



Micro-level welfare effects of integrated soil fertility management in Northern Ghana

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ABSTRACT

Integrated Soil Fertility Management (ISFM) is promoted as a sustainable approach to enhance farm productivity and ensure a reliable food supply. This study examines the association between ISFM, maize yield, income, total asset value, and food security using a quasi-experimental approach, drawing on data from 966 farm households in Ghana. The results show that ISFM adoption increases crop yield by 878 kg/ha, income by \$453, and total asset value by \$765. Regarding food intake, ISFM adoption boosts the consumption of calories, proteins, and fats during food-scarce periods by 2406 kcal/day, 52 kg/day, and 90 kg/day, respectively. Consistent with extensive margin findings, the intensity of ISFM adoption is positively correlated with yield, income, total asset value, and food security. However, increasing the number of ISFM practices does not necessarily lead to higher outcomes, as it may be associated with higher labour costs. These results are robust across various model specifications and combinations of ISFM practices. Sustaining the welfare gains from ISFM adoption will require improved access to agricultural production information from research institutions.

1. Introduction

Agricultural land, a valuable natural resource, is becoming increasingly scarce in many African countries due to degradation from both natural and human-induced factors. As population growth continues, the pressure to increase agricultural production on the same fixed land area intensifies. Urbanization has further reduced the availability of land for agricultural use (Vlek et al., 2008). This challenge is compounded by high levels of soil degradation, which lead to declining soil fertility and lower crop yields, posing a serious threat to food production and security (Food and Agriculture Organization [FAO], 2020). In recent years, many policies across Africa have aimed to intensify agricultural production by promoting technologies that address the production and post-harvest challenges faced by farm households. Some of these policies focus on enhancing land productivity while ensuring environmental sustainability. Strategies implemented under these policies include the accelerated adoption of improved crop varieties, increased use of organic and inorganic fertilizers, and the promotion of soil and water conservation technologies (Oduol et al., 2011; Bationo

and Waswa, 2011).

In Sub-Saharan Africa (SSA), smallholder farmers make up the majority of the agricultural production systems, yet they consistently face low productivity (Vlek et al., 2008). For instance, in northern Ghana, 80 percent of the farming population is engaged in subsistence farming, characterized by very low productivity and farm income (Ministry of Food and Agriculture [MoFA], 2011). Recognizing these challenges, many development projects in SSA have prioritized improving smallholder productivity and food security through collaborations with national agricultural research systems (NARS). These efforts have particularly emphasized the sustainable intensification of smallholder agriculture, with a strong focus on promoting Integrated Soil Fertility Management (ISFM).

ISFM promotes the use of mineral fertilizers, organic inputs, and improved germplasm, alongside localized knowledge to optimize the agronomic efficiency of nutrient applications and enhance crop productivity (Vanlauwe et al., 2010). Since development organizations began promoting ISFM, researchers have examined the factors influencing its adoption and its impact on yield and income (Martey and

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Kuwornu, 2021; Hörner and Wollni, 2021; Takahashi et al., 2020; Jayne et al., 2019). However, there is limited research linking ISFM to the access dimension of food security, particularly in relation to seasonality. While Barret & Bevis (2015) and Vanlauwe et al. (2010) suggest that ISFM aims to improve soil fertility, crop yields, income, and food security, empirical evidence on its seasonal effects on food access is scarce. This study addresses this gap by providing empirical evidence on how ISFM adoption affects maize yield, crop income, household asset value, and food security.

Several studies have explored ISFM adoption and its impact on welfare in Sub-Saharan Africa (SSA). The adoption of multiple agricultural technologies is often complex, dynamic, and involves elements of risk management, learning, and investment adjustments (Aldana et al., 2011; Barham et al., 2004; Fernandez-Cornejo et al., 2002). For risk-averse farmers with limited technology exposure, adoption decisions tend to be cautious. However, as farmers gain more exposure, they gradually adopt various components of ISFM practices on their plots. Even with complete information, adoption may remain low due to credit constraints. The benefits derived from ISFM adoption can reinforce farmers' willingness to continue using the technology. Past research has revealed varying impacts of ISFM on welfare. For example, Hörner and Wollni (2021) found differential positive effects from adopting core ISFM components on labour demand, income, food security, and school enrolment, with variations based on agroecological zones. They concluded that the welfare effects of agricultural innovations depend on farmers' income diversification strategies. Adolwa et al. (2019) reported that in Northern Ghana and Western Kenya, ISFM adoption boosts crop yields, though multiple adoptions did not show similar effects. Nata et al. (2014) found that adopting soil improvement practices had a positive impact on food security in Ghana, while Kato et al. (2011) observed a positive effect of ISFM on crop production in Nigeria. Similarly, Sauer and Tchale (2009) estimated a normalized yield-response model and found that ISFM adoption increased yields among Malawian farmers after accounting for other relevant factors.

Previous studies have yielded valuable insights and laid a foundation for development interventions. However, many of these studies lack a comprehensive understanding of how ISFM influences food intake. Additionally, important components of ISFM, such as crop residue, green manure, and mulch, have not been adequately explored, despite their critical roles in enhancing soil fertility. A significant gap in the literature is the hypothesis regarding whether increased income from ISFM adoption leads to asset accumulation that can be liquidated during adverse economic shocks to stabilize household consumption. For instance, while the Ghana study by Adolwa et al. (2019) provides useful insights, it is limited in geographical coverage. The effects of ISFM adoption on welfare outcomes may vary based on farmer location, and analysing these variations could significantly contribute to policy discussions on targeted agricultural technologies. Our analysis expands on the outcomes assessed by Adolwa et al. (2019) by including total asset value and food security. This is particularly relevant in the study area, where food insecurity poses a considerable challenge for many households (Balana et al., 2019; Nkegbe et al., 2017). The findings of our analysis are pertinent for academics, development partners, and agricultural practitioners in northern Ghana, as they can guide the dissemination of ISFM practices. In developing countries, where many farmers face constraints in adopting and utilizing technology, it is essential to recommend "best" practices that are both economically rewarding and cost-effective.

The remainder of the study is organized as follows: Section 2 provides an overview of the study area, including the sampling procedure, data collection methods, and summary statistics. Section 3 outlines the conceptual and methodological framework, as well as the identification strategy used to address the research question. Section 4 discusses the empirical results in detail. Finally, Section 5 offers concluding remarks and implications of the findings.

2. Data and summary statistics

2.1. Study area and sampling

Our study area is northern Ghana,¹ which encompasses the Northern, Upper East, and Upper West regions. This region is situated within the Guinea and Sudan savannah agroecological zones and covers a vast area with an estimated population of 3,317,478. Northern Ghana experiences an annual average rainfall of approximately 1000 mm. The terrain is generally flat, characterized by predominantly lateritic soils containing less than 0.5% organic matter, which results in inherently low soil fertility (MoFA, 2010). The three regions are economically disadvantaged compared to the rapidly developing and urbanizing southern regions of the country (Gage et al., 2012). Northern Ghana has about seven million hectares of arable land, with 70% available for agricultural production. The vegetation is primarily grassland, and agriculture serves as the mainstay for the majority of the inhabitants. Numerous government and donor intervention programs have been implemented to transform these regions into the breadbasket of Ghana (MoFA, 2011).

The sampling procedure employed in this study is a multistage sampling design. In the first stage, ten districts from the Northern Region were purposively selected, along with six districts each from the Upper West and Upper East regions. This selection was based on the quantity of maize produced and the soil fertility status of the areas. In the second stage, five communities were randomly chosen from a list of farming communities within each selected district. Finally, ten smallholder farmers were randomly selected from a list of farmers in each chosen community. This process resulted in a total sample of 1100 households. However, the sample size was reduced to 966 households due to missing responses on some explanatory variables. To ensure the representativeness of our sample relative to the population, we conducted a power test, which indicated that the sample is highly representative (Yamane, 1967).

