Sustainable Futures 7 (2024) 100185

Contents lists available at ScienceDirect

Sustainable Futures

journal homepage: www.sciencedirect.com/journal/sustainable-futures

Impact of integrated soil fertility management on maize yield, yield gap and income in northern Ghana

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ARTICLE INFO

JEL codes:
Q10
Q16
Q50

Keywords:
Soil fertility enhancement
Technology adoption
Determinants
Farm performance
Inverse-probability-weighted regression adjustment

ABSTRACT

This paper analyzes the impact of integrated soil fertility management (ISFM) on maize yield, yield gap and net income in northern Ghana using an inverse-probability-weighted regression adjustment (IPWRA). In this study, ISFM is restricted to the adoption of crop rotation (CR), inorganic fertilizer (FT), and farmyard manure (MN) either in isolation or in combination. We find a synergy in yield gain (86.52 % increase in yield) and a decrease in yield gap (of 10.22 %) with the adoption of all three technologies as a package (CR+FT+MN). The joint adoption of all three technologies is also associated with a 51.29 % increase in net income from maize production and has a Benefit-Cost Ratio of 3.23.

1. Introduction

Poor soil fertility, crop pests and diseases, and the increasing risk of land degradation are major threats to farming in most of the vulnerable regions of the developing world [1–3]. These stressors have mostly been associated with an increase in the risk of food insecurity [4] and a decrease in yields and incomes of rural families [1,5–7]. Studies show that about 65 % of the land area in sub-Saharan Africa (SSA) is degraded [8,9], and about 20–25 % is considered severely degraded [10]. Soil degradation costs the region over US$68 billion a year and is associated with a 3 % decrease in the region's gross domestic product (GDP) [10, 11]. Soil-related constraints to agricultural production in the region result in a loss of about 280 million tons of cereal crops per year (The Economics of Land Degradation (ELD) Initiative and United Nations Environment Programme UNEP, 2015)

Beside these adverse effects of soil and land degradation, threats such as crop pests, diseases and poor soil fertility are responsible for major yield and income losses in several agro-ecological zones [1,6,7]. These threats, along with inefficient management, soil nutrient shortages [12], low use of agricultural inputs, limited use of yield enhancing innovations and good agronomic practices [13,14], and overexploitation of croplands due to population pressures [15–17] contribute to high yield gaps and hinder sustainable food supply in SSA [15,17,18]. High yield gaps reflect potential for improvement, but in most SSA countries, especially in West Africa, yields have been declining for decades for some major crops or stagnant at best for others [15,18,19]. For example, for maize, which serves as a staple food for more than 900 million people in developing countries [20], Ray et al. [16] reported yield gaps of over 90 % for many countries in SSA. Other studies reported yield gaps of about 80 % for Ghana [17,21], 70 % −80 % for Ethiopia [22,23], and greater than 50 % for Kenya [24].

As in many African countries [12,15,25], maize is the most important cereal crop on the domestic market in Ghana. It accounts for about 3.3 % of total agricultural production value and more than 50 % of the total cereal production in Ghana [26]. The crop is cultivated by more than 50 % of rural households in Ghana, and by 16 % of urban households [12]. Despite its importance, maize is mostly produced by smallholders under low-input conditions, resulting in extremely low yields and high yield gaps, especially in the semi-arid northern Ghana [12]. Compared to a water-limited potential yield of 5.5 t/ha, average yield of maize in Ghana is estimated at 1.99 t/ha [27], implying a yield gap of about 64 %. In addition, van Loon et al. [17] reported maize yield gaps of about 67 % to 84 % in two major maize growing regions in Ghana (Brong Ahafo and Northern regions).

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https://doi.org/10.1016/j.sftr.2024.100185
Received 14 August 2023; Received in revised form 12 March 2024; Accepted 14 March 2024
Available online 24 March 2024

Integrated soil fertility management (ISFM) is one of the most effective and efficient solutions to reduce yield gaps in maize production [2,3,28]. It entails a bundle of farm innovations such as inorganic and organic fertilizers, the implementation of good agronomic practices, agroforestry [14], and the use of appropriate germplasm. Rookbroeck et al. [29] found that ISFM improves productivity by increasing crop yields and ensuring the stability of yields in rainfed systems and reduces greenhouse gas emissions from soils and fertilizers. This makes ISFM a valuable practice for climate-smart agriculture and helps to increase the resilience of farming systems. For example, the practice of crop rotation as a component of ISFM helps to improve and/or maintain soil fertility, enhance crop health, limit soil erosion, reduce pest infestation, ensure effective use of soil nutrients, mitigate the risk of weather variability, and help build a healthy soil over time [30]. Crop rotation also enhances water infiltration and retention and ensures the stability of crop yields [31,32]. The use of chemical fertilizer, which is the most commonly used by maize farmers, helps to increase crop yields, improve yield quality, and provides an efficient source of nutrients [33]. However, the sole and continuous use of chemical fertilizer is associated with soil/land degradation, environmental pollution, and lower yields [34,35]. The use of organic fertilizer including farmyard manure, helps to improve soil texture/structure, increase water holding capacity of soils, recycle nitrogen, reduce topsoil erosion, and enhances microbial activities that help to supply soil with relevant trace minerals [36].

Despite the benefits of ISFM, there are limited empirical studies on its impact on farm performance using farm level data in SSA, with exception of Adem et al. [37] in Ethiopia, Kihara et al. [2] in Tanzania, and Setsoafia *et al.* [38] in Ghana. Most studies are field trials [39,40], while other studies [3,41–43] have focused on factors influencing adoption of either the individual components of ISFM or a combination of the components without estimating the impact on farm performance. Most studies have analyzed the adoption and the impact of the individual components of ISFM on farm performance [1,5,13,34,44–46] but only few studies [2,35,37] have evaluated the impact of the adoption of ISFM as a package. In Asia, for example, Mahmood et al. [34] found that growth and yield of maize improved substantially with the application of fertilizer alongside organic manures in Pakistan. Hua et al. [5] found that the combined application of inorganic and organic fertilizers leads to increased crop yield and soil organic matter in China. In Bangladesh, Urmi et al. [35] found that the sole application of inorganic fertilizers is inefficient in increasing the yield of rice compared to the joint application of both organic and inorganic fertilizers. Similar results are reported by Bastia et al. [44] for India. The majority of these studies are experimental.

In Africa, specifically in Ethiopia, Adem et al. [37] found, based on farm-level data, that the use of manure or compost alone had a moderate impact on maize yield, while the joint application of inorganic fertilizer and manure had a greater impact on yield. Kihara et al. [2] found that the productivity and economic impacts of ISFM depended on the number and specific components adopted, adding that benefits increased with the number of ISFM components in Tanzania. Using the baseline survey data for Ghana from the Africa RISING (Africa Research in Sustainable Intensification for the Next Generation) program, Setsoafia *et al.* [38] found that adopting improved maize seed, fertilizer and soil and water conservation as a package has larger positive impact on farm income and food security than adopting single or two of these technologies. They however reported that adopting only fertilizer, or fertilizer and improved seed leads to significant decrease in farm income. Adolwa et al. [1] found that while the adoption of ISFM increased maize yield by 27 % and 16 % in Tamale (Ghana) and Kakamega (Kenya), respectively, there were no major improvements in yields as the number of the ISFM components increased, and no significant effect on total household income were found in either location. A major limitation of the study by Adolwa et al. [1] is that instead of estimating the impact of each individual component and the combinations, adoption was classified into four categories, namely, non-adoption, partial adopter 1 (adoption of two components), partial adopter 2 (adoption of three components) and complete adoption (for the adoption of four components). Technology adoption involves costs and benefits, and different technologies and their combinations have different effects on yield, yield gap and income. Although some combinations may increase yield, they are not necessarily income/profit-enhancing because of the associated costs of adoption, and categorizing combinations based on number instead of components may be less informative.

Our paper aims to bridge this knowledge gap by analyzing the impact of the practice/use of crop rotation, inorganic/chemical fertilizer and farmyard manure on maize yields, yield gap and net returns in semi-arid northern Ghana. Specifically, the paper seeks to achieve the following objectives: (1) to analyze farmers' use of crop rotation, inorganic fertilizer, and farmyard manure in maize production in northern Ghana (2) to determine factors that influence the use of these practices, and (3) to estimate the impact of combined and individual ISFM components on maize yield, yield gap and net returns in the study area.

Our paper contributes to expanding the literature on ISFM in the following ways. First, given the poor soil fertility and the prevalence of weeds, diseases, and pest infestations (notably *Striga hermonthica*, and fall army worm) that pose threats to maize production in Ghana [47,48], it is believed that the adoption of the above-mentioned components of ISFM in an integrated manner could help to address the overlapping production constraints from these threats. Traditional farming methods in Ghana, especially those related to maize production, mostly focus on inorganic fertilizer application, or treat the three technologies as substitutes [49,50]. However, the joint adoption of these technologies has been proved to be an effective and sustainable soil management strategy for enhancing crop yields in Ghana, although most findings supporting this statement are based on field experiments [39,51]. Hence, unlike previous studies, our paper formulates eight ISFM strategies, namely adoption of only crop rotation (CR), adoption of only inorganic fertilizer (FT), adoption of only farmyard manure (MN), adoption of only crop rotation and fertilizer (CR+FT), adoption of only crop rotation and manure (CR+MN), adoption of only inorganic fertilizer and manure (FT+MN), and the adoption of all three components (CR+FT+MN). This approach allows us to gain insights on usage of these strategies and identify factors influencing farmers' decision to use a specific ISFM strategy. Second, this study provides insights into which specific ISFM strategies lead to optimal farm outcomes so that appropriate policies can be formulated to promote their widespread use. We also identify the yield- and income-enhancing effects of the farm technologies to determine which practices and combinations are both yield and income enhancing, and which practices are solely yield or income enhancing. To identify the channels through which these technologies affect income from maize production, we estimate the impact of the technologies also on gross income and cost of production. This helps to reflect on the productivity and cost implications of adopting the respective components and their combinations. This is a very important aspect missing in earlier studies on the adoption and impact of integrated soil fertility management.

The rest of the manuscript is organized as follows. We present an overview of the agricultural sector in Ghana in Section 2 and the conceptual framework for the study in Section 3. We provide an overview of the data, and the estimation methods used in Section 4. Results for the respective analyses are presented and discussed in Section 5, while Section 6 concludes the study.

2. An overview of the agricultural sector in Ghana

The agricultural sector continues to play an important role in sustainable economic growth and development of Ghana. It accounts for 19 % of Ghana's gross domestic product (GDP) and employs 34 % of the labor force [52]. It also provides livelihoods for many households. Over the years, the contribution of agricultural sector to Ghana's GDP has declined, indicating a structural transformation in the country's economy (World Development Indicators, 2023). Labor force has shifted from the agricultural sector to the service and industry sectors. From 1990 to 2005, the agricultural sector was the largest contributor to GDP, although it declined from 45 % to 37 %, respectively (Fig. 1). Since 2010, the contribution of agricultural sector to GDP has been decreasing and agriculture now accounts for the smallest share (Fig. 1). Currently, the services and industry sectors are first and second largest contributors to Ghana's GDP (Fig. 1). Ghana's agricultural sector consists of four sub-sectors, namely crop, forestry and logging, fishing, and livestock. Among these sub-sectors, crop production is one of the largest contributors to agricultural production. The major crops grown in Ghana include cereals (maize, rice), vegetables and fruits, cassava, and cocoa. Cocoa is a major source of foreign exchange and employment, and a key driver of economic growth. Between 2008 and 2015, the average annual agricultural productivity growth rate was 4.2 %, below the 6 % growth target (Fig. 2). In 2008 and 2012, fishing (17.4 % and 9.1 %, respectively) was the main driver of agricultural productivity growth rate. However, in 2009, crops contributed the largest to productivity growth. In 2010 and 2011, the cocoa sector alone accounted for 26.6 % and 14 %, respectively, of the annual growth of crops. Except for livestock, the growth rates of most sub-sectors were unstable from 2008 to 2015 (Fig. 2).

