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Predictors of integrated soil fertility management practice among cocoa farmers in Ghana

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ABSTRACT

This study defines and estimates the proportion of organic and inorganic crop-land husbandry practices in the composite of Integrated Soil Fertility Management (ISFM) by cocoa farmers in Ghana using their socioeconomic and ecological attributes. A binary logistic regression was used to determine how these factors predict the proportion of organic materials in the composite. The results showed that only 13% of farmers use pure organic-based ISFM while 87% use different combinations of organic-based and inorganic ISFM. The estimates revealed that frequency of access to ISFM information and awareness, level of education and age of farmers below 30 years significantly influenced various degrees of organic-based ISFM. Among the significant ecological predictors were locations of cocoa agroforests, and intercropping cocoa with food crops and other tree crops at establishment phase (0–5 years) of cocoa plantations. These results imply that during the establishment phase, farmers are more likely to use low (<50%) organic-based ISFM. In contrast, farmers who manage matured monocrop cocoa plantations (21–30 years) are more likely to utilize high (≥50%) organic-based ISFM. The use of high organic-based ISFM by farmers can be improved by increasing their access to ISFM information, education and awareness.

1. Introduction

Managing soil fertility to attain acceptable crop yields without adverse effects on the environment is a global challenge to agricultural land-use systems [1,2]. The efficiency of cocoa (*Theobroma cacao* L) soil management in Ghana is still among the lowest in cocoa-producing countries [3,4]. In the last 15 years, average cocoa productivity has remained low, 234–400 kg ha^{-1} compared to an attainable yield of 2500 kg ha^{-1} [4]. The key crop growth limiting factors are low soil moisture, low soil organic matter and deficiencies in soil phosphorus (P), potassium (K) and magnesium (Mg) [3,5]. Current soil management practices have failed to curtail the declining soil nutrients that drive farmers to clear more forests to produce cocoa [4,6].

One solution to low soil fertility is the use of integrated soil fertility management (ISFM). The ISFM is an agricultural crop-land husbandry practice designed to fit specific local socioeconomic and natural ecological conditions to optimize the efficiency of nutrient and water use by crops, and yield improvement [7,8]. It has been shown that ISFM can significantly improve soil fertility and increase yield in sub-Saharan Africa [8,9], by improving soil fertility and resilience to crop pests and diseases. The combined application of organic and inorganic soil amendments on selected cocoa agroforestry in the Ashanti Region of Ghana, resulted in significant increase in cocoa yields as shown by Afrifa et al., [3]. Uptake of efficacious and improved soil conservation and crop production technologies through ISFM [10] is usually hampered by socioeconomic, ecological and technical limitations of cocoa farmers [11–13]. While the adoption of ISFM is expected to reduce expansionary agriculture, deforestation and adverse climate change effects [6], there is a paucity of scientific information about the practice among farmers in sub-Saharan Africa [7,8] and on how socioeconomic and ecological factors influence farmer's decision to practice improved technologies [11,13]. The absence of this information compounds intervention efforts to promote improved farming technologies to address the diminishing soil fertility which causes low cocoa productivity [3,4] and extensive agriculture and forest land loss [2,14]. The removal of soil nutrients through harvesting of cocoa pods is unavoidable but it is important to

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balance the net removal by replacing the quantity lost [3]. A deficiency in these soil nutrients limits growth, flowering and fruiting thereby reducing cocoa yield.

Previous studies defined ISFM as a crop-land husbandry that embraces soil nutrients, water, crop variety and vegetation management to suit a specific cropping and farming system [7,15]. It embraces the principles of agro-ecology encompassing soil amendment practices such as composting, poultry and farmyard manure, mulching, crop rotation, intercropping, cover cropping and bush fallowing. The practice optimizes the soil physical, chemical, biological and hydrological conditions [7,15] to enhance crop productivity while minimizing land degradation and deterioration of the ecology.

Agricultural soil, as a component of plant ecology is a natural body of the loose earth's surface materials in which plants through their roots find nourishment and anchorage [15]. Soil fertility is the ability of soils to provide conditions that favor root growth and supply sufficient water and nutrients for crops to grow well. Fertile soils are rich in plant nutrients and humus. Soil fertility is dependent on the organic matter content and chemical substances (NPK), water, air and activities of microbial organisms [16,17]. Anthropogenic activities of farmers can alter these substances to support plant growth or otherwise [15].

The use of organic fertilizers or manure is good for improving the physio-chemical conditions of soils, their microbial activities and crop nutrient uptake [15,18]. Farm soil organisms are stimulated to improve soil structure and cause the release of extra nutrients through their activities [19].

In Ghana, the common organic-based materials used by cocoa farmers include poultry manure (droppings), cocoa pod husks, compost and farmyard manure. Approximately 1800 kg of poultry manure and 370 kg of cocoa pod husks are required per hectare per year [3]. Farmyard manure is a mixture of dung, urine and litter from livestock pens [15]. Compost is a decomposed organic material prepared from materials such as rotting crop residues, manure, cocoa pod husk, ashes, lime, straw and kitchen wastes. These materials are rich in soil nutrients. Research shows that cocoa pod husk alone comprised 2.20% potassium [3].

