Journal of Environmental Management 320 (2022) 115810

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Perceptions of COVID-19 shocks and adoption of sustainable agricultural practices in Ghana

Edward Martey [a,*], Prince M. Etwire [a], William Adzawla [b], Williams Atakora [b], Prem S. Bindraban [b]

[a] *Socio-economics Section, CSIR-Savanna Agricultural Research Institute (CSIR-SARI), P.O. Box TL 52, Tamale, Ghana*
[b] *International Fertilizer Development Center (IFDC), Muscle Shoals, AL, 35662, USA*

ARTICLE INFO

Keywords:
COVID-19 shocks
Pandemic
Sustainable agricultural practices
Multivariate probit model
Ghana

ABSTRACT

Most studies on the novel COVID-19 pandemic have focused mainly on human health, food systems, and employment with limited studies on how farmers implement sustainable agricultural practices (SAPs) in response to the pandemic. This study examines how perceptions of COVID-19 shocks influence the adoption of SAPs among smallholder farmers in Ghana. We find that perceptions of COVID-19 shocks influence the probability and intensity of SAPs adoption. Secondly, households who anticipated COVID-19 shocks recorded heterogeneity effects in the combinations (complementarity and substitutability) of SAPs. Farmers who anticipated an increase in input prices and loss of income due to COVID-19 recorded the highest complementarity association between pesticide and zero tillage while farmers who expected limited market access reported the highest complementarity between mixed cropping and mulching. Farmers who projected a decrease in output prices complements pesticides with mixed cropping. The findings suggest that understanding the heterogeneity effects in the combinations of SAPs due to COVID-19 shocks is critical to effectively design, target and disseminate sustainable intensification programs in a post-pandemic period.

1. Introduction

The COVID-19 pandemic is a recent major health crisis that has disrupted every sector of the economy and a challenge to meeting the sustainable development goals (SDGs), especially among developing countries. Several strategies including as lock-downs, widespread shelter-in-place orders, and limited in-person contacts have been adopted globally to contain the spread of the virus (Wang et al., 2020). These restrictions have disrupted domestic and global agricultural production and value chain systems (Barrett, 2020; Elleby et al., 2020). For example, the supply-side shocks such as availability and cost of labour have impacted negatively on production costs and distribution (Sumner, 2021). The economic costs of these measures are extremely high, with several implications on food security, income, and poverty (Amare et al., 2021; Kansiime et al., 2021; Ayanlade and Radeny, 2020; Chen et al., 2022). In developing countries, the pandemic has resulted in about 115 million additional people being extremely poor (World Bank, 2020).

The impact of the COVID-19 pandemic on food systems is one of the major priorities of scholars and policy-makers (Amare et al., 2021; Arndt et al., 2020; Barrett, 2020). Several empirical studies have reported a negative effect of increased food prices on food security due to external shocks. According to Bellemare (2015), high food prices result in social unrest, nutritional deficiency, a decline in social capital, psychosocial stress, and increase in poverty (Ravallion, 2020; Headey and Fan, 2008; Hadley et al., 2012; Ferreira et al., 2013). Ruan et al. (2021) analyzed the effect of nationwide lockdown on vegetable price in China and the findings show that the lockdown and resurgence of COVID-19 led to an increase in vegetable prices. Akter (2020) finds that COVID-19 stay-at-home restrictions increase food prices (meat, fish and seafood, and vegetables) in 31 European countries. In Bangladesh, Gatto and Islam (2021) used panel data to show that COVID-19 reduces agricultural production, the share of output sold, diet diversity, and education expenditure. In Nigeria, Amare et al. (2021) find that exposure to COVID-19 and lockdowns increase food insecurity due to a significant reduction in labour market participation. Ahmed et al. (2021) revealed that households who experience negative income shock due to

---

* Corresponding author.
E-mail addresses: eddiemartey@gmail.com (E. Martey), etwiremaxwellprince@gmail.com (P.M. Etwire), wadzawla@ifdc.org (W. Adzawla), watakora@ifdc.org (W. Atakora), pbindraban@ifdc.org (P.S. Bindraban).

https://doi.org/10.1016/j.jenvman.2022.115810
Received 8 March 2022; Received in revised form 25 June 2022; Accepted 18 July 2022

COVID-19 resulted in increased food insecurity, especially among hired labourers.