The above graphs show clearly that the performance of Ghana's agricultural sector is poor, characterized by low yields for both staple and cash crops. Cereal yields, for example, are estimated at 1.7t/ha compared to the regional average of 2t/ha and with potential yields of over 5t/ha. The average cocoa yield in Ghana is estimated at 400–450 kg/ha, among the lowest in the world [54]. Also, Ghana is a net importer of basic raw and processed foods such as rice, poultry, sugar, and vegetable oils. Annual expenditures on food imports exceed estimated annual revenues from cocoa exports of $2 billion [54]. Population growth, high urbanization rates, and rising incomes are the main drivers of the import bills, as they result in higher demand for high-quality and safe food products such as meat, dairy, and horticulture. The food import bill is expected to quadruple over the next 20 years, unless agricultural production increases significantly [54]. The main barriers to agricultural development in Ghana include low public spending on agricultural research and development, inadequate infrastructure (e.g., roads, markets, and irrigation), and poor socioeconomic indicators (such as low education and skills, poor access to finance, land tenure problems, low adoption of agricultural technologies), among others [55,54]. To address these challenges and promote agricultural development, a number of programmes and policies have been designed and implemented. They include the Medium-Term Agricultural Investment Plan (METASIP) and the Food and Agriculture Sector Development Policy (FASDEP), which focus on agricultural development with an emphasis on northern region [54].

Other programmes that aim to improve maize yield include the Fertilizer Subsidies, Mechanization, and Buffer Stock Schemes. The Ghana Grains Development Project (1979–1997) and the Food Crops Development Project (2000–2008) introduced and promoted the cultivation of early maturing, drought-tolerant and high-yielding maize varieties. The current programmes such as the Modernizing Agriculture in Ghana Programme (2017–2023), Savannah Agricultural Value Chain Development Programme (2021–2026), and Savannah Investment Programme (2020–2025) also focus on agricultural development with maize as one of the target crops [56]. Despite these policy efforts, observed yields for maize are well below the achievable, especially in northern Ghana where maize yield gap ranges between 52.5 % - 84.2 %

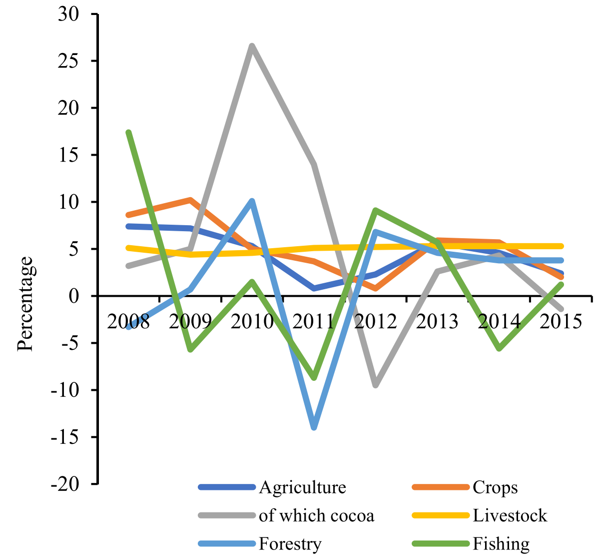

Fig. 2. Productivity growth rates by agricultural sub-sectors.
Source: Ministry of Food and Agriculture [53]

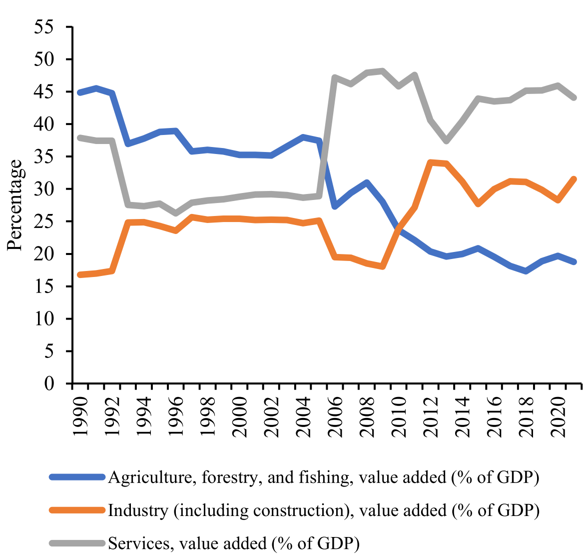

Fig. 1. Shares of agriculture, industry, and service to Ghana's GDP.
Source: World Development Indicators (2023)

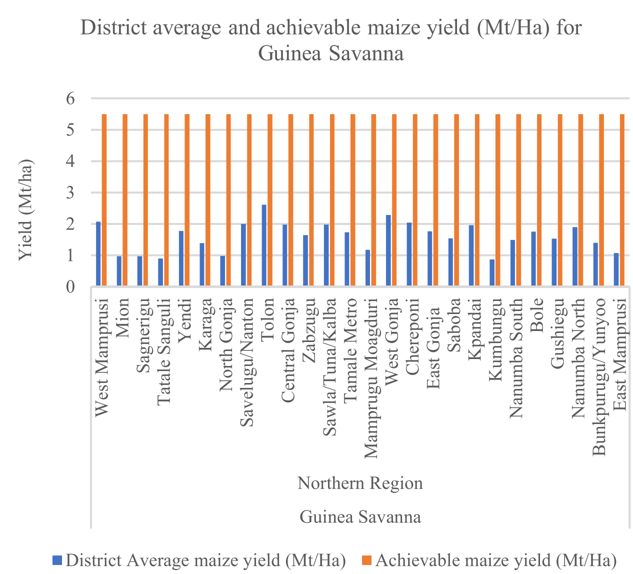

Fig. 3. District average and achievable maize yield for the Guinea Savanna of Ghana.
Source: Ministry of Food and Agriculture [57] (2019)

in the Guinea Savanna and between 37.5 % - 80.5 % in the Sudan Savanna (see Figs. 3–6). This necessitates the promotion and adoption of yield-enhancing technologies to help bridge maize yield gap in Ghana.

3. Conceptual framework

This study is based on the presumption that farmers adopt diverse technologies to help address threats from the joint occurrence of multiple stresses in farming, notably pest and disease incidences, soil infertility and poor water retention among others. While most of such technologies may be yield-enhancing, cost implications of their adoption could be a hindrance to the adoption and continuous implementation of the technologies. This implies that while some technologies could enhance farmers' yields, a farmer may decide to forgo the adoption of such technologies if they fail to enhance his returns, especially in the case of a farmer who operates to maximize his profits. It is generally assumed that a farmer will adopt a technology or a set of technologies if the gains from adoption outweigh the cost. However, as well established in literature, the adoption of agricultural technologies, and as shown in Fig. 7, is influenced by several factors which may generally be grouped in socioeconomic factors, institutional factors, farm/plot level factors, and geographic/locational factors [1,4,37,41,43,46].

These variables have the potential to influence the adoption of the individual technologies, as well as the adoption of a combination of such technologies. Existing literature [1,4,46] show that these variables are also potential factors influencing outcome of the technologies adopted, where the outcomes could be welfare indicators like income (farm, agricultural or household income), food security, household expenditure, or productivity related measures like yield, yield gap and soil organic carbon levels. The outcomes of interest to this study are yield, yield gap and income from maize production.

While the yield effects from the adoption of inorganic fertilizer and farmyard manure may result from increased availability of vital nutrients to plants for growth, the effect for crop rotation may generally be attributed to the suppression of weeds, control of pest and diseases, and to enhanced fertility of soils. The income effect may however depend on the number and components of ISFM adopted, the cost implications, and the productivity effects associated with the technologies adopted. For this reason, we hypothesize that the use of ISFM increases maize yields and income, but reduces yield gap for maize, and the gains from the adoption of ISFM are greater with the use of a higher number of components.

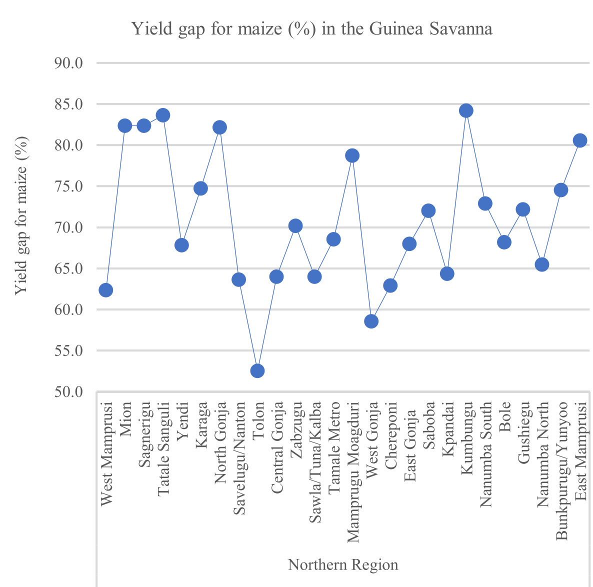

Fig. 4. Yield gap for maize in the Guinea Savanna of Ghana.
Source: Ministry of Food and Agriculture [57] (2019)

4. Methods

4.1. Data

The baseline survey data for Ghana from the 'Africa Research in Sustainable Intensification for the Next Generation (Africa RISING)' program [58] was used for the analysis. The Africa RISING program, made up of three research-for-development projects, aims to create opportunities for smallholder farm households in selected countries to move out of hunger and poverty. This is to be achieved through sustainably intensified (SI) farming systems that would help to improve food, nutrition, and income security in the target countries, especially for women and children, and help to conserve the natural resource base [58]. Gathered between 13th May and 3rd July 2014, the survey, which was based on a stratified two-stage random sampling (see [58] for details) covered a total of 50 communities and 1284 farm households in 9 districts. The districts covered are Wa East, Nadowli and Wa West in the Upper West region, West Mamprusi, Tolon-Kumbungu, and Salvelugu in the Northern region, and Bongo, Talensi-Nabdam and Kassena-Nankana in the Upper East region. The households covered by the survey operated approximately 5500 plots. Household interviews were conducted using structured questionnaire [58] and data collected using Computer Assisted Personal Interviewing (CAPI). Among the data gathered are ISFM practices used by farmers, agricultural production, harvests and allocation, livestock production and sales, access to credit and markets, household non-land assets, off-farm income sources and amounts, and experiences of food shortages among others. The three regions covered in this study are characterized by unimodal rainfall conditions and most households in the study area depend on low-input agriculture under rainfed conditions for their livelihood. Located in the semi-arid northern Ghana (see Fig. 8), the regions serve as a hub for the production of major staples like maize, rice, groundnuts, sorghum, millet, cowpea, soybean, Bambara nuts and yam. Among the livestock species produced by farmers in the study area are cattle, goat, sheep, poultry, pigs, and equines. This study is however based on data from 1038 maize producing households covered by the survey.