Cocoa farms are agroforestry systems. Traditionally cocoa farming incorporates multiple strata of forest trees and crops including plantain, cassava, cocoyam and oil palm [2]. This integration has both economic and ecological benefits [20]. Intercropping refers to the practice of growing two or more crops on the same land. Intercrops provide shade for young (<5 years) cocoa plants [21]. In mature cocoa, the practice is enhanced by grooming forest trees that have different growth patterns such that available air, water and nutrients can be better utilized [22]. In young farms, intercrops grown in rotation generate quality C:N ratio residues which aid mineralization of N [21]. Leguminous intercrops such as cowpea and *Mucuna pruriens* fix extra N and rotating deep feeders with surface or shallow feeders make extra plant nutrients deep below the soil available [23].

Mulching, cover cropping, erosion control, agroforestry, afforestation and bush fallowing lead to conservation and restoration of soil productivity [24]. When soils are bare, water runoff from tropical rains can wash away large amounts of the top soil, causing a loss of soil fertility [20]. Cocoa farmers can control soil erosion using erosion barriers such as installing bamboo straps, mulching, sandbags and planting of cover crops and trees in or near predisposed farmlands and river banks. Bush fallow is the practice of leaving farmlands uncultivated for a long period (5–10 years) to regain its soil fertility naturally and to interrupt pest life cycles. With the increasing human population, the fallow periods in West Africa are too short to be effective [2]. When animals such as fowls, ducks, goats and sheep are incorporated in cocoa agroforestry, their excreta and urine enrich the soil.

Nutrients can be directly added to soils through the application of granular or liquid chemical fertilizers. Popular granular cocoa fertilizers in Ghana are asaasewura (0:22:18 NKP + CaCO+7 S +6MgO), cocoafeed (0:30:20 NPK) and cocoamaster [3,5]. Sidlco and cocoasett are common liquid (foliar) fertilizers in Ghana. According to Afrifa et al. [3] liquid fertilizers are the quickest means of nutrient uptake and are most suitable for young cocoa and cocoa seedlings.

However, the application of chemical fertilizers alone is not adequate for retaining sufficient level of soil fertility [3,18]. If the organic matter in the soil decreases, crop-land productivity will fall, even if a large amount of fertilizer is applied. The absence of organic matter in the soil causes breakup of the soil structure thereby decreasing the capacity of the soil to retain nutrients and water, and subsequently results in an increase in soil acidity. Therefore, it is preferable to use an integrated approach that combines the application of chemical fertilizers and organic manure [7,8,17].

The most relevant principle of ISFM is the combined application of improved planting materials, organic manure and inorganic fertilizers [8,16,17] as illustrated in Fig. 1. The combined application of chemical fertilizers and organic manure has been found to yield more benefits than the application of mineral fertilizer or organic manure individually because; there are extra nutrients or trace elements in organic manure, compost and crop residues [5,8].

Secondly, the moisture within organic manure makes the mineral nutrient in fertilizers to be more available thirdly, activities of soil organisms that improve porosity, water and nutrient retention capacity of soils are increased due to the organic material and lastly, there is gradual and uniform supply of available nutrients because the fast release of nutrients from the inorganic fertilizers is augmented with a more gradual release of nutrients from the organic materials throughout the entire cropping season [8,16].

Agricultural extension officers, economists, and social and soil scientists have been studying the socioeconomic and ecological factors that influence the adoption of farming technologies. Much of this literature employs Tobit, Probit, Logit or Logistic models to assess the uptake of improved technology as a discrete choice model of farmer decision-making behavior [10,25] to examine the adoption of cropping systems in Africa.

The resulting literature shows that diverse socioeconomic and ecological factors affect the use of efficacious innovations [12,13]. For example, Baah et al. [12] and Gwandu et al. [10] found that farmer knowledge and awareness of chemical fertilizers, farm size, and access to information and extension agents are significant factors influencing the adoption of improved technology. According to Doe [13] and Wiredu et al. [25], secondary sources of household income, young farmers, access to credit and extension services enhanced the adoption of cocoa technology. Other factors such as education, household assets and cocoa yield have characterized the adoption of various cocoa technologies [12,13,26]. However, scientific evidence about the components of ISFM practiced by Ghanaian cocoa farmers and how the practice is impacted by their socioeconomic and plantation attributes is rare. The authors of this study seek to fill the literature gap on cocoa ISFM to modify or confirm the existing literature based on the findings in this study.