Regarding the food and agricultural supply chains, the pandemic leading to restrictions in movement affected labour supply, input distribution (Kumar et al., 2021; Afridi et al., 2020; Kabir et al., 2020; Karim et al., 2020; Laborde et al., 2020), and limited access to input and output markets for both sellers and buyers (Zabir et al., 2021). According to Barrett (2020), the COVID-19 lockdown and movement restriction threaten the livelihoods of poor people due to the loss of jobs, businesses and limited access to markets. The disruption in the transportation sector due to concerns over safety and requirements for COVID-19 tests for truckers have resulted in delayed supply of food in Kenya (Roussi, 2020). Restriction and closure of informal markets in some urban and peri-urban areas disrupted the supply of fresh produce such as eggs and milk, fruits and meat especially among low-income urban households that depends on informal food markets (FAO, 2020). Labour shortages in the informal markets also impacted negatively on food processing, particularly for meat processing plants thus, leaving women in particular without access to informal markets (FAO, 2020). In terms of job and income losses, a study has shown that women were more affected than men, thus reducing their food consumption and increasing their savings (Dang and Nguyen, 2021). The lockdown measures have also disrupted the agricultural extension and advisory services by reducing farmers' access to extension services (FAO, 2020).

Despite the growing number of studies on the pandemic on national and global indicators, there is limited research on coping mechanisms or mitigation strategies due to the COVID-19 shocks. A study by Paganini et al. (2020) show that coping strategies employed by farmers due to the pandemic includes keeping vegetable gardens, reduction in spending, change of diets, and expansion of area under food cultivation. Tripathi et al. (2021) find that in Tanzania farmers operated a more localized system by trading more among themselves whiles farmers in South Africa relied on family labour to reduce cost, consume own production, reduce the quantity of crops cultivated, share labour and rent out land, and sell assets such as livestock. However, there is limited understanding of how the pandemic influence the adoption of sustainable agricultural practices (SAPs). It is important to understand how perceptions of the COVID-19 shocks influence farm-level decisions and strategies employed to mitigate the negative effects.

This study examines how perceptions of COVID-19 shocks influence farm-level decisions on adoption and combination of SAPs among smallholder farmers in Ghana. More specifically, we examine the complementarity and substitutability associations among SAPs due to farmers' experience of the disruptive effect of the pandemic on agriculture. SAPs are knowledge and labour-intensive agricultural practices that influence crop yields with subsequent effect on the environment depending on how they are combined and implemented on farmers' plot. Understanding how external shocks influence combinations of SAPs is important in guiding development practitioners on the mitigation strategies to promote, taking into consideration the environmental impact. This study makes two contributions to the agricultural intensification literature. First, the paper extends the analysis beyond probability to the intensity of SAPs adoption by considering the effects of COVID-19 shocks. We find that the intensity of SAPs adoption is significantly determined by socio-economic, demographic, production, social capital and increased input price due to the COVID-19. Second, the study contributes to the understanding of how perceptions of COVID-19 shocks influence coping strategies (choice and combinations of SAPs) employed to sustain crop yields. Our results show heterogeneity in the combinations of SAPs either as complements or substitutes depending on the type of COVID-19 shocks.

The remainder of this paper is organized as follows. Section 2 describes the data and summary statistics followed by the empirical strategy in section 3. Section 4 discusses the empirical results while section 5 provides the concluding remarks and policy recommendations.

2. Data and descriptive statistics

2.1. Study area and data

This study relies on a survey conducted in July 2020 that assessed farmers' crop yields, fertilizer use, food security, and COVID-19 shocks in Ghana's Guinea, Sudan, and Transitional[1] agroecological zones. Farmers in the Guinea and Savanna zones experience a unimodal annual average rainfall of about 1000 mm and 1100 mm, respectively lasting between May to October (Owusu, 2018) while farmers in the Transitional zone record an annual average rainfall of 1300 mm for the major season spanning from April to July (MoFA, 2017). The zone experiences a minor season which occurs between September and October and a dry spell in mid-August before the prolonged dry season between November and March. Fig. 1 shows the location of the farm households across the sampled regions of Ghana in the survey.