4.2. Analytical framework

A farmer's decision to adopt risk-minimizing/yield-enhancing technologies is assumed to be governed by a utility maximization framework in the presence of risk, where a farmer chooses a component or combination of the components of ISFM that maximizes his/her utility compared to the utility of other alternatives. Thus, when faced with alternative strategies, the farmer may choose a strategy, Q, that generates higher expected utility than any of the other alternatives, say R. i.e.

$$E(U_Q) - M_Q > E(U_R) - M_R \quad (1)$$

where, from Eq. (1) $E(U_Q)$ represents the expected utility of implementing strategy Q and the associated costs M_Q, while $E(U_R)$ and M_R are the corresponding representations for strategy R. Most empirical studies on farmers' technology adoption [1,41,43] have reported that farmers usually adopt different strategies to minimize the risk of yield loss or increase yield, and that adopting more strategies generate greater gains [59,60]. In some cases, agricultural technologies have been shown to have a synergistic effect [43]. The use of multiple agricultural technologies could help to mitigate the adverse effects of overlapping production constraints [43]. However, to develop appropriate policies to promote the adoption of farm technologies, including integrated soil fertility management practices (e.g., crop rotation, inorganic fertilizer, and farmyard manure), it is important to identify factors that influence technology adoption and estimate the impact of technology adoption on farm outcomes (e.g., yield, yield gap, and net crop income). Yield

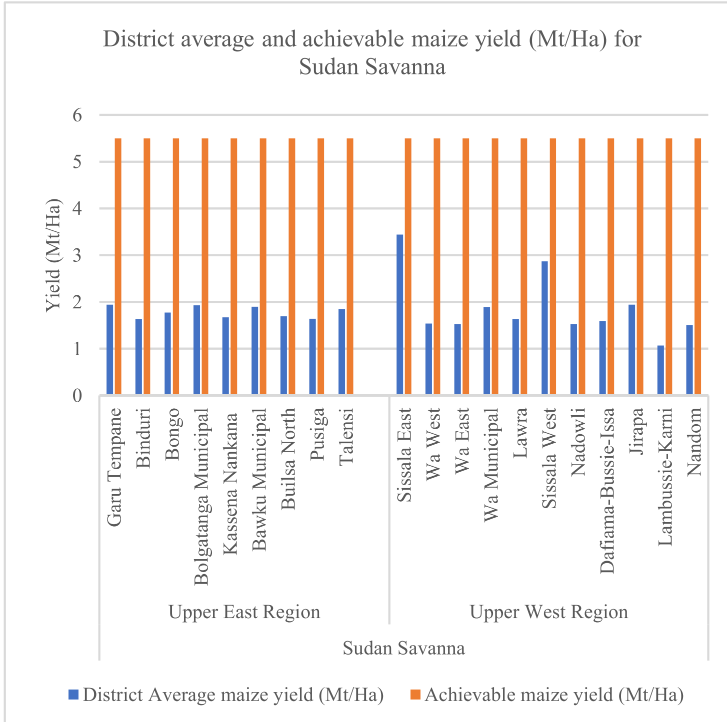

Fig. 5. District average and achievable maize yield for the Sudan Savanna of Ghana.
Source: Ministry of Food and Agriculture [57] (2019)

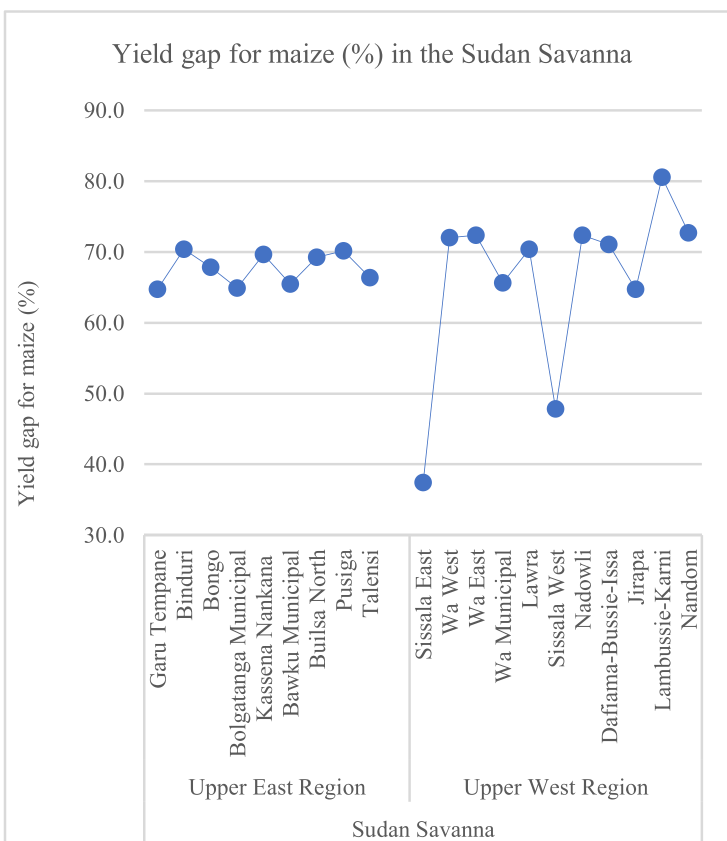

Fig. 6. Yield gap for maize in the Sudan Savanna of Ghana.
Source: Ministry of Food and Agriculture [57] (2019)

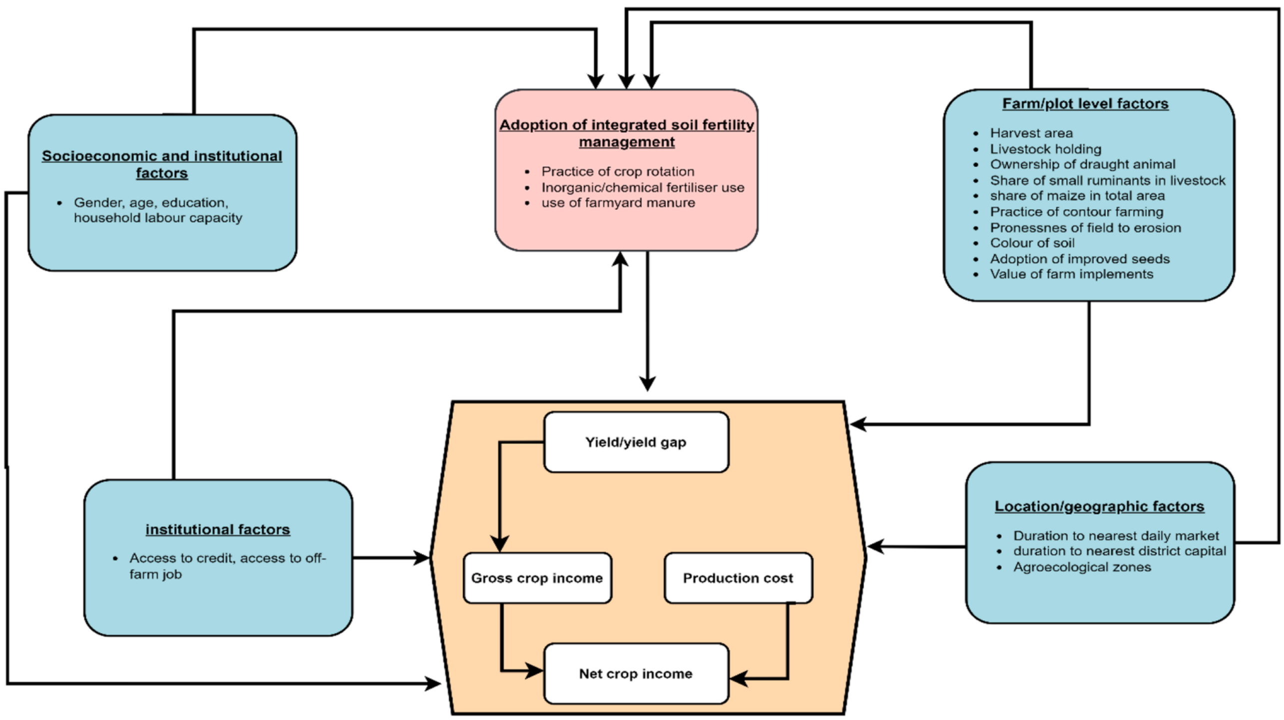

Fig. 7. Drivers and impact of integrated soil fertility management (ISFM).
Source: Authors' design

(kg/ha) is the maize output harvested from a unit of land area (hectares). Yield gap (%) is the difference between potential and observed yields, which is computed as:

$$Yield\ gap\ (\%) = [1 - (Y_a\,/\,Y_w) * 100] \tag{2}$$

where Y_a is the observed yield, and Y_w the water-limited potential yield.[1] Data for Y_a is obtained from the survey data, while data for Y_w is obtained from the Ministry of Food and Agriculture's (MoFA) website and confirmed by GYGA [21]. Net income from maize production is computed as follows:

$$Net\ income\ \left(\frac{US\$}{ha}\right) = \frac{(GI - cS - cF - cHl - cPH - chFPH\ )}{harvested\ maize\ area} \tag{3}$$

From Eq. (3), GI is the gross income from maize production (*total output* × *price per kg*), *cS* is the total cost of seeds, *cF* is the total cost of fertilizer applied, *cHl* is the cost of hired labor, *cPH* is the cost of pesticides and herbicides used, and *chFPH* represents charges on fertilizer, pesticides and herbicides application. The study uses a simple production function, where farm performance measures (Y_{ik}) such as yield, yield gap and income are expressed as a linear function of farm (plot) level variables (*FMv*), socioeconomic factors (SE), institutional factors (*Iv*), location/geographic factors (*LGv*), and an error term μ_i.

$$Y_{ik} = \propto_k + \beta_k ISFM_{ik} + \theta_k FMv_{ik} + \gamma_k SEv_{ik} + \vartheta_k Iv_{ik} + \tau_k LGv_{ik} + \mu_i \tag{4}$$

Eq. (4) can be estimated with a multiple linear regression using ordinary least squares. However, the coefficient (β_k) of integrated soil fertility management and their combinations ($ISFM_{ik}$) (the variable of interest) may be biased due to the endogeneity problem from farmers' self-selection of the agricultural technologies. In the literature, different approaches such as propensity score matching (PSM), endogenous switching regression (ESR), instrumental variable approach (IV) and doubly robust estimation using inverse-probability-weighted regression adjustment (IPWRA) with multivalued treatments have been used to control for this endogeneity or selection bias. It is criticized that the propensity score matching is unable to address selection bias from unobservable factors [61,62]. Endogenous switching regression (ESR) can address selection bias from both observable and unobservable factors. However, ESR estimation requires valid instruments, which makes their application difficult in practice [61,63]. In addition, it is criticized that they cannot be applied to multivalued treatment situations. Although the multinomial endogenous switching regression (BFG) approach [64] can be used in the multivalued treatment case, the approach is unable to estimate the average treatment effects of moving from one treatment level to another [65]. Due to the multivalued nature of our treatments, we apply an IPWRA with multivalued treatments. IPWRA does not require valid instruments and it is a doubly robust estimator, combining the inverse probability weight (IPW) estimator and the regression adjustment (RA) estimator to provide unbiased estimates, even if one of the models is mis-specified [66].