2.2. Data

The data collected for this study encompasses various aspects, including household demographics, farm characteristics, social capital, soil improvement technologies, crop and livestock production, income and expenditure, household experiences with credit, climate variability and shocks, social interventions, crop insurance, and food security. The study specifically focused on five out of the nine practices identified in the survey. These practices include crop residue management, green manure application, mulching, composting, and the use of mineral fertilizers. The selection of these practices was based on their potential impact on soil fertility and their role in supporting plant growth.

We constructed ISFM measurements in two forms: as a dummy variable (1/0) and as a continuous variable (representing the number of practices adopted). By convention, ISFM comprises various management practices that enhance soil fertility. A farmer is considered to be practicing ISFM only if they employ more than one management practice aimed at improving soil fertility. According to this conventional classification, we define adopters of ISFM as farmers who utilize at least two components of ISFM. Conversely, non-adopters are those farmers who use only one ISFM practice or who do not use any of the ISFM practices. The dummy ISFM variable measures the extensive margin of ISFM adoption, while the continuous ISFM variable assesses the impact of additional ISFM practices on the outcome variables. This study examines four outcome variables: yield, crop income, total asset value (in Ghana cedis), and food security, all of which are expected to be positively influenced by ISFM adoption. The first outcome, yield, is measured by the quantity of output per hectare (kg/ha). Crop income is evaluated

¹ The administrative regions of Ghana are now 16 effective February 15, 2019 but at the time of the survey, the administrative regions were ten.

based on the total value of crop production per hectare (Ghana cedis/ha). This measure accurately reflects the yields of farmers, particularly smallholder farmers in Sub-Saharan Africa (SSA), where many plots are intercropped with multiple crops (Jansen et al., 2006; Pender and Gebremedhin, 2008; Kato et al., 2010). The total asset value represents all assets owned by the farm households, assessed at current market prices (Ghana cedis). Food security is computed based on food access related to the actual food consumed by the sampled households. This included an assessment of the nutritional value (calories, protein, and fats) of the food consumed, considering both adequacy and nutritional quality. Since the sampled farmers primarily rely on agriculture, access to food fluctuates according to the crop calendar. To evaluate the stability of the nutritional intake of households, we estimated the nutritional values of the food consumed during three key seasons: the normal access period, the abundance period, and the lean period.

2.3. Summary statistics

Table 1 presents the regional adoption rates of various ISFM components among farmers. Approximately 77% of farmers utilize crop residue, while 78% use mineral fertilizers. Additionally, around 19% of the sampled farmers employ compost, and 31% and 24% use green manure and mulching, respectively. When examining the data by region, the adoption of crop residue is notably higher among farmers in the Upper West (83%) and Upper East (82%) regions compared to those in the Northern Region. For mineral fertilizer usage, the Upper East region stands out with about 94% of farmers utilizing it, while the Upper West and Northern regions show adoption rates of 79% and 68%, respectively. The use of mulch is particularly prevalent in the Upper West Region (32%), whereas 73% of green manure users are found in the Upper East Region of Ghana. These findings indicate that ISFM adoption is significantly more pronounced among farmers in the Upper East and Upper West regions compared to those in the Northern Region.

Table 2 presents the differences in outcome variables based on ISFM adoption status. Among the sampled farmers, adopters make up 74% of the total. The results reveal statistically significant differences between adopters and non-adopters concerning calorie intake during normal, abundant, and lean periods. Specifically, non-adopters of ISFM reported higher calorie intakes compared to adopters, with 2329 kg versus 1866 kg during normal periods, 2688 kg versus 2215 kg during abundant periods, and 2105 kg versus 1435 kg during lean periods. However, no statistically significant differences were observed between adopters and non-adopters regarding yield, income, total asset value, protein, and fat consumption.

Table 3 outlines the differences in explanatory variables based on ISFM adoption status. Adopters of ISFM were significantly distinct from non-adopters in several aspects, including household size, farm size, slope of farmland, soil status, farmer location, experiences with drought or flood, loss of livestock due to flooding, distance to the nearest research office, and the proportion of households with televisions, cars, tractors, and cell phones. Notably, non-adopters have larger household sizes and farm sizes and travel an average of 3.73 km farther than adopters to access technical farming support. A higher proportion of non-adopters reside in the Northern Region and have experienced

Table 1
ISFM components based on regional status.

ISFM components	Northern Region		Upper East Region		Upper West Region		Pooled Sample	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Crop residue	0.700	0.459	0.822	0.384	0.827	0.379	0.770	0.421
Green manure	0.158	0.365	0.725	0.447	0.151	0.359	0.307	0.462
Compost	0.224	0.417	0.221	0.416	0.102	0.303	0.187	0.390
Mulching	0.208	0.406	0.209	0.408	0.324	0.469	0.242	0.429
Mineral fertilizer	0.682	0.466	0.938	0.242	0.792	0.406	0.783	0.413

Note: SD refers to standard deviations.

Table 2
Outcome variables by adoption status.

Variable	Non-adopters		Adopters		Mean Difference
	Mean	Std. Dev.	Mean	Std. Dev.	
<i>Intermediate outcomes</i>					
Maize yield (kg/ha)	600.16	734.47	659.84	767.04	-59.69
Maize income (GHS)	824.41	1501.73	989.76	1659.74	-165.36
<i>Welfare outcomes</i>					
Asset value (GHS)	1759.28	2236.04	1831.30	2038.97	-72.02
Calories in normal period	2328.98	2261.27	1866.12	2142.21	462.85 ^a
Calories in abundant period	2687.62	2341.60	2214.94	2320.68	472.68 ^b
Calories in the lean period	2104.92	2702.29	1434.86	1286.52	670.07 ^a
Protein in normal period	39.50	44.79	35.93	33.75	3.57
Protein in abundant period	46.45	54.38	46.09	56.09	0.37
Protein in the lean period	33.25	41.73	28.50	35.95	4.74
Fat in normal period	25.19	45.10	22.50	40.04	2.69
Fat in abundant period	26.68	42.71	23.75	32.09	2.93
Fat in the lean period	27.53	99.25	17.51	27.82	10.02

Notes: The exchange rate is US\$1 = GHS3.81 (Bank of Ghana, 2016).

*Significant at the 10% level.

^a Significant at the 1% level.

^b Significant at the 5% level, and.

adverse conditions such as drought and flooding, as well as loss of livestock due to floods. Additionally, they tend to have a greater percentage of households with cell phones compared to adopters. In contrast, most adopters cultivate land with loamy soil and on sloped terrain more frequently than non-adopters. Regarding village-level controls, adopters exhibit a higher proportion of households owning televisions and cars in their villages compared to non-adopters. Detailed descriptions of the data, categorized by the intensity of ISFM adoption (non-adopters, low adopters, and high adopters), are available in the appendix (Table A1).

3. Conceptual and methodological frameworks

3.1. Farm household adoption decision

Partial adoption of new technology among smallholder farmers can be analysed through the lenses of risk and uncertainty, market imperfections, and input fixity (Sadoulet and De Janvry, 1995; Smale et al., 1994). The adoption process typically involves an experimentation stage at the farmer level, where both new and existing technologies are employed concurrently. This allows farmers to evaluate the outcomes and make informed decisions regarding the final adoption of the technology.

Following Ali and Abdulai (2010), the technology adoption decision is modelled within the random utility framework. Let K^* denote the

Table 3
Summary statistics of explanatory variables by adoption status.