The study employed a multi-stage sampling technique to sample 1450 farmers in the three agroecological zones of Ghana. In the first stage, three districts were purposively selected based on their participation in the Planting for Food and Job (PFJ) program.[2] Four communities were selected in the second stage due to their engagement in crop production. These communities were selected from different geographical points in relation to the district capital to capture diversity in the district. We employ systematic random sampling to select 15 farmers in each community in the final stage. To accommodate potential attrition, we further sampled 10 extra farmers to bring the total sample to 1450. Table 1 shows the distribution of the sampled households per region.

The primary data includes the socio-economic characteristics, type and fertilizer use, sustainable agricultural practices, food expenditure, crop production and utilization, crop commercialization, food security, poverty, household assets, and perceptions of COVID-19 shocks. This study relied on the sections of the data on SAPs and perceptions of COVID-19 shocks. The main SAPs considered based on their impact on the environment (Table A1), soil and plant are no tillage, mulching, mixed cropping, pesticides, and inorganic and organic fertilizer. The perceptions of COVID-19 shocks variables are decreased output prices, increased input prices, limited access to input and output markets, and inability to maintain farm activities due to loss of income. We complemented the survey data with secondary data on monthly food inflation from January 2018 to February 2021.

2.2. Descriptive statistics

Fig. 2 shows the monthly food inflation in Ghana from January 2018 to February 2021. Ghana experienced fluctuations in the monthly food inflation over the entire period. Except for July–October 2018, Ghana experienced inflationary prices with a spike observed in April 2020. The COVID-19 pandemic partly explains the monthly food inflationary price hike in April 2020. Ghana implemented a partial lockdown in March 2020 coupled with restrictions in input and commodities transportation due to the rising number of COVID-19 cases. This resulted in a disruption in the food systems and subsequent effects on food prices.

Table 2 reports farmers' perception of COVID-19 shocks on

---

[1] The transition zone represents an area where the forest is quickly becoming wooded lands due to climatic factors such as increasing temperatures and decreasing precipitation.

[2] Planting for Food and Jobs is a flagship agricultural Campaign of the Government, with five (5) implementation modules (Food Crops (PFJ), Planting for Export and Rural Development (PERD), Greenhouse Technology Villages (3 Villages), Rearing for Food and Jobs (RFJ), and Agricultural Mechanization Services (AMSECs)). The goal of the project is to modernize the agriculture sector of the economy in order to improve food security, create employment opportunities and reduce poverty (MoFA, 2019; https://mofa.gov.gh/site/images/pdf/PFJ.pdf).