Like the ESR, the IPWRA has a selection function (which is estimated based on inverse probability weighting (IPW)) and an outcome function (which is estimated based on a regression adjustment approach (RA)). The outcome model fits appropriate linear regression models for adopters and non-adopters of the alternative ISFM strategies and predicts covariate-specific outcomes for each subject under each of the adoption statuses [67]. In considering three components of ISFM, a total of 8 strategies are formulated for the analysis; namely non-adoption of any of the practices (None), adoption of only crop rotation (CR), adoption of only inorganic fertilizer (FT), adoption of only farmyard manure (MN), adoption of only crop rotation and fertilizer (CR+FT), adoption of only crop rotation and manure (CR+MN), adoption of only inorganic fertilizer and manure (FT+MN), and the adoption of all three components (CR+FT+MN). Based on the predicted outcomes for each of these strategies, the mean differences between the predicted outcomes (MPO^A) for adopters under adoption and a hypothetical non-adoption is obtained, and the predicted outcome can be expressed as follows [67,68]:

[1] This refers to the maximum possible yield under rainfed conditions [73]

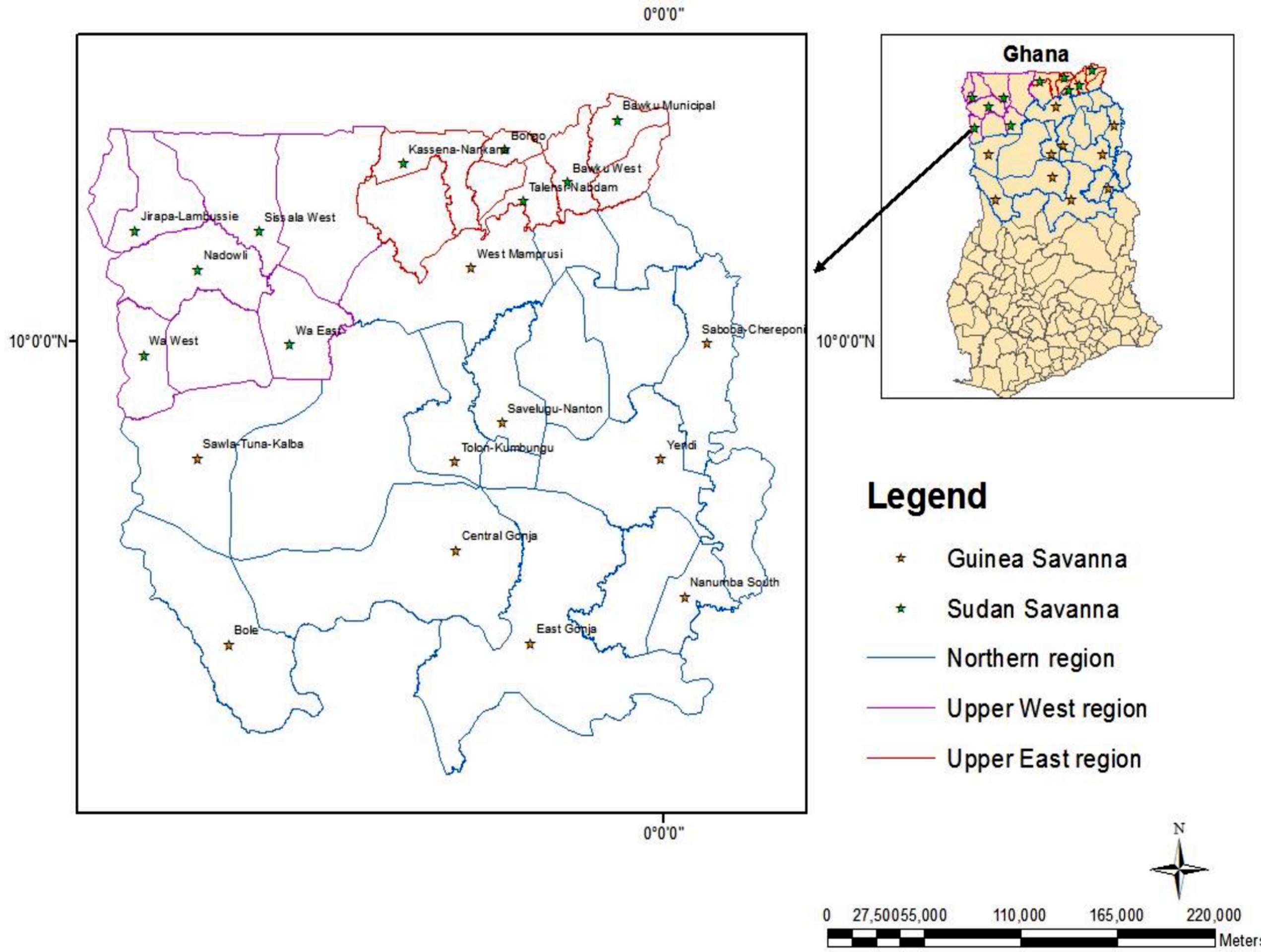

Fig. 8. Map of Ghana indicating the study area.
Source: Authors construct

$$MPO^{A}_{IPWRA} = n_A^{-1}\sum_{i=1}^{n} T_i[r_A(Z,\gamma_A) - r_N(Z,\gamma_N)] \tag{5}$$

From Eq. (5) n_A represents the number of adopters of each strategy (T_i), $r_A(Z,\gamma_A)$ *and* $r_N(Z,\gamma_N)$ describe the regression models for adopters (A) and non-adopters (N), Z is a representation of the covariates, while γ_i represents estimated parameters. In this study, emphasis is placed on the average treatment effect on the treated (ATET). This indicator estimates the expected average effects of adopting an ISFM strategy compared to the alternative of non-adoption of any of the ISFM components (base category), and is expressed mathematically as follows:

$$\begin{aligned} ATET^{T_a|T_0} &= E\{Y^{T_a} - Y^{T_0}|S = T_a\} \\ &= E\{Y^{T_a}|S = T_a\} - E\{Y^{T_0}|S = T_a\}, \quad S\epsilon\{1,2,\ldots.,8\} \end{aligned} \tag{6}$$

where T_a denotes adoption of (individual or combined) components of ISFM, and T_0 denotes non-adoption of any of the ISFM components. From Eq. (6), Y^{T_a} and Y^{T_0} represent the farm performance indicators for households that choose T_a and T_0 respectively. The respective ISFM strategies are represented by the index 'S', which ranges from 1 (for non-adoption) to 8 (the adoption of the complete package).

For a deeper insight into the economic performance of the respective ISFM components, the study further analyzes the profitability of adopting each of the components as well as the risk of income loss (negative returns) from adopting the respective strategies. The former is analyzed based on returns on investment (ROI) and benefit-cost ratio (BCR), both of which are expressed mathematically as follows:

$$ROI_i = \frac{Net\ income_i}{Cost\ of\ production_i} \tag{7}$$

$$BCR_i = \frac{Gross\ Income_i}{Cost\ of\ production_i} \tag{8}$$

The risk of income loss is assessed by computing the probability of observing a negative net income from the adoption of each of the components of ISFM.

5. Results and discussion

In this section, we present and discuss results for the respective analyses. We begin with a brief presentation of the characteristics of farms and farm households in the study area, benefits and costs of adoption of ISFM, impact of the ISFM strategies on farm performance, and present results on the determinants of the alternative strategies, placing emphasis on those found to be more yield and/or income enhancing. We then discuss relevant findings from the respective analyses.

5.1. Results

5.1.1. Characteristics of maize farmers and farms in the study area

The survey data shows an average yield of 768 kg/ha for the three regions in northern Ghana, with the yield gap estimated at 86 % of the water-limited potential yield (Table 1). This is consistent with van Loon et al., [17] who estimated a maize yield gap of 84 % for Northern region.

Table 1
Characteristics of maize farmers and farms in the study area.

Variable	Definition	Mean	Std. Dev
Outcome variable			
Maize yield	Output per hectare cultivated (Kg/ha)	768.1	545.7
Maize yield gap	Deviation of observed yield from achievable (%)	86.03	9.92
Net maize income	Net income per hectare of maize area (US$/ha)	222.4	272.1
Gross maize income	Gross income per hectare of maize area (US$/ha)	375.6	272.0
Cost of maize production	Variable cost for maize production (US$/ha)	153.2	157.5
Treatment			
None (No Adoption)	Dummy=1 if the household head has not adopted any of the three ISFM practices, 0 otherwise	8.77	
CR	Household adopted only crop rotation (1=Yes, 0 otherwise)	8.09	
FT	Household adopted only inorganic fertilizer (1=Yes, 0 otherwise)	28.32	
MN	Household adopted only manure (1=Yes, 0 otherwise)	2.89	
CR+FT	Adoption of both crop rotation and fertilizer only (1=Yes, 0 otherwise)	37.38	
CR+MN	Adoption of both crop rotation and manure only (1=Yes, 0 otherwise)	2.31	
FT+MN	Adoption of both inorganic fertilizer and manure only (1=Yes, 0 otherwise)	5.97	
CR+FT+MN	Adoption of crop rotation, inorganic fertilizer and manure (1=Yes, 0 otherwise)	6.26	
Explanatory variables			
Socioeconomic variables			
Male headed household	Dummy=1 if household head is a male, 0 otherwise	0.863	0.344
Age of household head	The age of the head of the household in years	47.72	14.28
Years of schooling	The number of years the household head spent schooling	2.365	4.714
Household labor capacity[1]	An index for labor availability (supply) measured in Man-equivalent (ME)	4.113	2.346
Institutional variables			
Access to credit	Dummy=1 if household head has access to credit, 0 otherwise	0.106	0.308
Access to off-farm employ	Dummy=1 if household head has access to off-farm employment, 0 otherwise	0.697	0.460
Farm/plot level variables			
Harvested maize area	Total area of maize cultivated (in hectares)	1.997	3.170
Livestock holding	Total units of livestock head by the household (in Tropical Livestock Unit[2])	4.151	10.54
Ownership of draft animals	Dummy=1 if household owns cattle or equine, 0 otherwise	0.176	0.381
Share of small ruminants in livestock	A measure of TLU of small ruminants as percent of total TLU held (%)	52.40	36.12
Share of maize in total land area	A measure of hectares of maize cultivated as percent of total cropland (%)	0.555	0.286
Practice of contour farming	Dummy=1 if household practiced contour farming, 0 otherwise	0.604	0.489
Field is prone to erosion	Dummy=1 if household perceive their field to be prone to erosion, 0 otherwise	0.109	0.312
Black soil on farm	Dummy=1 if the soil on which maize is cultivated is black	0.294	0.456
Adoption of new/ improved variety	Dummy=1 if household planted new/ improved maize variety, 0 otherwise	0.076	0.265
Value of farm implements	Total value of farm implements owned by the household (US $/household)	604.1	2238.2
Location/geographic variables			
Duration to nearest daily market	How long it takes to get to the nearest daily market with usual transport (in minutes)	22.65	17.72
Duration to nearest capital	How long it takes to get to the nearest district capital with usual transport (in minutes)	57.17	42.01
Agro-ecological zone	Dummy=1 if household is located in the Guinea Savanna, 0 if in Sudan Savanna	0.536	0.499

Source: Authors own computations.

[1] Computed using the following conversion factors; for Females: 0–5years (0.00), 6–10 years (0.05), 11–17years (0.40), 18–65 years (0.50), > 65 years (0.10); for males 0–5years (0.00), 6–10 years (0.10), 11–17years (0.80), 18–65 years (1.00), > 65years (0.70); (modified version of age range proposed by [69]).

[2] Computed using the following conversion factors [69,74]; Cattle (Bullock (0.80), Bull (0.70), Cow (0.70), Calf (0.35)), Sheep (Ram (0.10), Ewe (0.10), Lamb (0.05)), Goat (Billy goat (0.10), Nanny goat (0.10), Kid (0.05)), Pig (Boar (0.20), Sow (0.20), Piglet (0.10)), Chicken (0.01), Guinea fowl (0.01) Duck (0.01), Turkey (0.02), Horse (0.80), Donkey (0.50).

The average maize farmer had a net income of US$222.4/ha. Although most of the farmers adopted at least a component of the ISFM practices, about 8.77 % adopted none of the components. The main strategies adopted by the farmers were the joint adoption of crop rotation and inorganic fertilizer (37.4 % of households), and the sole adoption of inorganic fertilizer (28.3 % of households). These estimates are similar to those reported by Hörner and Wollni [67] for the adoption of ISFM in Ethiopia, where the authors report estimates of around 7 % and 34 % for non-adoption of ISFM and the sole adoption of inorganic fertilizer by farmers. Setsoafia *et al.* [38], also report estimates of 6.78 % and 7 % for non-adoption and complete adoption of the components of sustainable agricultural practices (improved seeds, fertilizer, and soil and water conservation) by crop farmers in northern Ghana. From Table 1, the least adopted strategy was the combination of crop rotation and farmyard manure (2.31 % of households or 24 households in absolute terms). We find that 86 % of the farm households were headed by males. Most farmers were 48 years old and had 2 years of formal schooling. The average labor capacity of most farm households was 4 men. Table 1 shows that 70 % of the households had access to off-farm employment opportunities and only 10.6 % of the farm households had access to credit. The households cultivate on average 2 hectares of maize. On average, farmers had to travel 23 min to the nearest daily market place, and 57 min to the nearest district capital.

Less than 30 % of the farmers produce maize on black soil. The average livestock holding for the area is estimated at 4.15 TLU per household and only 17.6 % of the households own draft animals (cattle and/or equines). While about 60 % of the farmers practice contour ploughing/farming for maize production, only 10.9 % perceive that their fields are prone to erosion.