The findings of this study provide information to help promote the use of ISFM to improve cocoa soil fertility, physio-ecology of the plant and its ecological services. This study examines the practice of ISFM in cocoa agroforestry systems to understand the factors predicting the use of the technique among cocoa farmers in Ghana. This study further seeks to provide scientific evidence to explain how cocoa farmers practice ISFM and the factors influencing or barricading the practice in Ghana. Specifically, this study attempts to determine the proportions of

Fig. 1. Showing cocoa agroforestry and some of the organic and inorganic materials that are potentially used for soil fertility management in Ghana. Note: b = improved germplasm cocoa seedlings; c = empty bunches from oil palm; d = granular chemical fertilizers; e = biochar; f = cocoa pod husk and potash produced from same.

inorganic and organic-based crop-land husbandry practices in the ISFM composite by farmers and how these proportions are influenced by their socioeconomic conditions and the ecological attributes of their cocoa plantations.

1.1. Materials and methods

1.1.1. Study area

Farmers in 17 cocoa farming communities were selected for the study and interviewed (Fig. 2). The cocoa farm locations are within the humid tropical agro-ecological zones with evidence of high cocoa production potential and high concentration of smallholder farmers. The suitable cocoa climate decreases from the wet evergreen (WE) to the dry semi deciduous fire zone (DSFZ) and dry semi deciduous inner zone (DSIZ) agro-ecologies (Fig. 2) [6,27].

1.2. Study design

This study was designed as a quantitative cross-sectional survey of 500 household heads of cocoa farms. The use of two multi-stage stratified random samplings ensured that representative farm households were selected to represent households and plantations in the study community. The communities were randomly selected and simple random sampling was used to select household heads per community.

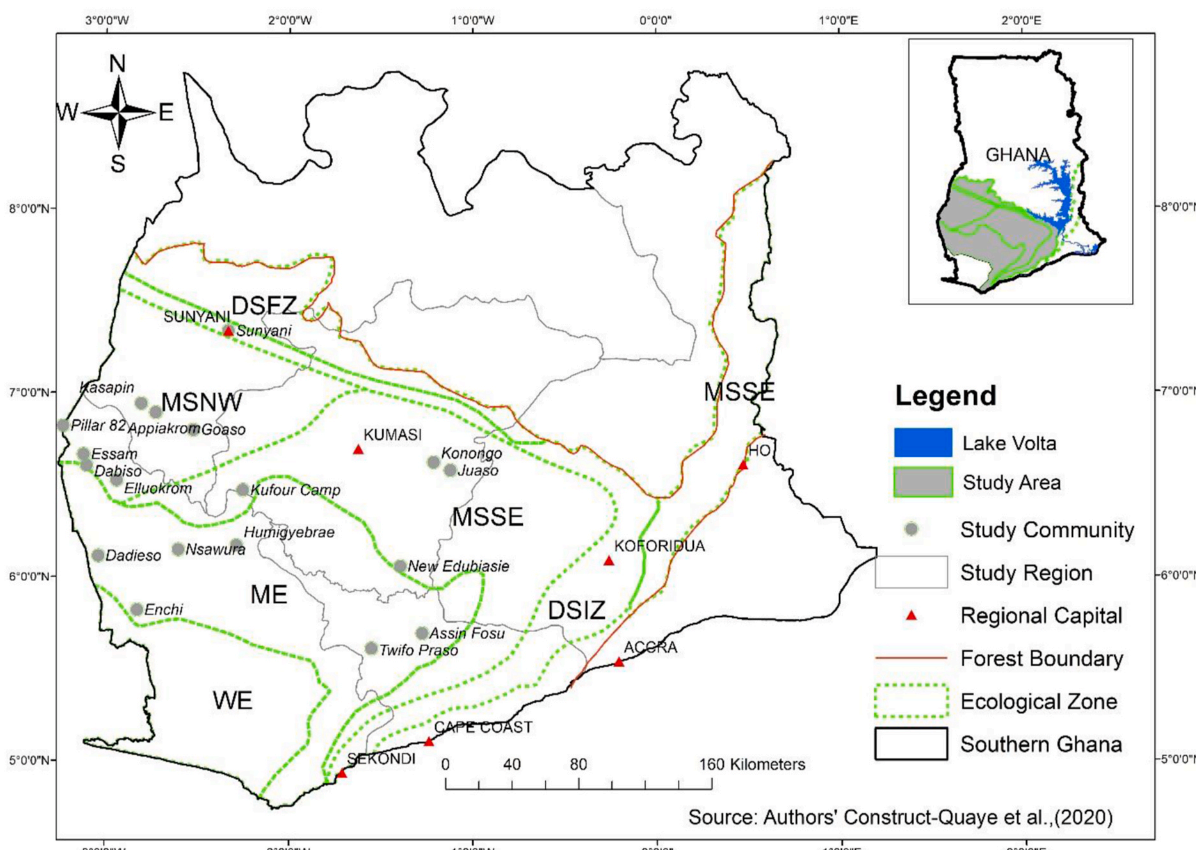

Fig. 2. Map of the study area showing community and cocoa plantation locations in the Agro-ecological zones. Note: DSFZ = Dry Semi-Deciduous Fire Zone; DSIZ = Dry Semi-Deciduous Inner Zone; WE= Wet Evergreen forest zone; ME = Moist Evergreen forest zone; MSNW = Moist Semi-Deciduous North West forest zone; MSSE = Moist Semi-Deciduous Southeast forest zone.