Variable	Non-adopters		Adopters		Mean Difference
	Mean	Std. Dev.	Mean	Std. Dev.	
<i>Household and farm variables</i>					
Age of household head	47.65	13.75	47.13	13.54	0.52
Sex of household head (1 = Male)	0.95	0.22	0.96	0.19	-0.01
Education status (1 = Educated)	0.43	0.50	0.43	0.50	-0.01
Household size	9.61	4.33	8.20	3.64	1.40 ^a
Years of farming	11.79	10.96	12.80	9.79	-1.02
Intercropping (1 = yes)	0.81	0.39	0.79	0.41	0.02
Number of farm plots	2.99	1.50	2.93	1.87	0.06
Distance to farm land	1.94	2.06	1.76	2.07	0.18
Farm size	4.37	5.30	3.26	2.87	1.11 ^a
Slope of farmland (1 = Slope)	0.70	0.46	0.85	0.36	-0.15 ^a
Soil status (1 = Loamy)	0.42	0.49	0.50	0.50	-0.08 ^b
Location of the farmer (1 = Northern)	0.65	0.48	0.36	0.48	0.29 ^a
Land ownership (1 = Owner)	0.91	0.29	0.92	0.28	-0.01
<i>Climate-related variables</i>					
Suffered from drought/flood (1 = Yes)	0.67	0.47	0.53	0.50	0.14 ^a
Loss of livestock due to flood (1 = Yes)	0.26	0.44	0.13	0.34	0.13 ^a
Long-term change in mean temperature (1 = Yes)	0.96	0.19	0.96	0.19	0.00
HH member sustained injury due to flood (1 = yes)	0.00	0.06	0.00	0.05	0.00
<i>Institutional variable</i>					
Distance to the nearest research office	24.50	15.59	20.77	15.42	3.73 ^a
<i>Village level controls</i>					
Proportion of T.V. owners in the village	15.74	23.16	20.42	23.50	-4.68 ^b
Proportion of bicycle owners in the village	58.23	32.36	49.64	31.33	8.59
Proportion of motorcycle owners in the village	24.92	24.81	22.68	24.24	2.24
Proportion of car owners in the village	0.41	1.07	0.78	1.54	-0.36 ^a
Proportion of tractor owners in the village	0.61	1.76	0.41	0.93	0.20 [*]
Proportion of cell phone owners in the village	58.43	30.48	53.62	30.45	4.80 ^b
Proportion of male literates in village	21.06	19.62	21.76	20.22	-0.69
Proportion of female literates in village	11.64	14.62	10.05	12.13	1.59
Observations	254		712		

Notes: The mean difference is computed as the mean of non-adopters minus the mean of adopters.

^a Significant at the 1% level and.

^b Significant at the 5% level.

difference between the utility from adoption (U_{jA}) and non-adoption (U_{jNA}) of ISFM. A utility-maximizing farm household; j makes an adoption decision on ISFM if the utility derived from adoption is greater than the utility from non-adoption such that $K^* = U_{jA} - U_{jNA} > 0$. Given that utility is unobservable, it can be expressed as a function of observable components in the latent variable as follows:

$$K_{ij}^* = \delta X_{ij} + \mu_{ij} > 0 \quad \text{where} \quad K_{ij} = \begin{cases} 1 & \text{if } K_{ij}^* > 0 \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

where K_{ij} is a binary indicator variable for individual i in household j that equals 1 if a farmer adopts ISFM ($K_{ij} = 1$) and zero otherwise ($K_{ij} = 0$); δ is a vector of parameters to be estimated; X_{ij} is a vector of explanatory variables; and μ_{ij} is the error term. The adoption of ISFM is expected to increase farm level and welfare outcomes.

The baseline equation linking ISFM adoption decision and the outcome variables, Y_{ij} (crop yield, income, total asset value, and food security) is expressed as follows:

$$Y_{ij} = \vartheta X_{ij} + \beta K_{ij} + D_v + \varepsilon_{ij} \quad (2)$$

where D_v is village-level fixed effects, and ε is a random error term.

Self-selection is a significant problem in adoption decision which confound the true estimated impact in equation (2). The adoption decision is likely influenced by unobservable or omitted characteristics (e. g., innate abilities, motivation, managerial skills, innovativeness, and average land fertility) that may correlate with the outcome variables. Similarly, the endogeneity problem may result from measurement error, which may likely underestimate the actual effect of ISFM adoption on farm and welfare outcomes (Card, 1999). Within the context of the regression framework, β will be correlated with K and μ in equation (1).

3.2. Instrumental variable estimation

Estimating equation (2) with ordinary least squares (OLS) will lead to a biased estimate due to the endogeneity in the adoption of ISFM. The study employs instrumental variable (IV) in a two-stage least square (2SLS) approach to resolve the endogeneity. Using the 2SLS approach, the standard errors must be adjusted since adoption is predicted rather than actual (Winters, Salazar & Maffioli, 2010).

The first stage (equation (3)) involves regressing ISFM adoption on an instrument, Z_{ij} (distance to the agricultural research station), control variables (X_{ij}), and village-level fixed effects, D_v to obtain the estimated values of ISFM (\hat{K}_i). In the second stage, \hat{K}_i is included in equation (4) to determine its effect on the outcome variables.

$$K_{ij} = \varphi + \delta Z_{ij} + \gamma X_{ij} + D_v + \mu_{ij} \quad (3)$$

$$Y_{ij} = \gamma + \beta \hat{K}_{ij} + \vartheta X_{ij} + \theta D_v + \varepsilon_{ij} \quad (4)$$

The distance from farmers' locations to the nearest research institution (geographic proximity) is expected to negatively affect the decision to adopt ISFM, as research institutions serve as the primary channels through which farmers are exposed to ISFM practices. Proximity to these research stations significantly influences the level of exposure to ISFM information and technical support. Since the location of research institutions is exogenous to farmers' own locations, we posit that farmers situated closer to these stations are more likely to receive the necessary technical assistance and information regarding ISFM practices, which, in turn, influences their adoption decisions. Given that farmers typically inherit their farmland from relatives, they are unlikely to relocate to areas closer to research institutions. Therefore, we argue that geographic proximity to research stations serves as an instrumental variable that incentivizes ISFM adoption without directly affecting the outcome variables. The choice of this instrument is informed by previous literature (Cawley et al., 2018; Callan and Harmon, 1999; Card, 1999).

Certain communities are more likely to be exposed to ISFM practices than others due to factors such as geographic proximity to research institutions, strong political ties, and the village-level endowment of resources. Village-level controls include the proportion of literate individuals, the presence of extension programs, and the percentage of the population with access to various forms of transportation (e.g., motorcycles, bicycles, cars, tractors), cell phones, and irrigation infrastructure. These controls help to account for the varying levels of resources and support available within different communities, which may impact farmers' decisions to adopt ISFM practices.

3.3. Alternative estimation: inverse probability weighted regression adjustment (IPWRA)

To check for the robustness of the results, we implement the doubly robust inverse probability weighted regression adjustment (IPWRA)

method as proposed by Wooldridge (2010). The IPWRA estimator is expressed as:

$$ATET_{IPWRA} = n_A^{-1} \sum_{i=1}^n T_i [r_A^*(X, \delta_A^*) - r_N^*(X, \delta_N^*)] \quad (6)$$

where n_A is the number of ISFM adopters, $r_i(X)$ is the regression model for ISFM adopters and non-adopters (N) regressed on observed covariates X , and parameters $\delta_i = (\alpha_i, \beta_i)$. This estimator averages the predicted outcomes (farm and welfare outcomes) to calculate the treatment effects.

