from this study corroborate the study by Liao and Brown [62] who opined that smallholders do not obtain their expected incomes or economic worth. Similarly, Adolph et al. [23] revealed that most households in West Africa sell a small proportion of their produce due to limited off-season vegetables and livestock products. This finding has numerous implications for SAI because if smallholders are not benefiting economically, some may quit farming to venture into other jobs which may exacerbate food insecurity. There was evidence of people migrating from the north, especially Upper East Region to seek greener pastures in the south or abroad [23,63]. Also, those who continue to farm may decide to shift from SAI to extensification which would defeat the idea of increasing yield on the same piece of land with little or no environmental impact.

Similarly, the results of the social dimension of SAI revealed that most (62.21%) of the respondents disagreed with having access to extension services in both districts. Interestingly, in both districts, there was a relatively higher percentage of agreement to not being discriminated against as a farmer due to their economic status. Considering the results from both districts, the responses suggest that the social dimension of SAI was good. However, the fact that 62.21% of respondents in both districts reported a lack of access to extension services highlights a significant gap in agricultural support. Without access to extension services, farmers may struggle to adopt sustainable practices, leading to potential inefficiencies and reduced productivity. This has been explained by Haggar et al.[63] as an uneven playing field for smallholders. According to Liao and Brown [62], social well-being plays a crucial role in SAI because social inequality significantly affects the other dimensions of SAI.

Regarding the environmental dimension of SAI, respondents from both districts disagreed with using more fertilizers/pesticides for farming. This is not contestable because they used compost from their backyards [13]. However, Adolph et al. [23] found an increase in the use of fertilizers in West Africa. Also, considering their income distribution, raising money for fertilizers or pesticides would be a challenge. Also, it was found that most of the respondents from both districts disagreed with using irrigation for farming. This explains the high competition for lands closer to waterbodies or river banks [64]. Out of the four items used in assessing the environmental dimension of SAI, the results indicate that there was no clear pattern of agreement or disagreement with environmental sustainability. Synchronisation of all the items through factor analysis revealed that smallholder farmers in both districts practised moderate SAI. Gleaning from the three dimensions, the economic and environmental dimensions need to be enhanced to achieve a high practice of SAI among smallholders.

5.2. Predictors of SAI

To achieve a good practice of SAI, the influence of smallholders' characteristics ought to be assessed. Based on the multinomial logistic regression, it was found that socio-demographic characteristics (age, monthly income, religion), farming characteristics (farm size, land tenure) and environmental characteristics, farm size, land tenure, slope, NDVI, distance to water, access to water and land surface temperature (LST) influenced smallholder farmers' practice of SAI. Regarding age, it was found that the older one gets, the more likely they are to practise SAI, which supports the findings of several studies [43–45]. Similarly, it was revealed that the more income one has, the more likely they are to practise SAI. This finding supports the studies by Abdul-Kareem & Şahinli [43] and Schut et al. [7], where financial resources such as income were found to influence smallholders' practice of SAI. In terms of religion, it was found that traditionalists were more likely to practise SAI compared to Christians because they are believed to worship through nature (environment) so they have a responsibility to protect it.

Land tenure determined the practice of SAI; smallholders who owned their farmlands were less likely to practise SAI than those who used family lands or rented. This confirms the studies by Abdul-Kareem and Şahinli [43], Mutimura et al. [44], and Syafruddin et al. [45] where the type of land tenure was found to have influenced farmers' practice of SAI. Also, slope was identified as a predictor of SAI where those who farmed on steep slopes [OR=3.734, CI=1.630, 8.557] were more likely to practise SAI compared to those whose farms were on gentle slopes. This finding validates the study by Snyder and Cullen [13], which indicated that smallholders at higher elevations need to adopt SAI measures to retain water for higher annual production. Thus, farmers on high elevations cultivate high-value crops; for that matter, practising SAI is very important.

Smallholders cultivating in areas with dense vegetation were found to be more likely to practise SAI to leverage the natural advantages of their environment, preserve critical ecosystem services, and maintain sustainable agricultural productivity. Also, it was found that smallholders with bigger farm sizes (above 0.5 acres) were less likely to practice SAI. According to Adolph et al. [23], farmers with small farm sizes have a sense of belonging to a community and a family. This explains why smaller farm sizes would be used for SAI. On the other hand, farmers found in areas with high land surface temperature (LST) were less likely to practise SAI due to reduced soil fertility, increased water stress, high input costs, crop vulnerability and lack of awareness and support. Access to water (subjective access measurement) and distance to a dam (objective distance measurement) were found to be significant predictors of smallholders practising SAI. The plausible reason is that water availability in a savannah region encourages the practice of SAI, which is confirmed by the findings of Jayne et al. [65].