Data collection was done through the use of a semi-structured questionnaire. The questionnaire was pre-tested using 50 cocoa farmers at Duayaw Nkwanta in the Brong Ahafo region before it was finally administered to the targeted respondents by trained technical field assistants.

1.3. Theoretical framework

Periodic changes in the socioeconomic, environmental, and technological mechanisms of the cocoa industry require farmers to change their management practices. The success of farmers in improving their cocoa farm productivity is thus dependent on their ability to change or take advantage of new technologies such as ISFM. A risk-averse farmer, who encounters low yield due to poor soil fertility, ageing stands or erratic rainfall, will choose a mix of ISFM technology to address the situation [9].

The maximum utility for the decision to utilize ISFM can be specified using a function. The choice of a farmer to use ISFM is directly linked to certain characteristics ($X_{ij=x}$) which include a combination of organic matter (*oM*), inorganic fertilizers (*iF*), intercrops (*Ic*) and other features (x) of themselves and their cocoa plantations. The socio-economic (x_{1i}) characteristics examined in this study are the gender of the farmers, their main income sources and age. Others include ISFM knowledge and access, formal education and farm ownership. The set of ecological factors (x_{2i}) examined included the location of their farms, farm size (acres), intercrop systems, age of the cocoa plantation and yield from previous years.

1.4. Model specification

The choice of farmers to use ISFM (Y_{ij}), consisting of *oM*, *iF Ic*, and X_{ij}, was modeled using the production function (Y_{ij}) in equation (1).

$$Y_{ij} = Y_{ij}\left[sN(oM, iF), Ic, X_{ij}, \varepsilon\right] \tag{1}$$

Where *sN* is soil nutrients derived from the use of *oM* and iF, *Ic* denotes crop resilience to climate variability derived from the intercropping system. The ε is an error term that denotes the risk and uncertainty of utilizing the technology. This model of farmers' decision to use a mix of ISFM was estimated using two binary logistic regressions. Scientists, natural resource managers and economists have historically used logistic regressions to examine the potential variables influencing choices [28].

In this study, the choice of ISFM practiced was classified into two binary variables, namely High (1,0) and Low (1,0) organic inputs in the composite of the ISFM package (Fig. 2). In the first model, 1 denotes farmers who use High (≥50%) organic inputs (High-ISFM) and 0 denotes farmers who use less than 50% organic inputs. In the second model, 1 denotes farmers who use low (<50%) organic-based materials (Low-ISFM) and 0 denotes farmers who use greater (≥50%) organic materials. The parameters in each model were selected using the best-possible set of explanatory variables [28].

The regressions explore the potential socioeconomic (x_{1i}) and ecological (x_{2i}) predictors (x_{ij}) on the probability of using one of the ISFM technologies.

The mathematical theory underlying the use of binary logistic regression is the natural log of the odds ratio (OR), which is expressed in equation (2) [28].

$$log(Y_i) = ln\frac{p}{1-p} = \beta_0 + \beta_i x_i + \varepsilon\ , \tag{2}$$

where ε = stochastic error term, and β_j are coefficients of x_i and $Y_i$represents the choice of a coca farmer to use one of the ISFM technologies. The antilog of equation (2) gives equation (3)

$$Y_i = \frac{e^{\beta_0+\beta_i x_i+\varepsilon}}{1-e^{\beta_0+\beta_i x_i+\varepsilon}}\ , \tag{3}$$

where $e = 2.7182$, β_i determines the probability and direction (±) of the explanatory (predictor) variables (x_i) in relation to the dependent variable (Y_i). The estimation of β_i is possible through the Maximum Likelihood Estimation (MLE) procedure. The MLE chooses estimates of β_i such that, when applied to a set of data (Y_i, x_i), it yields the largest possible value of the probability of the observed data. In addition, for a given set of Y_i that exceeds a certain critical threshold (*), the log-likelihood function $L = \sum_i Y_i \log(x_i)$ assumes $Y_i = 1$ if a farmer chooses to adopt the ISFM and $Y_i = 0$ if the farmer chooses otherwise.

1.5. Measurement of socioeconomic variables

The observed socioeconomic (x_{1i}) variables are explained in this study. The gender of the farmer is measured as a dummy variable for males or females (1, 0). The main income sources of the farmers were measured as individual dummies denoting cocoa farming (1, 0), farming and trading (1, 0) and off-farm businesses (1, 0). Mean age was calculated from the observed age of the farmers. The age groups were dummies denoting age 15–29 (1, 0), age 30–45 (1, 0), age 46–60 (1, 0) and age 61–90 (1,0). The formal educational status of a farmer was also dummied; none (1,0), basic (1,0), junior secondary (1,0), senior secondary (1,0) and tertiary education (1,0). The level of farmer awareness of ISFM was measured using the sum of points obtained from a set of ISFM awareness questions. The frequency of farmer access to ISFM related information is the number of times a farmer assesses such information in a year. Lastly, farm ownership was also measured as binary variables include owner (1, 0), caretaker (1, 0) and sharecropper (1, 0). One level of each factor variable was dropped to avoid dummy variable trap.