4. Results and discussion

4.1. Local polynomial regression for outcome variables and ISFM adoption

Fig. 1 presents a non-parametric local polynomial regression that explores the relationship between the intensity of ISFM adoption and various outcome variables: maize yield (panel A), maize income (panel B), total asset value (panel C), calories consumed (panel D), protein consumed (panel E), and fat consumed (panel F). In panel A, we observe an inverse relationship between the intensity of ISFM adoption and maize yield, indicating that farmers who adopt all components of ISFM tend to achieve lower yields compared to those who adopt fewer components. This suggests that full adoption of ISFM may not necessarily correlate with higher yields. Panel B shows that low intensity of ISFM adoption is associated with higher income levels compared to high intensity of ISFM adoption. Similarly, in panel C, total household asset value appears to decline as the intensity of ISFM adoption increases, implying that farmers adopting all ISFM components may not experience a corresponding increase in asset value. Concerning panel D, we observed an inverse relationship between the intensity of ISFM adoption and the quantities of calories consumed by farmers who adopted less than four components of ISFM. However, farmers who adopt all the complete components of the ISFM are associated with high calorie consumption. The quantity of protein consumed declined with the number of ISFM practices adopted (panel E). This suggests that adopters of components of ISFM record higher protein intake than farmers who adopt all the ISFM practices. With reference to panel F, the figure shows an increase in fat consumption among farmers who adopted between one and two components of ISFM and more than three components of ISFM.

Fig. 2 explored the relationship between the intensity of ISFM adoption, the area under maize cultivation (panel A), and the distance to the nearest research station (panel B). This analysis is relevant given that ISFM adoption is labour-intensive and costly. The figure shows an inverse relationship between the intensity of ISFM adoption and farm size. Regarding farm size less than 8 ha, the figure shows a decline in the number of ISFM adoption. The result indicates the intensification of ISFM practices among smallholder farmers compared to farmers with relatively large farm size. Panel B shows that distance to the nearest research station is correlated with a decline in the number of ISFM practices adopted. Our result indicates that access to research stations is associated with high adoption of ISFM practices.

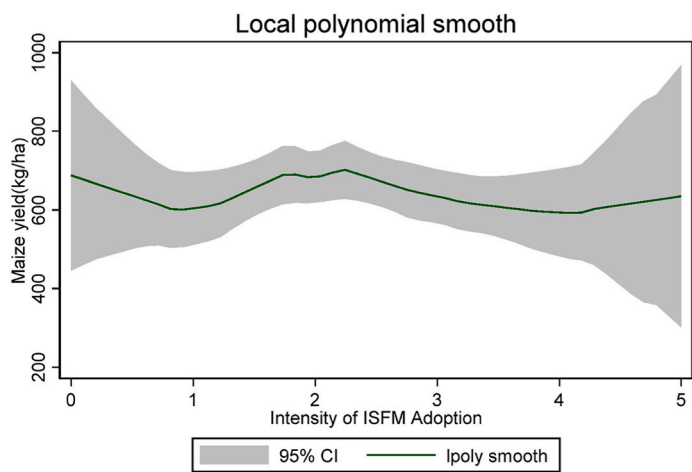
4.2. Factors influencing ISFM adoption

ISFM adoption is significantly influenced by education, household size, number of farm plots, slope of farmland, farmer location, experience of flood/drought, loss of livestock due to flood, and distance to the nearest research office (Table 4). Village-level controls (which capture capital and human assets) were included in the model to increase the statistical power of the results and control for community fixed effects. Significant village-level control dummies include the proportion of owners of T.V., bicycles, motorcycles and the proportion of male and

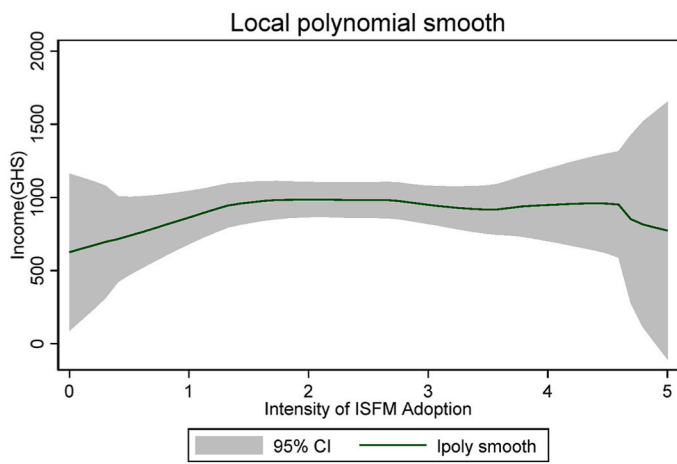
female literates in the community. Educated household heads and larger households were less likely to adopt ISFM practices compared to their uneducated and smaller household counterparts. This outcome may reflect the fact that education often leads to more engagement in off-farm employment, which might provide higher returns than farming activities. As a result, educated individuals might prioritize income-generating opportunities outside agriculture, reducing the likelihood of adopting labour-intensive ISFM practices. The result aligns with Martey and Kuwornu (2021) but contradicts the findings of Adem et al. (2023) and Teklewold et al. (2013). Conversely, education may provide alternative livelihood opportunities in off-farm activities, thereby reducing the available labour for agricultural production (Scherr and Hazell, 1994). The number of farm plots is positively associated with ISFM adoption. The results suggest that while ISFM is often adopted across multiple plots, this does not necessarily lead to full intensification, as intensification can be costly despite its potential economic benefits. Adem et al. (2023) revealed that soil fertility-enhancing technology packages are more likely to be adopted by families with larger agricultural holdings.

Farmers cultivating on sloped land are more likely to adopt ISFM practices, as the slope increases the risk of soil nutrient loss due to erosion. The study corroborates with Boansi et al. (2024) findings which indicate that field prone to erosion are more likely to adopt ISFM practice. Farmers' location is negatively associated with ISFM adoption, indicating that those residing in the Northern Region have lower ISFM adoption rates compared to farmers in the Upper East and Upper West regions. The finding is consistent with Boansi et al. (2024), who found that farmers in the Guinea Savanna zone were more likely to adopt ISFM compared to their counterparts in the Sudan Savanna zone. This finding may be attributed to the relatively favourable climatic, production and marketing conditions in the Guinea Savanna zone compared to the drier Sudan Savanna. Concerning the climatic shock variables, the result indicates that farmers who have suffered or experienced drought/flood and have experience loss of livestock due to flood have lower ISFM adoption than farmers who have not experienced drought/flood or loss of livestock due to flood. Farmers who have experienced climate shocks such as loss of livestock due to flood or suffered from drought/flood are financially constrained due to the loss of their assets, which can be liquidated in times of negative economic shock to sustain the adoption of improved agricultural technologies as well as smoothen household consumption. Our findings align with those of Shikuku et al. (2017), who established that smallholders exposed to adverse shocks are less likely to invest in soil fertility and land management practices due to the high initial costs, with benefits typically materializing only in the future.