Per the distribution of the farm performance indicators for the various ISFM strategies (see Fig. 9A to C), it is found that farmers who adopted at least one of the ISFM components generally had higher yields and lower yield gaps than the farmers who adopted none of the components. Except for the yield distributions for farmers who adopted crop rotation only and that for the non-adopters, which appear to have a bimodal distribution and right skewed, the yield distribution for all the other alternatives appears to be unimodal in nature and normally distributed. Most of the adopters of the ISFM components were better off in terms of yield and yield gap than the non-adopters of the components.

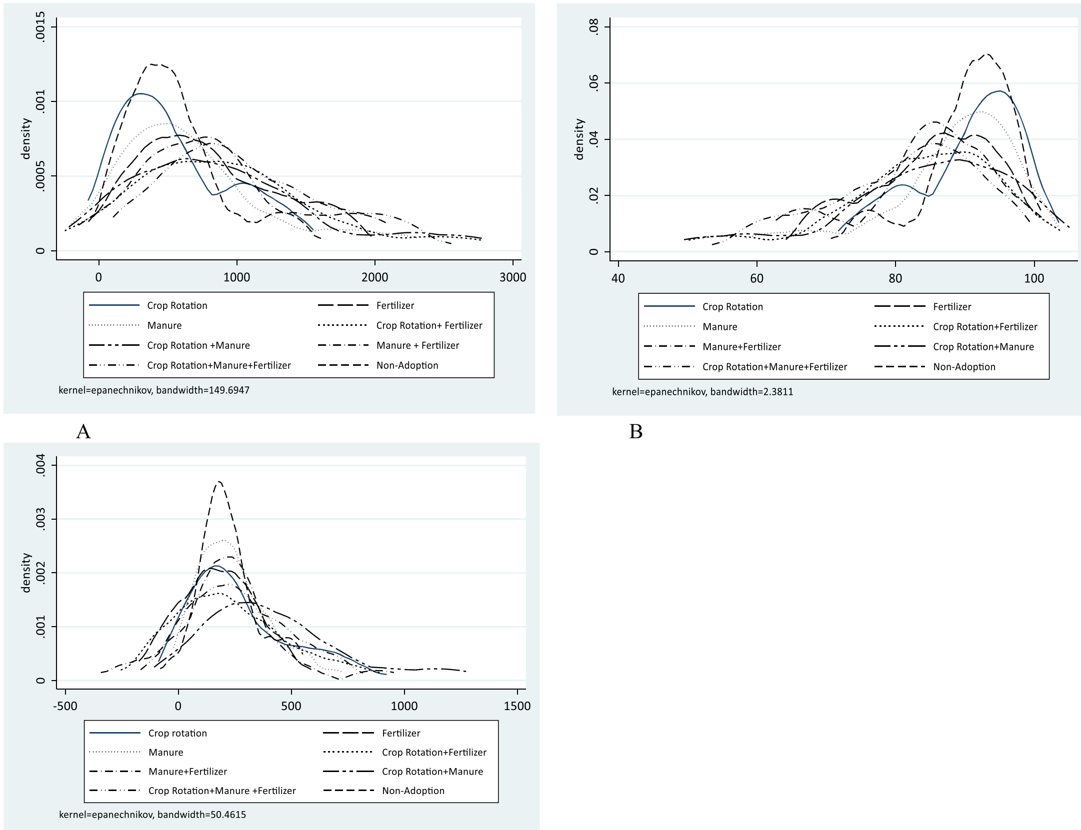

Fig. 9. A. Distribution of yields (kg/ha), B. Distribution of yield gap (%), C. Distribution of net income per ha of maize farm (US$/ha).
Source: Authors own construct

The adopters of all the three components of ISFM however appear to have recorded higher yields and lower yield gaps than the rest of the farmers. In contrast to the nature of the distribution for yield and yield gap, the plots for net income per ha for all the alternatives appear to be normally distributed, with peaks for most of the options (including non-adoption) being below US$300/ha. The adopters of crop rotation and manure (CR +MN), all three components (CR+FT+MN), and adopters of crop rotation only (CR) however had relatively higher proportion of farmers with net income above US$500/ha than the rest of the farmers.

5.1.2. Benefits and cost of adoption of ISFM in Ghana

In this section, we provide some information on net income, gross income, variable costs of production for the alternative ISFM strategies, returns on investment and the benefit-cost ratio for each strategy. Depending on the strategy adopted (including non-adoption of any of the components), net income ranged between US$170.5/ha (for adoption of FT only) and US$420.5/ha (for adoption of CR+MN only). Gross income ranged between US$282/ha (for non-adoption of any of the strategies) and US$489.3/ha (for adoption of all the three components of ISFM). Farmers who adopted FT only incurred the greatest variable

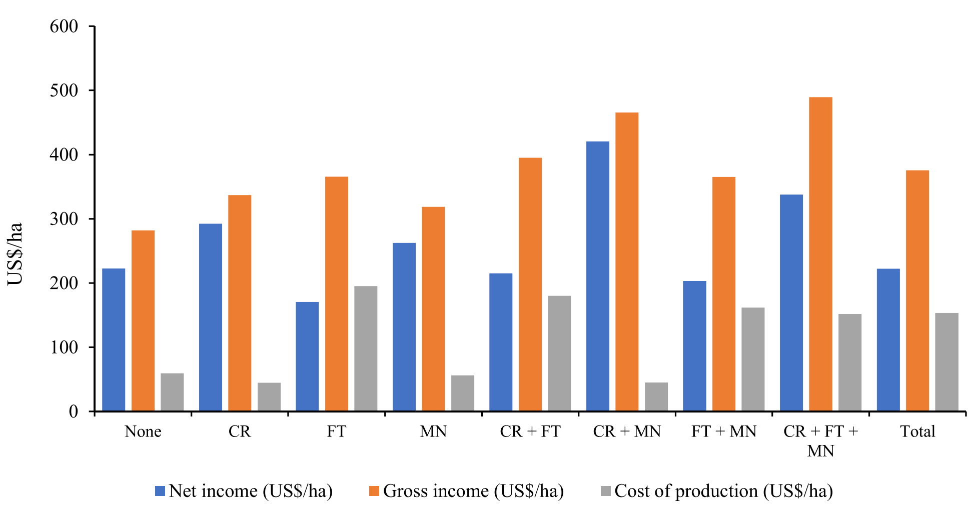

Fig. 10. Income indicators according to ISFM components adopted.
Source: Authors

cost of production (US$195/ha), while adopters of CR only incurred the lowest cost of production (US$44.5/ha) (See Fig. 10).

We estimate a benefit cost ratio of 2.45 for maize production using gross income-variable cost ratio (Fig. 11). This implies that it is beneficial/profitable to produce maize in the study area. Per the alternative strategies adopted; however, the ratio was greatest for adopters of CR+MN only, and lowest for adopters of FT only. A total of about 13 % of maize farmers in the study area recorded negative returns from maize production. The proportion of farmers who recorded negative returns was higher among adopters of FT only (20.1 %) (Fig. 12).

5.1.3. Impact of adoption of ISFM strategies on farm performance

In this section, we present the results for the estimated impacts of ISFM on yield, yield gap, net income from maize production, gross income, and cost of production, the latter of which is so far missing from earlier studies on the impact of ISFM. The empirical results from Table 2 shows that for the individual components, the adoption of inorganic fertilizer alone had the greatest yield-enhancing effect, with the observed increase in yield estimated at 40.96 % (significant at the 5 % level), and a corresponding decrease in yield gap of 4.84 %. However, in considering the adoption of two components, we found in terms of yield effects, adopting FT+MN (thus fertilizer and manure only) and CR+FT (crop rotation and fertilizer only) could be more appropriate, as adoption of these combinations result in yield increases of 41.23 % and 39.32 % with corresponding decreases in yield gap of 4.87 % and 4.64 %. These results, especially the case of FT+MN affirm reports from earlier studies that jointly applying inorganic fertilizer and farmyard manure leads to substantial increase in maize yield [5,34,35,44]. The observed effects of FT+MN implies that instead of treating the application of inorganic fertilizer and farmyard manure as substitutes in maize production, applying them as complements could be more yield-enhancing. This result supports earlier evidence from Hörner and Wollni [67] and Adem et al. [37] that farmers observe greater yield gains from the joint adoption of inorganic and organic fertilizers, than when either is applied in isolation. In addition, we found that while the yield on farms that adopted only crop rotation (CR) was not significantly different from those who adopted none of the components of ISFM, farmers who combined crop rotation with fertilizer application were better-off.

The most important of the yield effects estimated is the synergy from the adoption of all three components, with estimated yield increase of 86.52, and a corresponding decrease in yield gap of 10.22 %. This implies that applying/adopting all three components leads to greater yield effects than the exclusive combination of the separate effects of the individual components or the sum of any two alternative strategies. This is in line with an earlier report by Setsoafia et al. [38] on Ghana, that adopting three sustainable agricultural practices (SAPs) as a package result in greater yield gains than adopting single or two SAPs. The result is however in contrast with report by Adolwa et al. [1] who found no significant increase in yield with an increase in the number of ISFM components. Production-based efforts to bridge the yield gap for maize should place more emphasis on the adoption of all the three components as a package.

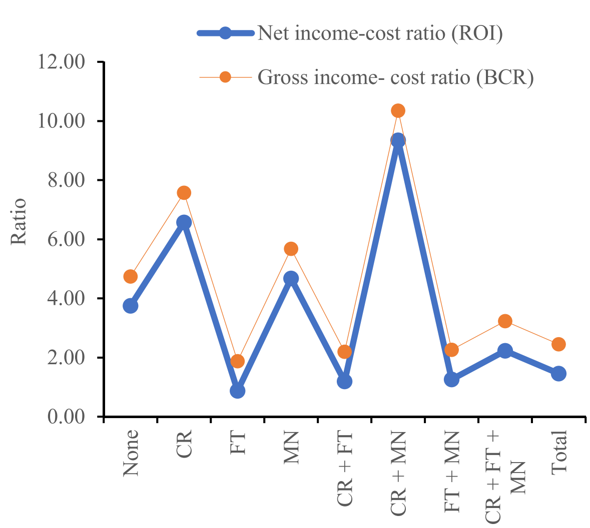

Fig. 11. Returns on investment and benefit-cost ratio for adoption of ISFM.
Source: Authors

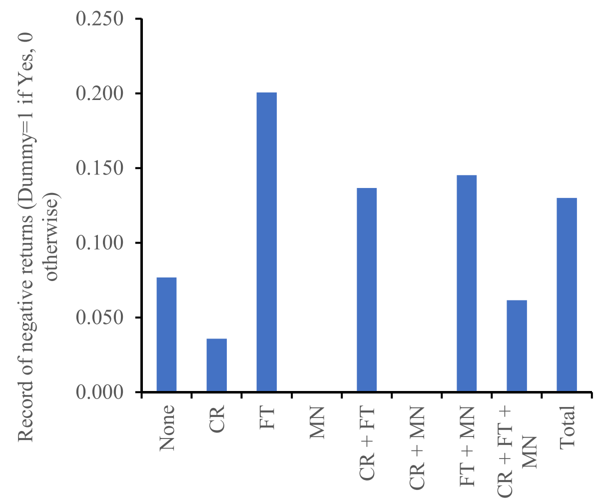

Fig. 12. Record of negative returns for alternative ISFM strategies.
Source: Authors

Table 2
Impact of ISFM on yield and yield gap for maize.

Indicator	ISFM practice	Yield (kg/ha)	% change from base	Yield gap (%)	% change from base
ATET	CR	−11.14 (99.77)	−1.92	0.202 (1.814)	0.226
	FT	237.98 ** (104.72)	40.96	−4.327** (1.904)	−4.838
	MN	170.59 (156.46)	29.36	−3.102 (2.845)	−3.468
	CR + FT	228.46 ** (91.85)	39.32	−4.154** (1.670)	−4.644
	CR + MN	−75.15 (402.97)	−12.94	1.367 (7.327)	1.528
	FT + MN	239.55 ** (114.47)	41.23	−4.355** (2.081)	−4.869
	CR+ FT +MN	502.66 *** (171.16)	86.52	−9.139*** (3.112)	−10.22
POmean	None (base)	580.97*** (96.33)		89.44*** (1.751)	

NB: ***, **, * represents 1 %, 5 %, and 10 % significance levels, respectively; (*) – robust standard errors.
Source: Authors own computations.