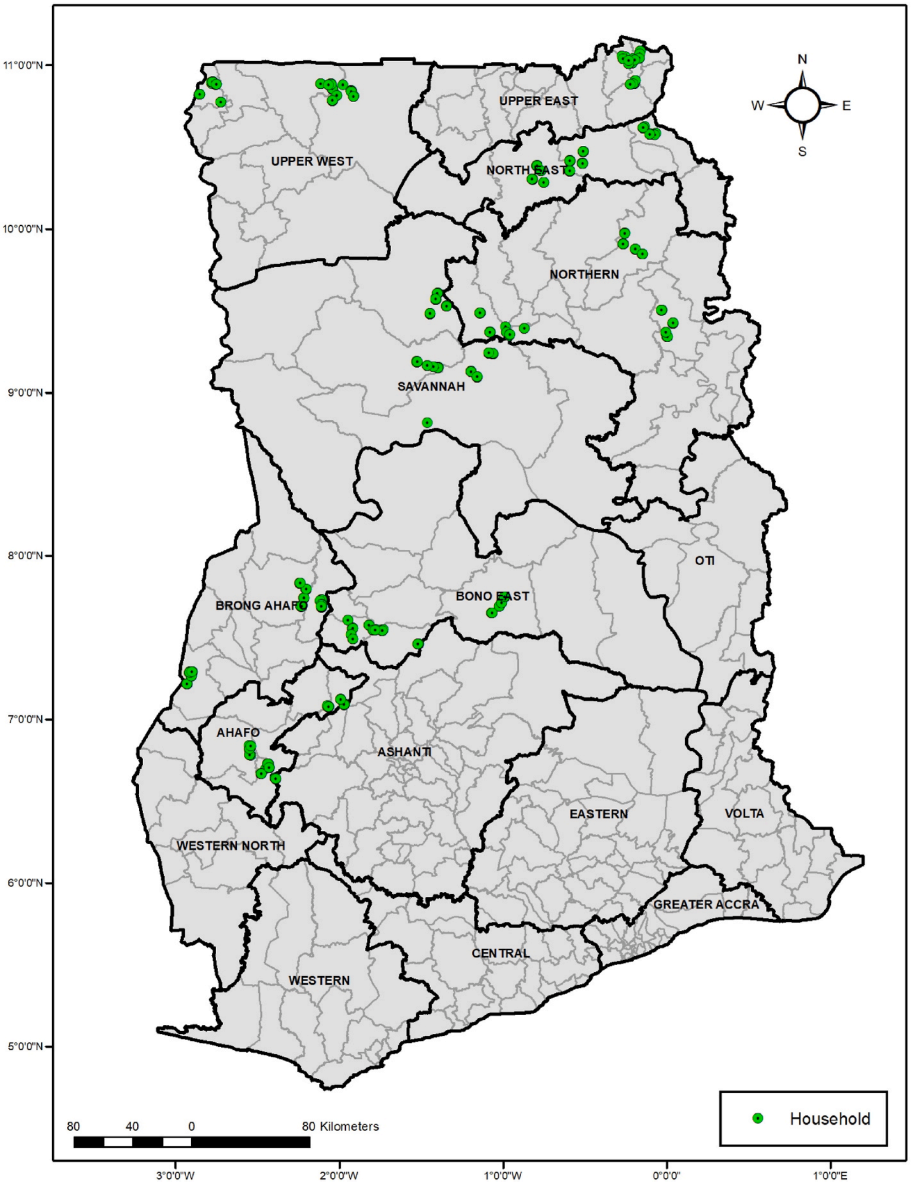

Fig. 1. Administrative map of Ghana showing the location of the farm households in the survey.

Table 1
Distribution of sampled households by region and agroecological zones.

Regions	Zone	Districts	Communities	Households
			(4 per District)	(15 per Community)
Northern	Guinea	3	12	180
North East	Guinea	3	12	182
Savannah	Guinea	3	12	180
Upper East	Sudan	3	12	180
Upper West	Sudan	3	12	180
Bono	Transition	3	12	183
Bono East	Transition	3	12	185
Ahafo	Transition	3	12	180
Total		24	96	1450

Notes: The total sample is supposed to be 1440 but 10 extra households were interviewed to accommodate future attrition thus increasing the sample size to 1450.

agriculture, including decreased output prices, increased input prices, limited access to input and output markets, and inability to maintain farm activities due to loss of income. Gauging farmers' response against

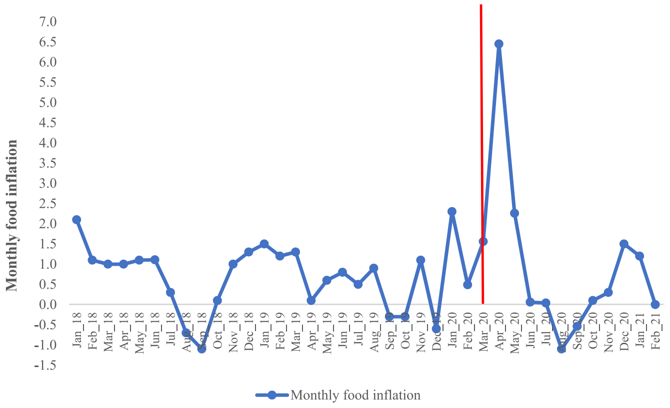

Fig. 2. Monthly food inflation due to COVID-19 pandemic. Note: The line shows the announcement of the lockdown by the government of Ghana in March 2021.