1.6. Measurement of ecological variables

The observed ecological variables (x_{2i}) are the regional location of cocoa farms, farm size in acres, intercrop systems measured as dummies, age of cocoa plantation in years and yield (total number of 64 kg bags) from previous years. As in Peng et al. [28], an exploratory stepwise best fit selection procedure enabled the selection of the best variables.

2. Results

2.1. The practice of ISFM

Elements of ISFM practices that were observed according to farmers' responses were categorized as organic based and inorganic based (Fig. 3). The frequency of response to inorganic based elements ranged from 47% to 92%. The common inorganic fertilizers used by farmers were liquid fertilizers such as sidalco (91%) and granular fertilizers such as asaasewura (91%), cocoafeed (87%) and cocoa master (71%).

The frequency of farmers' responses to organic inputs varied from 7% to 48%. The main organic inputs observed from farmers' responses were poultry manure (48%), compost (40%), bush fallowing (22%), agroforestry (17%) and afforestation (12%). Others such as mulching (16%), crop rotation (17%), minimum tillage (10%) and cover cropping (7%) were seldom used (Fig. 3).

Table 1 show that the majority (76.6%) of farmers practiced Low-organic-based ISFM which comprised 100%–50% inorganic fertilizers (Low-ISFM). On the other hand, 23.4% of the farmers use High organic-based ISFM involving 60%–100% organic soil fertility amendment practices (High-ISFM).

Farmers have engaged in different cropping systems over the past two years. As shown in Table 2, about 49% of them practiced either cocoa forest tree intercrops (42.6%, n = 228) or cocoa mono-crop

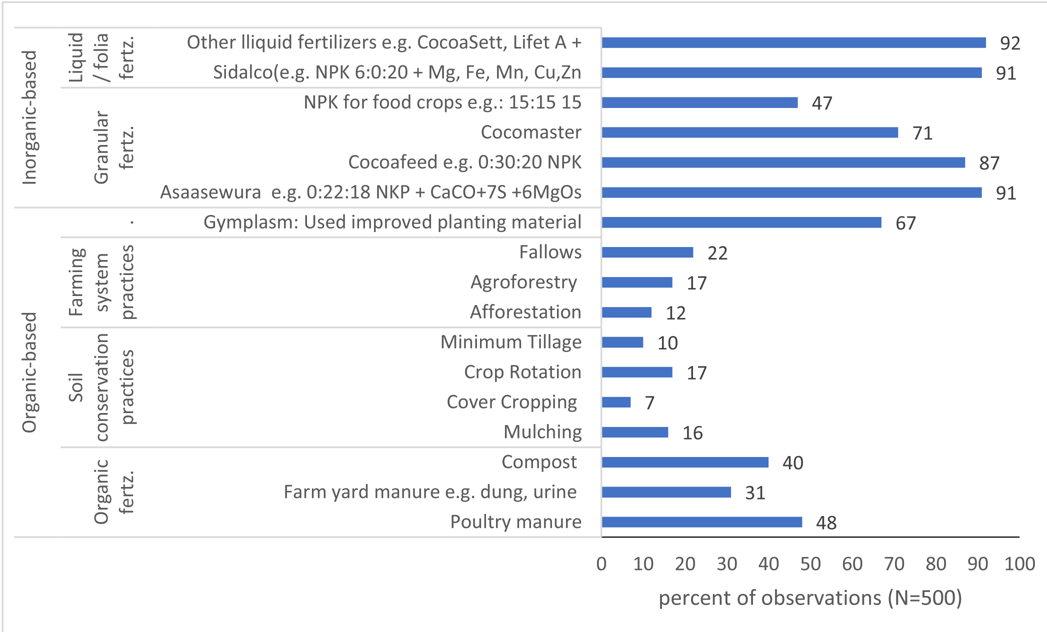

Fig. 3. Components of integrated soil fertility management practices by cocoa farmers in Ghana.

Table 1
Proportion of organic and inorganic crop-land husbandry practices as ISFM among cocoa.

Type of ISFM	Percent of organic and inorganic ISFM		Distribution of farmers	
	Inorganic material (%)	Organic material (%)	Frequency	Percent
Low-ISFM	100	0.0	65	13.1
	70	30	144	28.9
	50	50	172	34.5
High-ISFM	40	60	62	12.5
	30	70	47	9.4
	25	75	2	0.4
	20	80	1	0.2
	0	100	5	1
Total	Max = 100	Max = 100	498	100

Table 2
Cropping systems and soil fertility management practiced by farmers in the study area.