On the impact of the adoption of ISFM on income, the yield gain from the application of fertilizer alone (FT) was nullified by the cost of adoption (with the increase in cost estimated at 139.7 % compared to farmers who adopted none of the components of ISFM), as we found a 1.96 % decrease in net income among farmers who opted for this option (although not significant). Similar direction of effect was observed for the adoption of CR+FT. This result is in conformity with an earlier report by Setsoafia et al. [38] on Ghana (based on the baseline data for Ghana from the Africa RISING program), that adopting only fertilizer leads to unexpected decrease in farm income. It however contrasts the findings of Hörner and Wollni [70] in Ethiopia, that the adoption of fertilizer leads to incomes gains of about 50–60 %. While the positive effect for FT+MN was estimated at 26.73 %, it was not significant.

We found that while the adoption of CR and MN had insignificant effects on yield, they were associated with 38.81 % and 49.3 % increases in income, respectively. This, in the case of MN, implies that while the contribution of MN to yield may be positive but not significant, the relatively low cost of adoption of this alternative could help to minimize production cost, leading to a possible increase in income (Table 3). For the adoption of MN only, we estimated a 51.3 % decrease in the variable cost of production, compared to non-adopters of any of the components. Being associated with the suppression of weeds and the control of pest and diseases, the adoption of CR only was associated with a 43.6 % decrease in cost of production. This decrease in production cost ultimately helps to increase income, although the direct effect on yield may not be substantial. This is an indication that increments in farm income are not always the result of an increase in yield but could also stem from potential decreases in production cost that arise from the adoption of cheaper technologies or farm inputs [1,4,38,70]. We found that the greatest income effect was from the adoption of all three components, with an increase in income of about 51.29 % (significant at the 5 % level) estimated. Efforts to promote the adoption of all three components as a package could therefore be yield and income enhancing, although the effect is expected to be greater in terms of yield due to potential cost implications of adopting a greater number of strategies [70].

5.1.4. *Determinants of farmers' adoption of ISFM practices*

Table 4 shows heterogeneous effects of the variables on the adoption of the respective ISFM strategies. We present the results according to the categories of the variables, starting with socioeconomic and institutional factors.

5.1.4.1. Socioeconomic factors and institutional factors. Among the socioeconomic and institutional factors considered, education of the household heads, measured by years of schooling, was the most important factor influencing the adoption of the ISFM strategies, followed by household labor capacity and the age of the household heads. Except for the adoption of CR+MN, a year increase in schooling was positively associated with the adoption of all the other alternative ISFM strategies. The implementation of ISFM strategies is not only capital and labor intensive, but also knowledge-intensive, from both agronomic and bio-security perspectives, and the efficient and effective implementation of the respective components and their combinations may require greater technical knowledge and skills, which the more educated tend to possess. The results show a positive relationship between household labor capacity and the adoption of CR+MN (thus crop rotation + manure only). Although farmyard manure, which is readily available in the farmers' fields/homes, may be a cheaper input, its application is quite labor-intensive, which also applies to crop rotation. The combination of both strategies may therefore require more labor, and households with more men in terms of capacity are in a better position to effectively implement this strategy. We also found a positive association between age of the household head and adoption of all the three components of ISFM (CR +FT+MN). Older people, who are likely to have limited access to off-farm employment, tend to rely on agriculture for their livelihood, and are more likely to implement all three components to achieve higher yields to meet household food and income needs.

5.1.4.2. Farm/plot level variables. The farm size variable had a negative effect on the adoption of all the ISFM strategies, and the effect was significant on the adoption of CR, CR+FT, CR+MN, and CR+FT+MN. Since CR is common to all major strategies, it is probably less likely that large-scale farmers practice crop rotation. Farmers who had draft animals (cattle and equines) and were likely to readily access manure on farm tended to adopt MN, FT+MN, and CR+FT+MN. Farmers with a high share of small ruminants in their flock/herd, which can easily be converted to cash needed, were more likely to adopt FT, MN, CR+FT, FT+MN, and CR+FT+MN, most of which are both capital and labor intensive. As contour ploughing/farming has been shown to conserve/harvest water and control erosion, we found that farmers who engaged in this practice were more likely to adopt CR, MN, CR+ FT, CR+MN, and the full package (CR+FT+MN). This implies that efforts to conserve water and control soil erosion can enhance the adoption of ISFM practices. Farmers growing maize on erosion-prone fields were more likely to adopt CR+MN, while those who used new/improved maize varieties were more likely to adopt FT, FT+MN, and CR+FT+MN. This implies that efforts to promote the adoption of improved maize varieties could enhance farmers adoption of these strategies [46]. As an indirect measure of mechanization, an increase in the value of farm implements/equipment owned by the farmers leads to the adoption of all the ISFM strategies (significant at the 5 % level for all except CR).

5.1.4.3. Location/geographic factors. Due to limited access to inputs and vital resources for production, and potentially higher transaction costs, farmers living farther from the nearest daily marketplace were less likely to adopt CR+FT, but more likely to adopt FT+MN, and MN, the latter of which could be easily accessed from the farm. As a proxy for access to extension services, the variable 'duration to the nearest district capital' was negatively related to the adoption of FT and CR+FT, both of which require some level of technical knowledge and skills in their implementation.

Farmers in the Guinea Savanna zone were more likely to adopt CR, CR+FT, and CR+FT+MN compared to their counterparts in the Sudan Savanna zone. This observation may be attributed to the relatively favorable climatic, production and marketing conditions in the Guinea Savanna zone compared to the drier Sudan Savanna.

5.2. *Discussion*

While soil infertility and the prevalence of crop pests and diseases have severely hampered crop production in sub-Saharan Africa, it is evident that the yield- and income-related threats can be addressed through the adoption of ISFM practices, namely crop rotation (CR), fertilizer (FT) or farmyard manure (MN), either in isolation or preferably in combination. The empirical results have shown that the adoption of the components of ISFM in combination has a greater impact on farm performance than non-adoption of any of the components or the sole adoption of the individual components. However, the greatest yield and income gains are achieved when farmers adopt all the three components as a package, with our study finding a synergy in the effect on yield and yield gap. This result is consistent with previous studies [2,37,63,71]

Table 3
Impact of ISFM on net income, gross income, and cost of production for maize.

Indicator	ISFM Practice	Net income (US $/ha)	% change from base	Gross income (US $/ha)	% change from base	Cost of production (US $/ha)	% change from base
ATET	CR	81.79* (42.75)	38.81	47.37 (38.58)	16.4	−34.42** (15.64)	−43.6
	FT	−4.130 (43.33)	−1.960	106.0*** (38.59)	36.6	110.2*** (18.91)	139.7
	MN	103.9* (53.78)	49.30	63.43 (55.55)	21.9	−40.47* (21.92)	−51.3
	CR + FT	−4.864 (37.70)	−2.308	104.1*** (33.06)	35.9	108.9*** (13.62)	138.0
	CR + MN	−28.67 (167.0)	−13.60	−59.32 (163.9)	−20.5	−30.66 (19.73)	−38.8
	FT + MN	56.34 (67.28)	26.73	139.9** (64.51)	48.3	83.61*** (21.15)	105.9
	CR + FT + MN	108.1** (54.15)	51.29	208.7*** (72.10)	72.1	100.6** (49.12)	127.5
POmean	None (base)	210.7*** (34.08)		289.7*** (31.18)		78.91*** (14.03)	

Table 4
Determinants of farmers' adoption of ISFM practices.

	CR	FT	MN	CR + FT	CR + MN	FT + MN	CR+FT+MN
Socioeconomic variables							
Male headed household	0.026 (0.451)	−0.305 (0.339)	−0.929* (0.547)	0.172 (0.348)	−0.488 (0.630)	−0.374 (0.476)	0.105 (0.579)
Age of household head	0.005 (0.013)	0.003 (0.009)	0.010 (0.018)	0.003 (0.009)	0.012 (0.017)	−0.003 (0.013)	0.025** (0.012)
Years of schooling	0.099*** (0.037)	0.082** (0.033)	0.118** (0.048)	0.055* (0.033)	−0.068 (0.104)	0.106*** (0.038)	0.116*** (0.041)
Household labor capacity	0.075 (0.083)	0.066 (0.065)	−0.110 (0.130)	0.055 (0.066)	0.269*** (0.096)	−0.055 (0.090)	−0.011 (0.091)
Institutional variables							
Access to credit	0.572 (0.573)	−0.080 (0.504)	−0.660 (1.107)	0.724 (0.474)	0.210 (0.946)	0.496 (0.608)	0.297 (0.641)
Access to off-farm employment	0.142 (0.346)	0.167 (0.269)	−0.183 (0.466)	0.113 (0.266)	−0.119 (0.535)	0.094 (0.378)	0.612 (0.384)
Farm/plot level variables							
Harvested maize area	−0.251*** (0.081)	−0.056 (0.035)	−0.069 (0.073)	−0.086** (0.043)	−0.516* (0.278)	−0.054 (0.051)	−0.134** (0.064)
Livestock holding	0.026 (0.069)	0.002 (0.066)	0.051 (0.069)	0.034 (0.068)	0.051 (0.070)	0.054 (0.069)	0.037 (0.068)
Ownership of draft animals	0.393 (0.647)	0.742 (0.579)	1.840** (0.790)	0.742 (0.602)	1.136 (0.732)	2.210*** (0.659)	2.709*** (0.658)
Share of small ruminants in livestock	0.005 (0.005)	0.0089** (0.0038)	0.016** (0.007)	0.0093** (0.0038)	−0.005 (0.007)	0.016*** (0.005)	0.015** (0.006)
Share of maize in total land area	0.659 (0.629)	0.353 (0.521)	0.966 (0.914)	0.542 (0.506)	0.615 (1.109)	1.236* (0.707)	0.194 (0.697)
Practice of contour farming	0.869*** (0.331)	−0.087 (0.247)	1.086** (0.482)	1.039*** (0.248)	0.951* (0.514)	0.085 (0.358)	1.056*** (0.374)
Field is prone to erosion	0.605 (0.599)	0.232 (0.503)	0.042 (0.819)	0.668 (0.496	1.353* (0.692)	0.466 (0.637)	0.378 (0.661)
Black soil on farm	0.483 (0.341)	−0.193 (0.273)	0.294 (0.435)	−0.100 (0.275)	0.371 (0.516)	−0.618 (0.416)	−0.476 (0.417)
Adoption of new/improved variety	0.060 (1.043)	1.566** (0.767)	0.925 (1.251)	1.294 (0.788)	0.659 (1.341)	1.699* (0.878)	1.878** (0.882)
Value of farm implements	0.001 (0.001)	0.0009** (0.0004)	0.0010** (0.0004)	0.0009** (0.0004)	0.0009** (0.0004)	0.0009** (0.0004)	0.0009** (0.0004)
Location/geographic variables							
Duration to nearest daily market	−0.012 (0.012)	0.001 (0.008)	0.027*** (0.009)	−0.017** (0.008)	−0.0003 (0.017)	0.0154* (0.0085)	−0.009 (0.011)
Duration to nearest district capital	−0.005 (0.004)	−0.0048* (0.0025)	0.0026 (0.0034)	−0.006** (0.0027)	−0.0048 (0.0045)	0.0009 (0.0032)	0.0008 (0.0037)
Agro-ecological zone	1.092*** (0.379)	0.133 (0.299)	0.062 (0.442)	0.965*** (0.296)	0.035 (0.614)	−0.172 (0.428)	1.843*** (0.454)
Intercept	−2.190** (0.975)	0.147 (0.676)	−4.386*** (1.243)	−0.844 (0.689)	−3.224** (1.327)	−2.814*** (0.956)	−5.472*** (1.097)

NB: ***, **, * represents 1 %, 5 %, and 10 % significance levels, respectively; (*) – robust standard errors.
Source: Authors own computations.

that benefits from the adoption of agricultural technologies are greater with the number of technologies adopted. In addition, evidence shows that income gains from maize production are not only the result of yield gains but could also stem from potential decreases in the cost of production [4]. We found that some ISFM strategies that could be yield-enhancing may not necessarily be income- enhancing due to potential cost implications, while others that may not necessarily be yield-enhancing could be income enhancing due to the low cost of implementation. For example, we found that enhancing yield and/or reducing yield gap for maize may require the adoption of FT, CR+FT, FT+MN, or preferably CR+FT+MN. However, enhancing income from maize production may require the adoption of CR, MN, or preferably CR+FT+MN. We estimated yield gain of 86.52 %, a decrease in yield gap of 10.22 %, and an increase in net income of 51.29 % with the adoption of CR+FT+MN. These outcomes indicate that productivity and profit from maize production depend on the number and specific components of ISFM adopted by farmers [2], affirming the need to consider the effect of the individual components and their combinations when analyzing the impact of soil fertility management interventions.