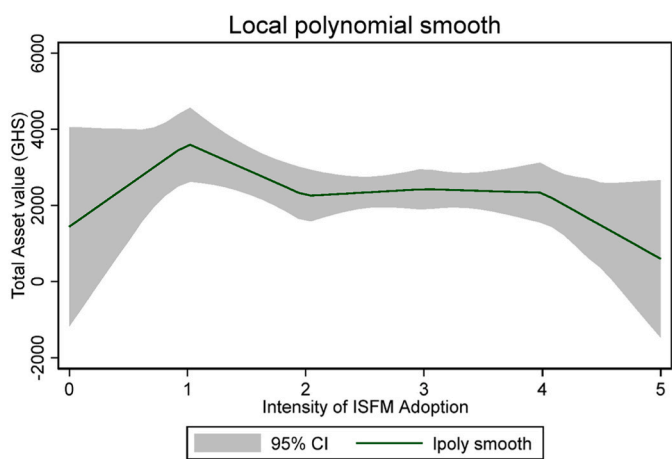
Distance from farmers' residence to research institute is negatively correlated with ISFM adoption which indicates that farmers located closely to research stations are more likely to receive technical information on ISFM that may result in adoption. The study by Martey and Kuwornu (2021) show that distance to extension and research are significantly and negatively associated with the adoption of ISFM aligning with our findings. Hence, farmers located near agricultural extension agents are more likely to adopt each of the practices (Kiprotich et al., 2024; Norton and Alwang, 2020; Takahashi et al., 2020). Village-level factors generally have a negative association with ISFM adoption, with the exception of the proportion of T.V. owners and the proportion of male literates, which positively influence adoption. The significance of these village-level controls suggests that excluding them from the model could result in biased estimates of the effect of ISFM adoption on welfare outcomes. Our research finding is consistent with the study of Adem et al. (2023) who found that adoption of soil fertility-enhancing technologies was more common in households who had radios or TVs. They further stated that access to information is crucial to increasing farmers' households' understanding of the importance of improved technologies, which has a direct effect on the decision to adopt and the rate at which technological diffusion occurs.



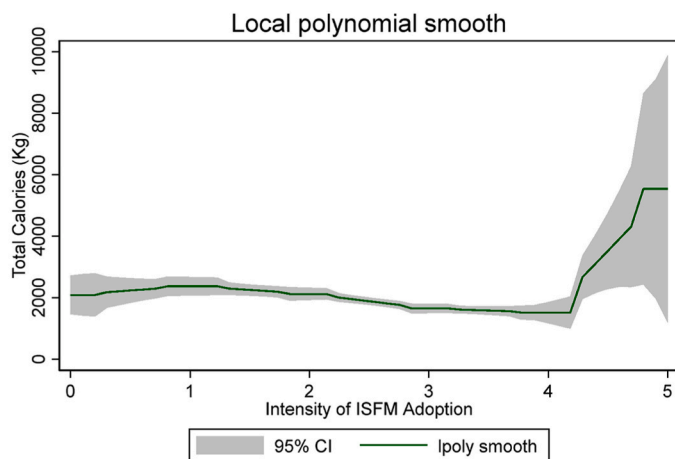
Panel A: Yield and Intensity of ISFM adoption



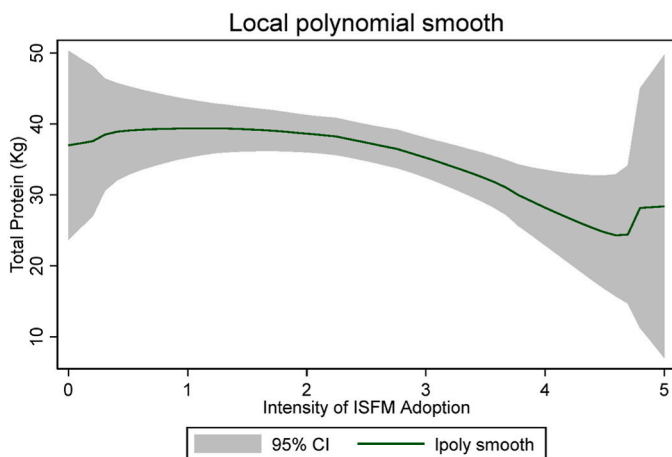
Panel B: Income and Intensity of ISFM adoption



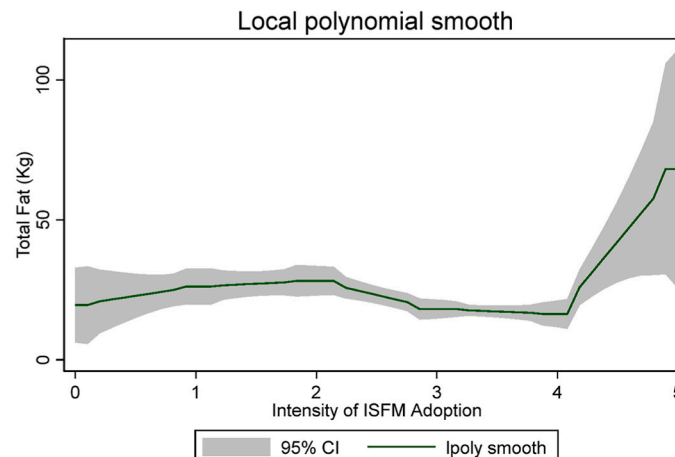
Panel C: Asset and Intensity of ISFM adoption



Panel D: Calories and Intensity of ISFM adoption



Panel E: Protein and Intensity of ISFM adoption



Panel F: Fat and Intensity of ISFM adoption

Fig. 1. Local polynomial regression for outcome variables and ISFM adoption.

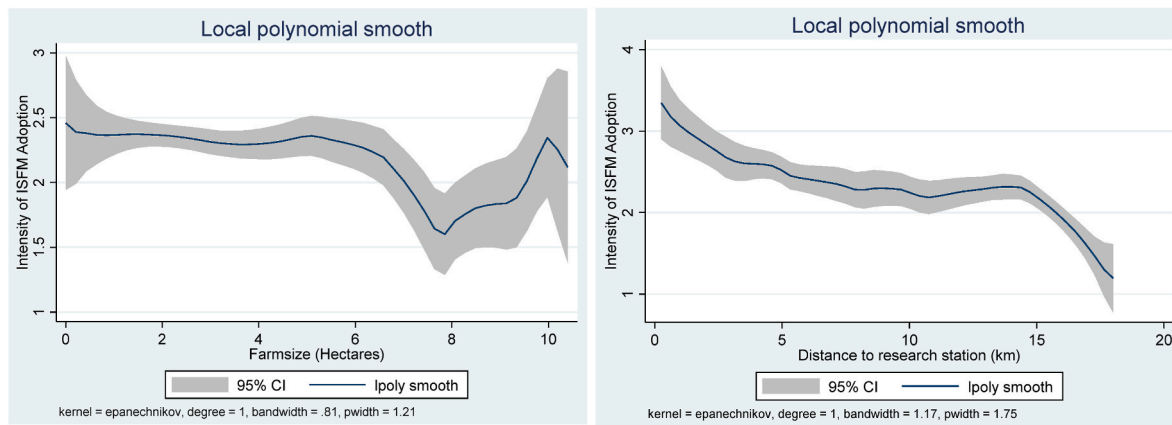


Fig. 2. Local polynomial regression for ISFM adoption and farm size.

Table 4
Determinants of ISFM adoption.