Crops grown by the respondents	Cropping system frequency			Percent of farmers practicing ISFM in the past 2 years		
	Intercrops	Mono-crop	Total	% Yes	% No	Total %
Cocoa (hybrid/ local)	228	17	245	42.6	6.4	49.0
Cocoa + food crops	167	25	192	29.4	9.0	38.4
Cocoa + other tree crops	17	4	21	3.4	0.8	4.2
Cocoa + food + other tree crops	2	0	2	0.4	0.0	0.4
Food crops only	38	2	40	7.8	0.2	8.0
Total (%)	452	48	500	83.6	16.4	100
Total (N)				418	82	500

agroforestry (6.4%, n = 17). About 38% were engaged in cocoa food crop intercrop systems of maize, cocoyam, plantain and cassava.

2.2. Predictors of integrated soil fertility management practices

The significant predictors of the High-ISFM and Low-ISFM are shown by the binary logistic regression estimates in Table 3. The high log-likelihood ratio Chi-square values, 98.7 ($p < 0.001$, df = 22) and 127.3 ($p < 0.001$, df = 21) were significant at 1%, indicating a good fit of the High-ISFM and Low-ISFM models respectively. The predictive accuracy from cross-classifications of the dependent variables and the predicted values were 78.7% and 79.3% respectively, indicating that the models were correctly classified.

The estimated odds ratios (ORs) showed that among young farmers, the frequency of access to information and ISFM awareness significantly influenced Low-ISFM. Young farmers (<30 years) were 3.863 times ($p < 0.05$, ±2.6) more likely to adopt Low-ISFM than older farmers. Similarly, the frequency of access to ISFM information (10 out of 27) is likely to influence the use of Low-ISFM 9.595 times ($p < 0.001$, ±0.04).

The estimates showed that higher levels of ISFM awareness were positively associated with the adoption of high-ISFM. Farmers who scored 7.8 out of 11 ISFM awareness test were 1.5 times (OR = 1.5, $p < 0.001$, ±0.09) more likely to practice High-ISFM than those who scored lesser points. Farmers' level of education influences the degree to which they would adopt and use organic inputs in their cocoa farms. This was demonstrated by the fact that those farmers who have attained the basic level of education up to junior and middle school (58.7%) which were significant (OR: 1.7, $p < 0.05$, ±0.4).

Among the significant ecological predictors of ISFM practices were farm location, age of plantations (<5 years) and intercropping systems. High-ISFM was significantly influenced by farmers in the Western Region (47%, OR = 2.9 ± 1.4, $p < 0.05$), Ashanti Region (17.8%, OR = 4.0 ± 2.2 = , $p < 0.01$) and Brong Ahafo Region (10.3%, OR = 3.3 ± 1.9, $p < 0.05$). Cocoa farms in the Central Region (12%, OR = 4.8 ± 3.108, $p < 0.05$) were associated with Low-ISFM. Furthermore, High-ISFM was positively influenced (OR = 2.0 ± 0.6, $p < 0.05$) by cocoa monocropping (49.6%). On the other hand, food (plantain-cassava-cocoyam-maize) intercrops (7.6%) had high influence (OR = 9.4 ± 5.7,

Table 3
Binary logistic regression estimates of predictors of the extent of ISFM used among cocoa farmers in Ghana.