Despite the greater benefits from the adoption of CR+FT+MN, we found that farmers in northern Ghana are more likely to adopt CR+FT (37.4 % of farm households) or adopt FT (28.3 % of farm households). They are however less likely to adopt CR+MN (2.3 % of farm households). Although policy makers and other stakeholders have so far focused on promoting the adoption of inorganic fertilizer as a solution to the prevailing low yields and high yield gaps for most of the crops in Africa [72], we found that while the adoption of inorganic fertilizer alone may be yield-enhancing, it may not necessarily be income-enhancing due to the potential cost implications of its adoption. We found that a total of about 20.1 % of the farmers who adopted only FT recorded negative returns. In addition, among the eight alternatives considered in this study, the benefit-cost ratio was lowest for adopters of FT only. The sole use of chemical fertilizers alone may therefore not be the only way of soil nutrient management and may not be enough for sustainable and profitable crop production [37]. A practice like crop rotation, which does not have a substantial effect on yield, appears to have a significant positive effect on income, due to its ability to enhance soil health and to suppress weeds and pests among other biotic and abiotic stresses [30,31], which can reduce production costs. Farmyard manure, which improves soil physical properties at a relatively lower costs, has both yield- (although not significant) and income-enhancing effects. With these observed effects, we anticipate that the joint adoption of crop rotation, inorganic fertilizer and farmyard manure could address multiple risks and enhance farm performance. The joint adoption of all three components of ISFM is associated with a benefit-cost ratio of 3.23, implying that it is profitable to jointly adopt all three components of ISFM in maize production.

However, the adoption and impact of the ISFM alternatives/strategies on farm performance are influenced by different socioeconomic and institutional factors, farm/plot level variables, and by geographical/location variables. Among the socioeconomic and institutional variables, the most important factors influencing the adoption of the alternative ISFM strategies are years of schooling, household labor capacity and the age of the head of the farm households. Both duration to the nearest daily marketplace and duration to the nearest district capital were found to be important factors affecting the adoption of ISFM strategies. For the farm/plot level variables considered in the analysis, those found to be the major factors of the adoption of ISFM are the maize area cultivated, ownership of draft animals, share of small ruminants in livestock held, the practice of contour farming, adoption of improved varieties and the value of farm implements. These results are consistent with earlier reports by Teklewold et al. [43], Kassie et al. [41], Tambo and Mockshell [63], Hörner and Wollni [70] and Setsoafia et al. [38]. While large-sized farms are likely to be equipped with more capital and resources that could enable them to invest in the ISFM practices, we found a negative association between farm size and the adoption of all the ISFM alternatives, although significant in four of the seven cases. This negative association may be attributed to uncertainty associated with the outcome of such investments, increasing cost of implementation with increasing farm size, and market and price risks associated with maize production in the study area.

Effort to address the constraints on farmers' access to market, promote the production of livestock (especially small ruminants and draft animals), educate farmers on the beneficial implications of ISFM, promote the practice of contour ploughing/farming, and promote mechanization of production could enhance the adoption of the ISFM practices in the study area. It was found that farmers in the Guinea Savanna zone are more likely to adopt CR, CR+FT, and CR+FT+MN than their counterparts in the Sudan Savanna zone.

6. Conclusion

Using an inverse-probability-weighted-regression adjustment model to analyze data from 1038 maize farming households in northern Ghana, this study has shown that the joint adoption of the components of integrated soil fertility management as a package leads to a synergy in yield gain, a major decrease in yield gap and enhances income from maize production. While the adoption of multiple components of ISFM could help to address overlapping constraints in production, the study finds that adopting the components as a package leads to increment in cost of production. However, the gains in yield for most of such combinations outweigh the cost of adoption. In considering the adoption of crop rotation, fertilizer and farmyard manure as the component of ISFM for the study area, the study finds that the adoption of fertilizer alone (FT) is more appropriate in enhancing yield than adopting crop rotation (CR) or farmyard manure (MN) alone. It is however beneficial to combine crop rotation and fertilizer than adopt crop rotation alone. While some practices/combinations were found to be yield-enhancing, others were found to be income enhancing, while the joint adoption of all three components was found to be both yield and income-enhancing. Given the estimated yield and income gains from the adoption of all the three components, policy and other stakeholder efforts should be made to promote the adoption of the components as a package. Due to the capital-, labor-, and knowledge-intensive nature of the practices however, efforts should be made to educate farmers on how these strategies can be efficiently and effectively implemented, and measures put in place to reduce liquidity, labor, and market access constraints that could hinder farmers' adoption of the practices in combination. It was found that an increase in the value of farm implements (mechanization), the practice of contour farming, the adoption of improved maize varieties, and an increase in the share of small ruminants in livestock held (that can easily be liquidated to purchase inputs) enhance the adoption of ISFM. Policy efforts to promote the practice of mechanization, the adoption of improved varieties and contour ploughing/farming in maize production, and the promotion of the rearing of small ruminants by farmers can help to increase the performance of maize farmers in northern Ghana. Having found a significant effect of the location variable in the respective models estimated, we recommend that the promotion of the ISFM practices should be tailored to local conditions.

Among the limitations of this study however is the use of a cross-sectional data, which precludes us from analyzing the dynamics of adoption of ISFM, and the use of proxies for some variables deemed relevant in technology adoption and impact assessments (*including access to extension services, which was proxied with the duration to the nearest district capita*l) which were missing from the data. The use of a panel data or an updated/newer version of the current cross-sectional data in the near future for a similar study could be more informative.

CRediT authorship contribution statement

David Boansi: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Victor Owusu:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Methodology, Investigation, Formal analysis, Conceptualization. **Emmanuel Donkor:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Formal analysis.

Declaration of competing interest

The authors declare that no conflict of interests exist.

Data availability

The data has been attached together with the code

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.sftr.2024.100185.

References

[1] I.S. Adolwa, S. Schwarze, A. Buerkert, Impacts of integrated soil fertility management on yield and household income: the case of Tamale (Ghana) and Kakamega (Kenya), Ecol. Econ. 161 (2019) 186–192.

[2] H. Kihara, J. Manda, A. Kimaro, E. Swai, C. Mutungi, M. Kinyua, P. Okori, G. Fischer, F. Kizito, M. Bekunda, Contributions of integrated soil fertility management (ISFM) to various sustainable intensification impact domains in Tanzania, Agric. Syst. (2022), https://doi.org/10.1016/j.agsy.2022.103496.

[3] P. Mponela, G.T. Kassie, L.D. Tamene, Simultaneous adoption of integrated soil fertility management technologies in the Chinyanja Triangle, Southern Africa, Nat. Resour. Forum. 42 (2018) 172–184.

[4] M.P. Tabe-Ojong, A.N. Fabinin, J.R. Minkoua, E.L. Molua, E.E. Fonkeng, Organic soil amendments and food security: evidence from Cameroon? Land. Degrad. Dev. (2022) https://doi.org/10.1002/ldr.4523.

[5] W. Hua, P. Luo, N. An, F. Cai, S. Zhang, K. Chen, J. Yang, X. Han, Manure application increased crop yields by promoting nitrogen use efficiency in the soils of 40-year soybean-maize rotation, Sci. Rep. 10 (2020) 14882.

[6] E. Martey, J.K.M. Kuwornu, J. Adjebeng-Danquah, Estimating the effect of mineral fertilizer use on land productivity and income: evidence from Ghana, Land. Use Policy 85 (2019) 463–475.

[7] M.P.Jnr. Tabe-Ojong, L.M. Ibarra, R.S. Andrade, R. Labarta, Soil conservation and smallholder welfare under cassava-based systems in Thailand, Land Degrad. Dev. (2022), https://doi.org/10.1002/ldr.4569.

[8] E. Nkonya, W. Anderson, E. Kato, J. Koo, A. Mirzabaev, J. von Braun, S. Meyer, Global cost of land degradation. Economics of Land Degradation and Improvement–A Global Assessment For Sustainable Development, Springer, Cham, 2016, pp. 117–165.

[9] E. Nkonya, T. Johnson, H.Y. Kwon, E. Kato, Economics of land degradation in sub-Saharan Africa. Economics of Land Degradation and Improvement–A Global Assessment For Sustainable Development, Springer, Cham, 2016, pp. 215–259.

[10] S. Zingore, J. Mutegi, B. Agesa, L. Tamene, J. Kihara, Soil degradation in sub-Saharan Africa and crop production options for soil rehabilitation, Better Crops 99 (2015) 24–26.

[11] T. Gomiero, Soil degradation, land scarcity and food security: reviewing a complex challenge, Sustainability 8 (2016) 281.

[12] L. Scheiterle, R. Birner, Assessment of Ghana's comparative advantage in maize production and the role of fertilizers, Sustainability 10 (2018) 4181, https://doi.org/10.3390/su10114181.

[13] W. Mupangwa, S. Twomlow, S. Walker, Reduced tillage, mulching and rotational effects on maize (Zea mays L.), cowpea (Vigna unguiculata (Walp) L.) and sorghum (Sorghum bicolor L. (Moench) yields under semi-arid conditions, Field Crops Res. 132 (2012) 139–148.

[14] D. Octavia, Murniati, S. Suharti, A. Hani, N. Mindawati, Suratman, D. Swestiani, A. Junaedi, N.K.E. Undaharta, P.B. Santosa, R.S. Wahyuningtyas, V Faubiany, Smart agroforestry for sustaining soil fertility and community livelihood, Forest Sci. Technol. 19 (2023) 315–328.

[15] S. Leitner, D.E. Pelster, C. Werner, L. Merbold, E.M. Baggs, F. Mapanda, K. Butterbach-Bahl, Closing maize yield gaps in sub-Saharan Africa will boost soil N_2O emissions, Curr. Opin. Environ. Sustain. 47 (2020) 95–105.

[16] D.K. Ray, N.D. Mueller, P.C. West, J.A. Foley, Yield trends are insufficient to double global crop production by 2050, PLoS. One 8 (2013) 1–7.