Variables	Coefficient	Robust Std. Error	P value
<i>Household and farm variables</i>			
Age of household head	0.001	0.001	0.519
Sex of household head (1 = Male)	0.102	0.067	0.129
Education status (1 = Educated)	-0.064	0.030	0.035
Household size	-0.013	0.004	0.003
Years of farming	0.002	0.002	0.311
Cropping system (1 = Intercropping)	0.010	0.035	0.775
Number of farm plots	0.019	0.008	0.023
Distance to farm parcel	-0.001	0.007	0.911
Farm size	-0.007	0.004	0.113
Slope of farmland (1 = Slope)	0.120	0.037	0.001
Soil status (1 = Loamy)	0.032	0.027	0.244
Location of a farmer (1 = Northern)	-0.211	0.033	0.000
Land ownership (1 = Owner)	0.038	0.049	0.441
<i>Climate-related variables</i>			
Suffered from drought/flood (1 = Yes)	-0.074	0.030	0.013
Loss of livestock due to flood	-0.138	0.047	0.003
Long-term change in mean temperature (1 = Yes)	0.019	0.065	0.777
HH member sustained injury due to flood (1 = yes)	-0.057	0.301	0.851
<i>Institutional variable (instrument)</i>			
Distance to the nearest research office	-0.004	0.001	0.000
<i>Village level controls</i>			
Proportion of T.V. owners in the village	0.001	0.001	0.040
Proportion of bicycle owners in the village	-0.002	0.001	0.001
Proportion of motorcycle owners in the village	-0.001	0.001	0.062
Proportion of car owners in the village	0.002	0.008	0.762
Proportion of tractor owners in the village	-0.023	0.014	0.108
Proportion of cell phone owners in the village	0.000	0.001	0.648
Proportion of male literates in the village	0.004	0.001	0.000
Proportion of female literates in the village	-0.003	0.002	0.089
Constant	0.810	0.133	0.000
Observation	966		
F (26, 939)	8.47 ^a		

Note.
^a Significant at 1% level.

4.3. Welfare effect of ISFM adoption

This section presents the instrumental variable regression estimates of the effects of ISFM adoption on farms and welfare outcomes (Table 5). Columns (1), (2), and (3) of Table 5 represent the results of the effect of ISFM adoption on yield, maize income, and total asset value. In all the

Table 5
Estimated results of ISFM adoption on maize yield, income, and asset value.

	(1)	(2)	(3)
	Yield (kg/ha)	Maize Income (GHS)	Total asset value (GHS)
ISFM adoption	847.69 ^c (482.07)	1725.807 ^c (965.157)	2913.48 ^b (1313.05)
Individual level controls	YES	YES	YES
Village level controls	YES	YES	YES
<i>First stage coefficients</i>			
Distance to nearest research office	-0.004 ^a (0.001)	-0.004 ^a (0.001)	-0.004 ^a (0.001)
Robust score schi2 (1)	6.09 ^b	3.43 ^c	12.39 ^a
Robust regression F (1, 938)	6.02 ^b	3.43 ^c	12.39 ^a
Effective F-statistics	15.87	15.87	15.87
Mean of non-adopters	[600]	[824]	[3305]
Observations	966	966	966

Notes: Standard errors are in parenthesis. All the outcome variables are logged except maize income. The exchange rate is US\$1 = GHS3.81 (Bank of Ghana, 2016). Individual controls are age, education, household size, cropping system, climate-related factors, number of farm plots, slope of farm plot, soil condition, and farm size. Village level controls are the proportion of male and female literate, the proportion of population with motor, bicycle, car, tractor, cell phone, and irrigation infrastructure. The mean outcomes of the non-adopters are in brackets.

^a Significant at 1% level.
^b Significant at 5% level, and.
^c Significant at 10% level. The percent of treatment effect is computed using the formula $100(e^{ATT} - 1)$ where e is the exponential.

models, village controls were included to account for village-level differences in resource endowment, access to institutions, and poverty. The significance of the robust regression and robust score chi-square values suggest that ISFM adoption is endogenous. Given this, failure to correct for the endogeneity using the OLS estimation technique will lead to a biased estimate of the effect of ISFM adoption on farm and welfare outcomes. The coefficient of the instrument from the first stage regression is highly significant at the 1% significance level with high effective F-statistic values across the different specifications. Following Stock et al. (2002), we conclude that the instrument is not weak because the effective F-statistic value is greater than 10.

Results from the instrumental variable regression model (equation

(5)) indicate that ISFM adoption is significantly associated with yield, income, and total asset value (Table 5). Adopters of ISFM are more likely to increase their yield, income, and total asset value by approximately 878 kg/ha, GHS1,726 (\$453), and GHS2,913 (\$765), respectively more than non-adopters of ISFM. The result suggests that using multiple soil fertility practices is essential in improving soil health which translates to positive yield. Our result is consistent with the findings of Adem et al. (2023), Doldt et al. (2023) and Adowla et al. (2019). Adem et al. (2023) show that the adoption of ISFM increases net crop value. Adowla et al. (2019) find that the adoption of multiple ISFM practices increases yield in Tamale. In Ethiopia, Doldt et al. (2023) found that crop yields increased with increased use of ISFM. A study by Manda et al. (2016) in rural Zambia shows that adopting multiple sustainable agricultural practices strongly and positively impacted maize yields. Fairhurst (2012) reported more than double in maize yield of farmers who participated in demonstrations of ISFM practices. Akinola et al. (2009) showed that in West Africa, using balanced nutrient management systems combining inorganic fertilizer and organic manure, the increased yield from 1.96 t/ha to 3.0 t/ha. Maize though a staple crop in northern Ghana is considered an essential food security crop; therefore, most farmers are more likely to adopt ISFM and allocate more labour to the maize plot to enhance productivity.

The positive income effect of ISFM is consistent with the findings of Hörner and Wollni (2021) and Manda et al. (2016) but contradicts the findings of Adowla et al. (2019), who suggested that maize income may not be significant enough to make a difference since a household may reallocate labour to more important crop with ISFM application. However, we argue that conditions within the market may favour maize commercialization with a subsequent positive effect on maize income. Concerning total asset value, we argue that an increase in crop income may translate to the accumulation of assets to guard against risk and smoothen household food consumption in the presence of an extreme weather shock.

Table 6 reveals a positive relationship between ISFM adoption and food intake. The results show that ISFM adoption increases calorie

intake by 2731 kcal/day during the abundance period and 2406 kcal/day during the lean period. Protein consumption increased by 47g/day, 63g/day, and 52g/day for the normal, abundance, and lean periods, respectively. Additionally, ISFM adopters saw fat consumption rise by 57g/day, 75g/day, and 90g/day during the normal, abundance, and lean periods, respectively. Notably, protein consumption was the lowest during the lean period, but ISFM adoption appears to secure food availability during this time. This may be attributed to increased yield and income, allowing farmers to store more food and smooth consumption during lean periods. Furthermore, higher household income likely boosts the purchase of food not grown on the farm. These findings align with Hörner and Wollni (2021), who observed a positive effect of ISFM on food security during the pre-harvest season in Ethiopia. Adem et al. (2023) show that adoption of ISFM increases food consumption expenditure.

Tables 7 and 8 show the results of the intensity of ISFM adoption on maize yield, income, asset value, and food security. The results measure the intensive margin of ISFM adoption. Consistent with the extensive margin results, ISFM is positively associated with yield, income, and total asset value. The result is consistent with the findings of Adolwa et al. (2019), who also found a positive effect of the intensity of ISFM adoption on yield. Furthermore, the intensity of ISFM adoption is positively associated with calorie, protein, and fat intake. However, when comparing the two margins, the extensive margin (binary choice) results exhibited a greater effect magnitude than the intensive margin (number of ISFM practices). This suggests that simply increasing the number of ISFM practices implemented on maize plots may not necessarily lead to better outcomes, as a higher number of practices can result in increased labour costs.