Explanatory variables	Description/measurement	Overall		High-organic ISFM (23%) 23.4%)			Low-organic ISFM (77%)		
		mean	SD	Users[†]	OR	RSE [‡]	Users[†]	OR	RSE [‡]
Socioeconomic ecological factors (x_{1i})									
Sex	Female farmers (1 = female, 0 = male)	0.192	0.394	13.7%	0.811	0.285	20.9%	1.484	0.437
Main income sources [a]	Cocoa farming (1 = yes, 0 = no)	0.176	0.381	16.2%	1.294	0.494	18.0%	0.779	0.365
	Farming and trading (1 = yes, 0 = no)	0.064	0.245	4.3%	0.601	0.454	7.0%	1.827	1.062
Age	Age farmer in years (mean)	48.93	11.589	49.7	1.006	0.026	48.7	1.018	0.017
Age group of farmers	15-29 years (1 = yes, 0 = no)	0.040	0.197	5.1%	0.765	0.901	3.7%	3.863**	2.571
	30-45 years (1 = yes, 0 = no)	0.355	0.479	30.8%	0.882	0.724	37.0%	excluded	
	46 to 60 years (1 = yes, 0 = no)	0.460	0.499	47.9%	1.097	0.565	45.4%	excluded	
	61 to 90 years (1 = yes, 0 = no)	0.145	0.352	16.2%	excluded		13.9%		0.747
Information access	Number of ISFM information accessed/year (mean)	9.946	6.602	11.1	excluded		9.6		1.107
Awareness level	ISFM awareness scorecard (out of 11 points)	5.528	3.059	7.8	1.532***	0.086	4.8	0.510***	0.040
Education level [b]	None (1 = yes, 0 = no)	0.262	0.440	30.8%	2.134	1.045	24.8%	excluded	
	Basic/primary (1 = yes, 0 = no)	0.050	0.218	6.0%	1.756	1.311	4.7%	excluded	
	Middle/Junior high school (1 = yes, 0 = no)	0.560	0.497	47.9%	1.127	0.511	58.5%	1.703**	0.404
	Above Senior high school (1 = yes, 0 = no)	0.040	0.196	8.5%	4.837**	3.375	2.6%	excluded	
Farmland ownership [c]	Owner (1 = yes, 0 = no)	0.752	0.432	73.5%	0.606	0.443	75.7%	0.803	0.248
	Caretaker (1 = yes, 0 = no)	0.186	0.389	20.5%	0.566	0.44	18.0%	excluded	
	Share cropper (1 = yes, 0 = no)	0.038	0.191	2.6%	0.306	0.306	4.2%	0.801	0.424
biophysical ecological factors (x_{2i})									
Cocoa farm location	Western Region (1 = yes, 0 = no)	0.498	0.500	47.0%	2.948**	1.394	50.7%	0.657	0.275
	Ashanti Region (1 = yes, 0 = no)	0.200	0.400	17.9%	4.043***	2.152	20.6%	1.659	0.702
	Brong Ahafo Region (1 = yes, 0 = no)	0.152	0.359	10.3%	3.279**	1.889	16.7%	excluded	
	Central Region (1 = yes, 0 = no)	0.150	0.357	24.8%	excluded		12.0%	4.779**	3.108
Farm size	Cocoa farm size in acres (mean)	11.45	12.958	14.7	1.006	0.016	0.989		0.014
Intercrops	Cocoa monocrop (1 = yes, 0 = no)	0.490	0.500	49.6%	1.979**	0.640		excluded	
	Cocoa + food crops (1 = yes, 0 = no)	0.384	0.487	33.3%	excluded		39.9%	1.208	0.396
	Cocoa + oil palm + citrus (1 = yes, 0 = no)	0.042	0.201	6.8%	excluded		3.4%	4.529**	3.091
	Plantain, cassava, cocoyam, maize (1 = yes, 0 = no)			9.4%	excluded		7.6%	9.382***	5.742
Plantation age group [d,e]	1-4 years (1 = yes, 0 = no)	0.032	0.176	2.6%	excluded		3.4%	3.971*	3.132
	21-30 years (1 = yes, 0 = no)	0.218	0.413	16.2%	0.575*	0.184		excluded	
Yield1	Number of 64.5 kg cocoa bags harvested/ year	28.092	38.428	38.9	1.005	0.005	1.004		0.004
Intercept						0.004		1.72	1.637
Number of observations		500		117	498		383	498	
Pseudo Log-likelihood (deviance test)					-213.100			-236.384	
Log-likelihood ratio Wald χ^2 (df)					98.68*** (22)			127.34*** (21)	
Pseudo R^2/Predictive accuracy correctly classified					0.215/ 78.7%**			0.301/ 79.3%**	

[†] Note: All % are based on the frequency of users of high and low organic-based ISFM and dummy variables, where 1=yes and 0=no (reference).
*** = significant at 1%.
** = significant at 5%.
*= significant at 10%.
‡ RSE = robust standard errors of the estimated regression coefficients.
[a] Excluded category = Other main income sources (1=yes, 0=no).
[b] Excluded category = Senior high school (1=yes, 0=no).
[c] Excluded category = Other types of land tenure (1=yes, 0=no).
[d] Excluded category = 5-10 years (1=yes, 0=no).
[e] Excluded category = 11-20 years (1=yes, 0= no).

$p < 0.01$) on Low-ISFM. Low-ISFM was also positively predicted (OR = 4.5 ± 3.1, $p < 0.05$) by a few (3.4%) cocoa farmers who practiced cocoa-oil palm-citrus intercropping. Other intercropping systems like cocoa-food intercrops and cocoa-tree-food intercrops were not significant. Young (<5 years) cocoa plantations predicted (OR = 4.0, $p < 0.10$, ±3.1) Low-ISFM while old (21–30 years) plantations were associated with High-ISFM (OR = 0.6, $p < 0.10$, ±0.18).

2.3. Discussion

The practice of ISFM among cocoa farmers in Ghana was largely (76.5%) inorganic-based. Only one quarter (23.5%) is organic-based. There were more (87–92%) farmers using various inorganic-based than organic-based ISFM practices (7%–48%). Although previous studies have showed that use of organic (poultry/farmyard) manure, compost, cover crops and intercrops can improve soil organic matter content and soil fertility [3,9,24] the results of this study revealed that few farmers use high organic-based ISFM practices. This finding is consistent with Lambrecht et al. [29] who reported the same result in DR Congo. The observed seldom use of organic-based ISFM practices raises the probable risk of limited soil organic matter build up in cocoa farms. With declining cocoa soil fertility [2,3,30], more organic soil amendment practices are required to improve soil fertility, soil structure, water content and microbial activities [9,17]. However, the results of this study showed that the adoption of High-ISFM was less common among cocoa farmers. This situation was not different from the previous studies [29].