[17] M.P. Van Loon, S. Adjei-Nsiah, K. Descheemaeker, C. Akotsen-Mensah, M. van Dijk, T. Morely, M.K. van Ittersum, P. Reidsma, Can yield variability be explained? Integrated assessment of maize yield gaps across smallholders in Ghana, Field Crops Res. 236 (2019) 132–144.
[18] L. Scheiterle, V. Häring, R. Birner, C. Bosch, Soil, striga, or subsidies? Determinants of maize productivity in northern Ghana, Agric. Econ. 50 (2019) 479–494.
[19] D. Boansi, Effect of climatic and non-climatic factors on cassava yields in Togo: agricultural policy implications, Climate 5 (2017) 28, https://doi.org/10.3390/cli5020028.
[20] A.M. Gezahegn, Role of integrated nutrient management for sustainable maize production, *Int. J. Agronomy* 2021 (2021) 1–7, https://doi.org/10.1155/2021/9982884.
[21] GYGA, (2018). Global yield gap Atlas. http://yieldgap.org/.
[22] B.T. Assefa, J. Chamberlin, P. Reidsma, J.V. Silva, M.K. van Ittersum, Unravelling the variability and causes of smallholder maize yield gaps in Ethiopia, Food Secur. 12 (2020) 83–103.
[23] M. van Dijk, T. Morley, M. van Loon, P. Reidsma, K. Tesfaye, M.K. van Ittersum, Reducing the maize yield gap in Ethiopia: decomposition and policy simulation, Agric. Syst. 183 (2020) (2020) 102828.
[24] S. Munialo, A.S. Dahlin, C.M. Onyango, W. Oluoch-Kosura, H. Marstorp, I. Öborn, Soil and management-related factors contributing to maize yield gaps in western Kenya, Food Energy Secur. 9 (2020) e189.
[25] U. Ashraf, M.N. Salim, A. Sher, S.R. Sabir, A. Khan, G. Pan, X. Tang, Maize growth, yield formation and water-nitrogen usage in response to varied irrigation and nitrogen supply under semi-arid climate, Turk. J. Field Crops 21 (2016) 87–95.
[26] C. Ragasa, A. Chapoto, S. Kolavalli, Maize Productivity in Ghana. IFPRI Policy Note 5, Ghana Strategy Support Program, International Food Policy Research Institute, 2014.
[27] MoFA, Agriculture in Ghana: facts and figures 2016. Ministry of Food and Agriculture: Statistics, Research and Information Directorate (SRID), Ghana, 2017.
[28] B. Vanlauwe, K. Descheemaeker, K.E. Giller, J. Huising, R. Merckx, G. Nziguheba, J. Wendt, S. Zingore, Integrated soil fertility management in sub-Saharan Africa: unravelling local adaptation, Soil 1 (2015) 491–508.
[29] Roobroeck, D., van Asten, P., Jama, B., Harawa, R., Vanlauwe, B., (2015). Integrated soil fertility management: contributions of framework and practices to climate-smart agriculture. Climate-Smart Agriculture Practice Brief. Copenhagen, Denmark: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).
[30] C. Thierfelder, S. Cheesman, L. Rusinamhodzi, Benefits and challenges of crop rotations in maize-based conservation agriculture (CA) cropping systems of southern Africa, Int. J. Agric. Sustain. 11 (2012) 1–17.
[31] L.L.R. Renwick, W. Deen, L. Silva, M.E. Gilbert, T. Maxwell, T.M. Bowles, A.C. M. Gaudin, Long-term crop rotation diversification enhances maize drought resistance through soil organic matter, Environ. Res. Lett. 16 (2021) (2021) 084067.
[32] A. Williams, M.C. Hunter, M. Kammerer, D.A. Kane, N.R. Jordan, D.A. Mortensen, R.G. Smith, S. Snapp, A.S. Davis, Soil water holding capacity mitigates downside risk and volatility in US rainfed maize: time to invest in soil organic matter? PLoS. One 11 (2016) e0160974.
[33] J. Timsina, Can organic sources of nutrients increase crop yields to meet global food demand? Agronomy 8 (2018) 214, https://doi.org/10.3390/agronomy8100214.
[34] F. Mahmood, I. Khan, U. Ashraf, T. Shahzad, S. Hussain, M. Shahid, M. Abid, S. Ullah, Effects of organic and inorganic manures on maize and their residual impact on soil physico-chemical properties, J. Soil. Sci. Plant Nutr. 17 (2017) 22–32.
[35] T.A. Urmi, M.M. Rahman, M.M. Islam, M.A. Islam, N.A. Jahan, M.A.B. Mia, S. Akhter, M.H. Siddiqui, H.M. Kalaji, Integrated nutrient management for rice yield, soil fertility, and carbon sequestration, Plants 11 (2022) 138, https://doi.org/10.3390/plants11010138.
[36] N. Rayne, L. Aula, Livestock manure and the impacts on soil health: a review, Soil. Syst. 4 (2020) 64, https://doi.org/10.3390/soilsystems4040064.
[37] M. Adem, H. Azadi, V. Spalevic, M. Pietrzykowski, J. Scheffran, Impact of integrated soil fertility management practices on maize yield in Ethiopia, Soil. Tillage Res. 227 (2023) 105595.
[38] E.D. Setsoafia, W. Ma, A. Renwick, Effects of sustainable agricultural practices on farm income and food security in northern Ghana, Agric. Food Econ. 10 (2022) 9.
[39] D.S. MacCarthy, N. Adamtey, B.S. Freduah, B.Y. Fosu-Mensah, G.K. Ofosu-Budu, A. Fliessbach, Modeling the effect of soil fertility management options on maize yield stability under variable climate in a sub-humid zone in Ghana, Front. Sustain. Food Syst. 7 (2023), https://doi.org/10.3389/fsufs.2023.1132732.
[40] H. Nezomba, F. Mtambanengwe, R. Chikowo, Sequencing integrated soil fertility management options for sustainable crop intensification by different categories of smallholder farmers in Zimbabwe, Exp. Agric. 51 (2015) 17–41.
[41] M. Kassie, H. Teklewold, M. Jaleta, P. Marenya, O. Erenstein, Understanding the adoption of a portfolio of sustainable intensification practices in eastern and southern Africa, Land. Use Policy 42 (2015) 400–411.
[42] M. Kwadzo, E. Quayson, Factors influencing adoption of integrated soil fertility management technologies by smallholder farmers in Ghana, Heliyon. 7 (2021) e07589.
[43] H. Teklewold, M. Kassie, B. Shiferaw, Adoption of multiple sustainable agricultural practices in rural Ethiopia, J. Agric. Econ. 64 (2013) 597–623.
[44] D.K. Bastia, S.K. Behera, M.R. Panda, Impacts of soil fertility management on productivity and economics of rice and food intercropping systems under rainfed conditions in Odisha, India, J. Integr. Agric. 20 (2021) 3114–3126.
[45] E. Donkor, S. Onakuse, J. Bogue, I. de los Rios, Fertiliser adoption and sustainable rural livelihood improvement in Nigeria, Land. Use Policy 88 (1) (2019) 1–12.
[46] E. Donkor, V. Owusu, Mineral fertilizer adoption and land productivity: implications for securing stable rice production in Northern Ghana, Land. (Basel) 8 (2019) 1–14.
[47] S.A. Bariw, S. Kudadze, W. Adzawla, Prevalence, effects and management of fall army worm in the Nkoranza South Municipality, Bono East region of Ghana, Cogent. Food Agric. 6 (2020), https://doi.org/10.1080/23311932.2020.1800239.
[48] E. Martey, P.M. Etwire, T. Wossen, A. Menkir, T. Abdoulaye, Impact assessment of Striga resistant maize varieties and fertilizer use in Ghana: a panel analysis, Food Energy Secur. 12 (2022) e432, https://doi.org/10.1002/fes3.432.
[49] E.O. Acheampong, J. Sayer, C.J. Macgregor, S. Sloan, Factors influencing the adoption of agricultural practices in Ghana's Forest-Fringe Communities, Land. (Basel) 10 (2021) 266, https://doi.org/10.3390/land10030266.
[50] B. Amfo, E.B. Ali, Beyond adoption: the interaction between organic and inorganic fertilizer application, and vegetable productivity in Ghana, Renew. Agric. Food Syst. 36 (2021) 605–621.
[51] A.A. Olowoake, A.I. Afe, T.M. Yusuf, S.K. Subair, The effect of farmyard manure and urea on grain yield and agronomic characteristics of maize, Ghana J. Agric. Sci. 57 (2022) 83–96.
[52] GSS (2019) Ghana living standards survey (GLSS) 7. Accra.
[53] MoFA (2015), Ghana statistical service, Revised 2014 Annual GDP Bulletin (June 2015).
[54] World Bank (2017). Transforming agriculture for economic growth, job creation and food security. Ghana: Agriculture Sector Policy Note.
[55] N. Houssou, S. Kolavalli, J. Silver, Agricultural intensification, Technology adoption, and Institutions in Ghana, IFPRI, Washington DC, 2016, 2016.
[56] MoFA (2022). Programmes. Available online: https://mofa.gov.gh/site/programmes.
[57] MoFA (2019). Agriculture in Ghana: facts and figures (2018). Statistics, Research and Information Directorate (SRID), Ministry of Food and Agriculture (MoFA), Accra.
[58] C. Tinonin, C. Azzarri, B. Haile, M. Comanescu, C. Roberts, S. Signorelli, Africa RISING Baseline Evaluation Survey (ARBES) Report For Ghana, International Institute of Tropical Agriculture/International Food Policy Research Institute, 2016.
[59] M.G. Khonje, J. Manda, P. Mkandawire, A.H. Tufa, A.D. Alene, Adoption and welfare impacts of multiple agricultural technologies: evidence from eastern Zambia, Agric. Econ. 49 (2018) 599–609.
[60] P.P. Marenya, G. Gebremariam, M. Jaleta, D.B. Rahut, Sustainable intensification among smallholder maize farmers in Ethiopia: adoption and impacts under rainfall and unobserved heterogeneity, Food Policy 95 (2020) 101941.
[61] G. Cerulli, Econometric Evaluation of Socioeconomic Programs, 1 ed, Springer, 2015. Vol. 49.
[62] S.L. Morgan, C. Winship, Counterfactuals and Causal Inference, 7 ed, Cambridge Press, 2010.
[63] J.A. Tambo, J. Mockshell, Differential impacts of conservation agriculture technology options on household income in sub-Saharan Africa, Ecol. Econ. 151 (2018) 95–105.
[64] F. Bourguignon, M. Fournier, M. Gurgand, Selection bias corrections based on the multinomial logit model: Monte Carlo comparisons, J. Econ. Surv. 21 (2007) 174–205.
[65] G. Issahaku, A. Abdulai, Household welfare implications of sustainable land management practices among smallholder farmers in Ghana, Land. Use Policy 94 (2020), https://doi.org/10.1016/j.landusepol.2020.104502.
[66] M.D. Cattaneo, Efficient semiparametric estimation of multivalued treatments effects under ignorability, J. Econom. 155 (2010) 138–154.
[67] D. Hörner, M. Wollni, Integrated soil fertility management and household welfare in Ethiopia, Food Policy 100 (2021) 102022.
[68] J.M. Wooldridge, Econometric Analysis of Cross Section and Panel Data, 2nd Ed, MIT Press, Cambridge, MA, 2010.
[69] Runge-Metzger, A., Diehl, L. (1993). Farm household systems in northern Ghana. A case study in farming systems oriented research for the development of improved crop production systems, Nyankpala Agricultural Research Report No. 9.
[70] D. Hörner, M. Wollni, Does integrated soil fertility management increase returns to land and labor? Plot-level evidence from Ethiopia, Agric. Econ. 53 (2021) 337–355.
[71] P. Wainaina, S. Tongruksawattana, M. Qaim, Synergies between different types of agricultural technologies in the Kenyan small farm sector, J. Dev. Stud. 54 (2017) 1974–1990.
[72] E. Martey, A. Wiredu, P. Etwire, M. Fosu, S.S. Buah, J. Bidzakin, B. Ahiabor, F. Kusi, Fertilizer adoption and use intensity among smallholder farmers in Northern Ghana: a case study of the AGRA soil health project, Sustain. Agric. Res. 3 (2014) 24–36.
[73] D.B. Lobell, K.G. Cassman, C.B. Field, Crop yield gaps: their importance, magnitudes, and causes, Annu Rev. Environ. Resour. 34 (2009) 179–204.
[74] M. Ghirotti, Rapid appraisal: benefiting from the experiences and perspectives of livestock breeders, World Anim. Rev. 77 (1993) 26–37.