5.3. Key drivers of SAI

The top four drivers of SAI were level of education, groundwater quality, government's policy on agriculture and urban growth. The emphasis on education suggests that increasing farmers' knowledge and skills is crucial for the adoption of sustainable practices, highlighting the need for targeted training and awareness programs. However, the respondents' ranking of education being a major driver of SAI confirms the studies by Abdul-Kareem and Şahinli [43], Haggar and Rodenburg [66] and Kotu et al. [67] where knowledge through extension service is paramount in the promotion of SAI. The concern over poor groundwater quality indicates that water management is a critical factor in SAI, necessitating investments in sustainable water use and conservation technologies [68]. Government policy on agriculture as a key driver also underscores the importance of supportive policies that incentivize sustainable practices and provide resources for farmers. Finally, the influence of urban growth points to the pressure on agricultural land and resources from expanding cities, suggesting that strategies for SAI must address the challenges of land use competition and ensure that urbanization does not undermine agricultural sustainability.

6. Conclusion

The study sought to assess smallholders' perspectives on the practice of SAI in the Guinea Savanna Agro-Ecological Zone (semi-arid) of Ghana. Using a cross-sectional design to gather data from 698 smallholders in the Upper East region, the study revealed that there was no statistically significant difference in the practice of SAI between Bolgatanga Municipality and Bongo District. However, statistically significant associations were found between the practice of SAI and socio-demographic, farming and ecological characteristics such as sex, level of education, age, cost distance to a river and water access. Positive predictors of the practice of SAI were age, monthly income, religion, slope, vegetation and water access. On the other hand, negative predictors of SAI were farm size, land surface temperature, cost distance to a dam and land tenure. Finally, it was found that poor groundwater quality, level of education, government policies on agriculture, engagement in group farming and others were drivers for adopting the practice of SAI.

These findings suggest that smallholders' adoption of SAI practices is strongly influenced by a combination of socio-demographic, ecological, and economic factors, with both positive and negative predictors shaping their decisions. Addressing these factors through targeted interventions such as improving education, access to water, and income support while considering the impacts of farm size, land temperature, and tenure systems, could enhance the adoption of SAI practices, thereby improving the sustainability and productivity of smallholder farming. For a global audience, these findings underscore the importance of a comprehensive approach to agricultural sustainability that considers the diverse and local socio-economic and environmental contexts in which farmers operate. On the basis of these findings, we recommend that governments, international organizations, and NGOs, including the Ministry of Food and Agriculture (MOFA), district assemblies, the International Institute of Tropical Agriculture (IITA), and Youth Harvest, should collaborate in promoting and implementing SAI technologies and providing targeted training for smallholders

The key strength of this study lies in its novel application of social science techniques to explore smallholders' perspectives on the practice of Sustainable Agricultural Intensification (SAI) in semi-arid, low- and middle-income contexts. However, there are some limitations. First, we relied on cross-sectional data, meaning no directionality or causal conclusions can be drawn regarding the observed associations between SAI, background characteristics, farming characteristics, and ecological indicators. Additionally, the use of a structured, self-reported instrument may introduce bias in the measured variables. Finally, the ecological indicators could be influenced by the Modifiable Areal Unit Problem (MAUP) due to the scale of the study area. Based on these limitations, future research should consider longitudinal approaches to better understand the predictors of SAI in semi-arid, low- and middle-income regions.

Disclosure statement

The authors declare that there are no competing interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability statement

The data supporting the findings of this study are available in the Figshare repository at https://doi.org/10.6084/m9.figshare.26528080.v1. The data are publicly accessible and can be freely used under the terms provided in the repository.

CRediT authorship contribution statement

Ebenezer N.K. Boateng: Writing – review & editing, Writing – original draft, Formal analysis, Conceptualization. **Gerald Atampugre:** Writing – review & editing, Methodology. **Patricia Solis:** Writing – review & editing. **Simon Mariwah:** Writing – review & editing, Supervision. **Ishmael Mensah:** Writing – review & editing, Supervision. **Christine Furst:** Funding acquisition. **Benjamin K. Nyarko:** Supervision, Funding acquisition.

Declaration of competing interest

None.

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