Several socioeconomic, ecological and technological challenges were known to limit farmers' ability to take up efficacious farming technologies [3,3,4,26]. Inadequate availability and barriers to accessing the required quantities of poultry manure and farmyard manure were challenges to adopting improved farming technologies [12,13]. Other challenges include the laborious nature of composting and scarcity of land for bush fallowing [2].

The second part of this study sought to explain how socioeconomic and ecological factors predicted or explained the proportions of High and Low organic-based ISFM practices. As revealed by the binary logistic regression estimates, factors such as age of farmers (<30 years), frequency of access to ISFM information (mean = 10 out of 27 times) and ISFM awareness (mean = 7.8 out of 11) were the main determinants of high organic-based ISFM practices. According to Wiredu et al. [25] and Asamoah et al. [26], these variables were important determinants of cocoa technology adoption. Farmers' age was a proxy to learning experience and knowledge. Older farmers tend to be more cautious about the extent of resources allocated to new technologies than younger farmers [25]. Younger farmers are more enthusiastic about investing more time and energy on new technologies [25,29,31]. Older farmers are weak and need to depend on external farm labour, thus hamper their ability to adopt composting and compost use [26].

There was positive association between farmers' level of ISFM awareness and their ISFM practice. Farmers who were highly (7.8 points out of 11) aware of ISFM were more likely to practice High- ISFM than those who were not aware of it. Similarly, farmers who had lower (middle school and junior high school) education (8.5%) were associated more with Low-ISFM. Farmers who attained above senior high school education (2.6%) adopted High-ISFM. These findings corroborate previous study. The levels of farmers' educational background, awareness and frequency of access to extension information improved their level of knowledge and understanding of the importance of improved technologies [13,29,31].

In line with Doran and Zeiss [23], we found out that, ecological conditions such as intercropping systems, regional locations of cocoa farms and age of plantations (<5 years) were likely to influence the practice of ISFM by cocoa farmers in Ghana. In general, high organic-based ISFM was positively influenced by cocoa mono-cropping (1.979) while food (plantain-cassava-cocoyam-maize) intercrop system showed high predictive influence (OR = 9.382) on Low-ISFM. Likewise, Low-ISFM was positively associated (OR = 4.529) with cocoa-oil palm-citrus intercropping systems.

The use of organic-based ISFM is comparatively lower in the current cocoa production hotspot of the Western Region than in the old cocoa production zones of the Ashanti and Brong Ahafo Regions. In these regions it has also been revealed that land use and agricultural livelihood systems have done little to reduce deforestation [14,30] especially in the Central Region [32]. Low organic-based ISFM practices were common in young cocoa plantations which were intercropped with food crops or mixture of food and other tree crops. In contrast, old mono-crop cocoa plantations (21–30 years) were more likely to receive high organic-based ISFM packages. These observations corroborated the findings of previous studies that showed that such cropping systems with low organic-based ISFM practices led to mining of soil nutrients and thereby resulting in low cocoa yield [2,6].

3. Conclusion and recommendations

We have for the first time determined the determinants of the practice of ISFM and estimated its predictors among smallholder cocoa farmers in Ghana. Cocoa farmers use more inorganic than organic crop and land husbandry practices due to low awareness of the ecological benefits of ISFM. Farmer education, awareness and access to extension information are the keys to rapid adoption of ISFM. Cocoa farmers who have young plantations that were intercropped with food crops or mixture of food and other tree crops were more likely to use less (<50%) organic inputs. In contrast, farmers who managed old cocoa plantations (21–30 years) were more likely to utilize higher levels (>50%) of organic inputs. Therefore, the proportion of organic materials used in the observed ISFM can be enhanced if cocoa farmers in Ghana have frequent access to ISFM information. These findings essentially aimed at addressing the diminishing cocoa soil nutrients, conversion of forests to agriculture, adverse climate change and cocoa plant resilience to pests and diseases which caused low cocoa productivity in Ghana.

Authors' contributions

This work was successfully carried out collaboratively among all authors. AKQ designed the original study, developed the questionnaire, trained enumerators, supervised data collection and ensured data quality. Author EKD performed the statistical analysis of the data, run the regression models and wrote the first draft of the manuscript. Author FA provided socioeconomic framework for the design of the study and assisted with data management and interpretation with regards to the socioeconomic aspect. Author AA and JAD assisted in the interpretation of data with regards to soil nutrient management practices and managed the literature searches. Author SK assisted in data management and analysis. All authors read and approved the final manuscript.

Data availability

The study data will be available at the Cocoa Research Institute of Ghana, P.O. Box 8, New Tafo – Akim. Ghana or the ORICD number below:

ORICD number: https://orcid.org/0000-0002-5730-3841
ORICD number: https://orcid.org/0000-0003-3248-8533
ORICD number: https://orcid.org/0000-0003-2696-6922

Compliance with ethical standards

The authors declare that they have no conflict of interest.

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.

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