Table 9 shows the results of the IPWRA model (equation (6)). Figure A1 in the appendix shows the common support for the adopters and non-adopters, with a significant overlap indicating the validity of the matching method. The statistical insignificance of the over-identification test indicates that the covariates are balanced. Comparing the results to the IV regression, we can conclude that our result is robust

Table 6
Estimated results of ISFM adoption on food intake.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Calories (Average)	Calories (Abundance)	Calories (Lean)	Protein (Average)	Protein (Abundance)	Protein (Lean)	Fats (Average)	Fats (Abundance)	Fats (Lean)
ISFM adoption	878.340 (1174.820)	2731.305 ^b (1180.207)	2405.826 ^b (984.748)	47.347 ^b (24.104)	62.533 ^b (31.602)	52.380 ^b (22.136)	56.507 ^b (23.451)	74.841 ^a (24.462)	90.093 ^a (30.154)
Individual level controls	YES	YES	YES	YES	YES	YES	YES	YES	YES
Village level controls	YES	YES	YES	YES	YES	YES	YES	YES	YES
<i>First stage coefficients</i>									
Distance to the nearest research office	-0.004 ^a (0.001)	-0.004 ^a (0.001)	-0.004 ^a (0.001)	-0.004 ^a (0.001)	-0.004 ^a (0.001)	-0.004 ^a (0.001)	-0.004 ^a (0.001)	-0.004 ^a (0.001)	-0.004 ^a (0.001)
Robust score schi2 (1)	0.68	10.36 ^a	11.98 ^a	5.28 ^b	5.34 ^b	8.31 ^a	7.46 ^a	21.51 ^a	18.34 ^a
Robust regression F (1, 938)	0.66	10.11 ^a	11.80 ^a	5.12 ^b	5.20 ^b	8.20 ^a	7.30 ^a	21.70 ^a	18.21 ^a
Effective F-statistics	15.87	15.87	15.87	15.87	15.87	15.87	15.87	15.87	15.87
Mean of non-adopters	[2329]	[2688]	[2105]	[40]	[46]	[33]	[25]	[27]	[28]
Observations	966	966	966	966	966	966	966	966	966

Notes: Standard errors are in parenthesis. All the outcome variables are logged except maize income. Individual controls are age, education, household size, cropping system, climate-related factors, number of farm plots, the slope of farm plot, soil condition, and farm size. Village level controls are the proportion of male and female literate, the proportion of population with motor, bicycle, car, tractor, cell phone, and irrigation infrastructure. The mean outcomes of the non-adopters are in the square bracket.

*Significant at 10% level.

^a Significant at 1% level.

^b Significant at 5% level, and.

Table 7
Estimation results of the intensity of ISFM adoption on yield, income and asset value.

	(1)	(2)	(3)
	Yield (log)	Income	Total asset (log)
Intensity of ISFM adoption	0.587 ^b (0.251)	758.582 ^c (429.565)	1.244 ^a (0.418)
Individual level controls	YES	YES	YES
Village level controls	YES	YES	YES
<i>First stage coefficients</i>			
Distance to the nearest research office	-0.008 ^a (0.002)	-0.008 ^a (0.002)	-0.008 ^a (0.002)
Robust score schi2 (1)	6.38 ^b	3.46 ^c	12.11 ^a
Robust regression F (1, 938)	6.30 ^b	3.39 ^c	12.01 ^a
Effective F-statistics	14.48	14.48	14.48
Mean of non-adopters	[600]	[824]	[3305]
Observations	966	966	966

Notes: Standard errors are in parenthesis. All the outcome variables are logged except maize income. The exchange rate is US\$1 = GHS3.81 (Bank of Ghana, 2016). Individual controls are age, education, household size, cropping system, climate-related factors, number of farm plots, the slope of farm plot, soil condition, and farm size. Village level controls are the proportion of male and female literate, the proportion of population with motor, bicycle, car, tractor, cell phone, and irrigation infrastructure. The mean outcomes of the non-adopters are in brackets.

- ^a Significant at 1% level.
- ^b Significant at 5% level, and.
- ^c Significant at 10% level.

across different estimation models. The results confirm the positive association between ISFM adoption and yield, income, total asset values, and food security. However, we also noted that while ISFM adoption

Table 8
Estimation results of the intensity of ISFM adoption on food intake.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Calories (Average)	Calories (Abundance)	Calories (Lean)	Protein (Average)	Protein (Abundance)	Protein (Lean)	Fats (Average)	Fats (Abundance)	Fats (Lean)
Intensity of ISFM adoption	386.076 (516.222)	1200.551 ^b (536.566)	1057.486 ^b (449.225)	20.811 ^c (10.972)	27.487 ^c (14.340)	23.024 ^b (10.129)	24.838 ^b (10.536)	32.896 ^a (11.277)	39.601 ^a (13.820)
Individual level controls	YES	YES	YES	YES	YES	YES	YES	YES	YES
Village level controls	YES	YES	YES	YES	YES	YES	YES	YES	YES
<i>First stage coefficients</i>									
Distance to the nearest research office	-0.008 ^a (0.002)	-0.008 ^a (0.002)	-0.008 ^a (0.002)	-0.008 ^a (0.002)	-0.008 ^a (0.002)	-0.008 ^a (0.002)	-0.008 ^a (0.002)	-0.008 ^a (0.002)	-0.008 ^a (0.002)
Robust score schi2 (1)	0.56	11.11 ^a	12.97 ^a	6.26 ^b	6.41 ^b	10.55 ^a	7.68 ^a	22.85 ^a	20.60 ^a
Robust regression F (1, 938)	0.55	10.86 ^a	12.83 ^a	6.09 ^b	6.25 ^b	10.44 ^a	7.50 ^a	23.11 ^a	20.57 ^a
Effective F-statistics	14.48	14.48	14.48	14.48	14.48	14.48	14.48	14.48	14.48
Mean of non-adopters	[2329]	[2688]	[2105]	[40]	[46]	[33]	[25]	[27]	[28]
Observations	966	966	966	966	966	966	966	966	966

Notes: Standard errors are in parenthesis. All the outcome variables are logged except maize income. Individual controls are age, education, household size, cropping system, climate-related factors, number of farm plots, the slope of farm plot, soil condition, and farm size. Village level controls are the proportion of male and female literate, proportion of the population with motor, bicycle, car, tractor, cell phone, and irrigation infrastructure. The mean outcomes of the non-adopters are in brackets.

- ^a Significant at 1% level.
- ^b Significant at 5% level, and.
- ^c Significant at 10% level.

reduces the quantities of calories and fats consumed during the abundance period, it increases the average protein intake. This suggests that promoting ISFM among resource-poor farmers is likely to enhance their diets by enabling them to consume more nutritious foods.

Table 9
IPWRA estimates of ISFM adoption on farm and welfare outcomes.

Log outcome variables	POmean	ATET	% Change
Yield	5.969 ^a (0.061)	0.175 ^b (0.068)	19.07%
Income	6.217 ^a (0.078)	0.189 ^b (0.084)	20.85%
Total asset value	6.556 ^a (0.080)	0.426 ^a (0.089)	53.08%
Calories (average)	6.987 ^a (0.167)	0.003 (0.197)	0.30%
Calories (abundance)	7.539 ^a (0.075)	-0.323 ^b (0.115)	-27.60%
Calories (lean)	6.707 ^a (0.157)	-0.044 (0.191)	-4.31%
Protein (average)	2.926 ^a (0.156)	0.009 ^c (0.179)	0.94%
Protein (abundance)	3.436 ^a (0.091)	-0.166 (0.116)	-15.31%
Protein (lean)	2.555 ^a (0.159)	0.018 (0.184)	1.78%
Fat (average)	2.345 ^a (0.143)	0.010 (0.166)	0.98%
Fat (abundance)	2.756 ^a (0.083)	-0.209 ^c (0.108)	-18.85%
Fat (lean)	2.098 ^a (0.140)	-0.039 (0.165)	-3.79%
Overidentification test, chi2(26)	32.655		
Observations	966	966	966

- Notes.
- ^a Significant at 1% level.
 - ^b Significant at 5% level, and.
 - ^c Significant at 10% level.

5. Conclusions and policy implications

This study highlights the critical role of ISFM as a strategy for enhancing soil health and crop productivity. Using data from a farm household survey and employing an instrumental variable (IV) estimation technique, the study contributes to the ISFM adoption literature by examining its relationship with total asset value and seasonal food security - an area that has received less attention. The results indicate that adopting ISFM practices leads to increases in yield, income, total asset value, and food security. Specifically, ISFM adoption improves the consumption of calories, proteins, and fats during the lean season, addressing seasonal food security concerns. Comparatively, the extensive margin results (binary choice of ISFM adoption) show a larger effect size than the intensive margin results. This suggests that simply increasing the number of ISFM practices on maize plots does not necessarily lead to better outcomes, as a higher number of practices can be associated with increased labour costs.

The study results highlight the connection between ISFM adoption and farm as well as welfare outcomes in a developing country context, offering valuable policy insights. First, establishing stronger linkages between farmers and research institutions is crucial, as increased ISFM adoption enables farmers to collaborate with researchers who can simplify ISFM information and practices. Second, development partners promoting ISFM should encourage farmers to adopt manageable practices, considering their time and budget constraints. Third, the study reveals that flood and drought negatively impact ISFM adoption. To address this, we recommend climate mitigation strategies - such as tree planting and well digging - that can reduce the risks posed by drought and floods, thereby increasing the likelihood of ISFM adoption. Finally, promoting ISFM adoption is essential due to the strong evidence presented in this study regarding its positive impact on food intake. The

adoption of ISFM can significantly enhance household food nutrition.

Despite the robust findings, there are some limitations that should be noted, along with suggestions for future research. First, the study relies on cross-sectional data, which limits the ability to establish causality. As a result, the findings should be interpreted as associations rather than definitive causal relationships. Future studies could use panel data to better assess the economic impact of ISFM adoption. Second, we were unable to explore the specific pathways through which ISFM adoption affects the outcome variables, which presents an area for further research. Third, the study focuses solely on the access dimension of food security, potentially overlooking ISFM's influence on other pillars of food security, such as availability, utilization, and stability. Future research could delve into these dimensions to provide a more comprehensive understanding of the relationship between ISFM adoption and food security.

CRedit authorship contribution statement

Edward Martey: Conceptualization, Data curation, Formal analysis, Methodology, Supervision, Validation, Writing – original draft, Writing – review & editing. **Prince M. Etwire:** Formal analysis, Methodology, Validation, Writing – review & editing. **John K.M. Kuwornu:** Methodology, Project administration, Supervision, Writing – review & editing. **Mustapha M. Suraj:** Data curation, Methodology, Validation, Writing – review & editing.

Declaration of competing interest

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

Appendix

Table A1
Descriptive statistics of variables by adoption status

Variable	Pooled sample		Non-adopters		Low adopters		High adopters	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
<i>Household and farm variables</i>								
Age of household head	47.27	13.59	47.65	13.75	46.65	13.31	49.32	14.43
Sex of household head (1 = Male)	0.96	0.20	0.95	0.22	0.96	0.19	0.96	0.19
Education status (1 = Educated)	0.43	0.50	0.43	0.50	0.44	0.50	0.40	0.49
Household size	8.57	3.88	9.61	4.33	8.27	3.74	7.91	3.16
Years of farming	12.54	10.12	11.79	10.96	12.31	9.29	15.05	11.59
Cropping system (1 = Intercropping)	0.80	0.40	0.81	0.39	0.79	0.41	0.81	0.40
Number of farm plots	2.95	1.78	2.99	1.50	2.97	1.75	2.76	2.36
Distance to farm parcel	1.80	2.07	1.94	2.06	1.77	2.10	1.71	1.92
Farm size	3.55	3.70	4.37	5.30	3.40	3.08	2.64	1.46
Slope of farmland (1 = Slope)	0.81	0.39	0.70	0.46	0.84	0.37	0.90	0.30
Soil status (1 = Loamy)	0.48	0.50	0.42	0.49	0.50	0.50	0.48	0.50
Residence of the farmer (1 = Northern)	0.44	0.50	0.65	0.48	0.37	0.48	0.32	0.47
Land ownership (1 = Owner)	0.91	0.28	0.91	0.29	0.91	0.28	0.93	0.26
<i>Climate-related variables</i>								
Suffered from drought/flood (1 = Yes)	0.57	0.50	0.67	0.47	0.55	0.50	0.43	0.50
Loss of livestock due to flood	0.16	0.37	0.26	0.44	0.12	0.33	0.16	0.36
Long-term change in mean temperature (1 = Yes)	0.96	0.19	0.96	0.19	0.96	0.20	0.97	0.17
HH member sustained injury due to flood (1 = yes)	0.00	0.06	0.00	0.06	0.00	0.00	0.02	0.12
<i>Institutional variable</i>								
Distance to nearest research office	21.75	15.54	24.50	15.59	20.97	15.16	19.89	16.56
<i>Village level controls</i>								
Proportion of T.V. owners in the village	19.19	23.49	15.74	23.16	20.14	23.76	21.71	22.31
Proportion of bicycle owners in the village	51.90	31.81	58.23	32.36	48.85	32.18	53.21	26.98
Proportion of motorcycle owners in the village	23.27	24.40	24.92	24.81	22.25	24.04	24.60	25.15
Proportion of car owners in the village	0.68	1.44	0.41	1.07	0.77	1.61	0.79	1.20
Proportion of tractor owners in the village	0.46	1.21	0.61	1.76	0.41	0.98	0.39	0.72

(continued on next page)

Table A1 (continued)

Variable	Pooled sample		Non-adopters		Low adopters		High adopters	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Proportion of cell phone owners in the village	54.88	30.52	58.43	30.48	54.03	30.29	51.79	31.23
Proportion of male literates in the village	21.57	20.05	21.06	19.62	21.25	20.24	24.05	20.01
Proportion of female literates in the village	10.47	12.85	11.64	14.62	9.82	11.83	11.08	13.43
Observations	966		254		583		129	

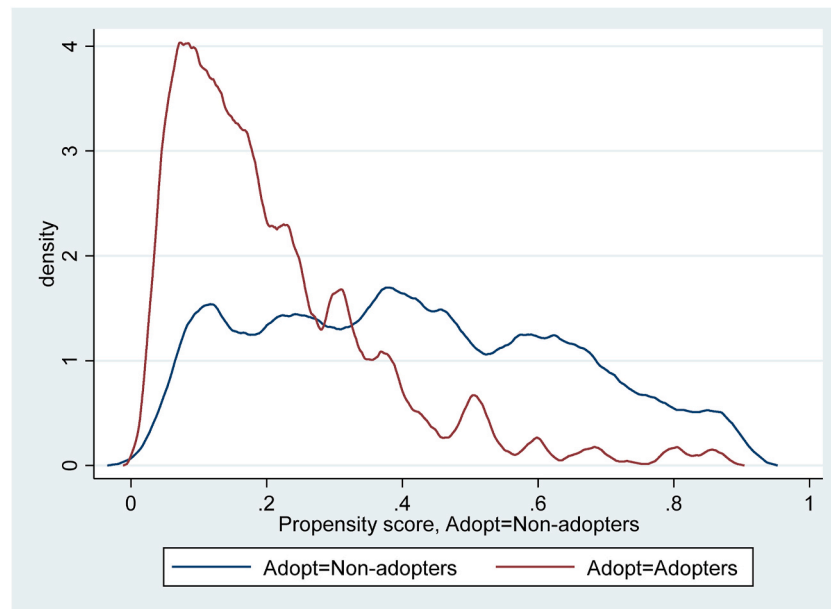


Fig. A1. Common support region for adopters and non-adopters of ISFM

Data availability

Data will be made available on request.

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