Table 2

Farmers' perceptions of COVID-19 shocks on agriculture.

Perceptions of COVID-19 shocks on agriculture	Total	Sudan	Guinea	Transition	Chi2
Decrease in output prices	1015 (70%)	221 (61%)	393 (73%)	401 (73%)	17***
Increase in input prices	884 (61%)	267 (74%)	360 (66%)	257 (47%)	79***
Limited access to input and output markets	963 (66%)	274 (76%)	339 (63%)	350 (64%)	20***
Loss of income	902 (62%)	254 (71%)	297 (55%)	351 (64%)	24***
Observations	1450	360	542	548	

Notes: Figures in parentheses are percentages, and without are counts. These are multiple responses; therefore, the individual percentages were estimated from the individual frequency over the total zonal sample; ***ρ < 0:01.

existing secondary data, we observed that output prices fluctuated over the study period. The majority (70%) of the farmers projected a decrease in output price. This may be due to the fact that most traders from the south were unable to travel to the north to buy grains (old stock) due to movement restrictions and uncertainties regarding community spread of the diseases; thus, farmers had to reduce the price of their grains to sell quickly to avoid colossal storage costs and losses. About 61% and 66% of the farmers projected that COVID-19 will lead to increase in input prices, and limited access to input and output markets. About 62% of the farmers perceive that COVID-19 pandemic will result in income loss.

The result shows statistically significant differences in the responses of the farmers across the agro-ecological zones. In the Sudan agroecological zones, increase in input prices (74%), limited access to input and output markets (76%), and loss of income (71%) were the most cited COVID-19 shocks. In the Guinea and Transitional zones, a decrease in output prices (73%) was the most cited COVID-19 shock.

Fig. 3 shows the adoption of SAPs based on farmers' perceived effects of COVID-19 shocks on their production. Organic fertilizer recorded the lowest adoption among all the SAPs, while inorganic fertilizer shows the highest adoption. Compared to other responses, farmers who projected decreased output prices recorded the highest adoption (51%) of no tillage. With reference to farmers who projected income loss and decrease in output prices, about 27% and 22% adopt mulching, respectively. The adoption of mixed cropping does not differ based on farmers' perception of COVID-19 shocks. There is an equal adoption (58%) of pesticides based on perception of COVID-19 shocks except for a decline in output prices. About 78% of the farmers who projected income loss adopt inorganic fertilizer, while 76% adopt inorganic fertilizer irrespective of their shocks. About 12% of the farmers who anticipated an increase input price, limited access to input and output markets, and income loss adopt organic fertilizer. High adoption of inorganic fertilizer and chemicals/pesticides may be a mitigation strategy to respectively boost crop yields and reduce crop.

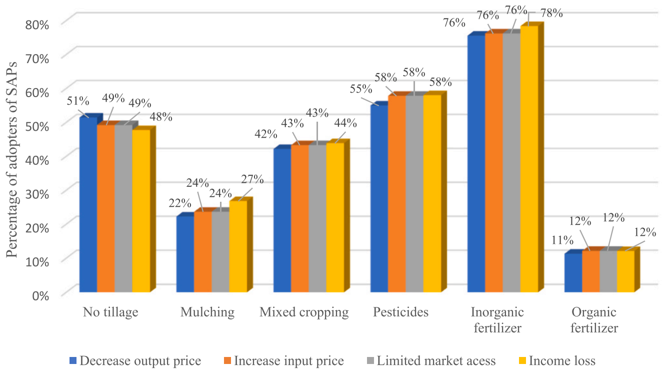

Fig. 3. Adoption of SAPs by COVID-19 shocks.

The summary statistics of the explanatory variables based on SAPs adoption are presented in Table 3. We categorized the farmers into non-adopters, low and high adopters based on the number of SAPs adopted. Per the classification, non-adopters do not use any of the SAPs while low adopters are farm households that adopt any one or two of the SAPs. High adopters are farm households that adopt more than two of the SAPs reported in Fig. 3. More than 80% of the non-adopters, low- and high-adopters are males and relatively young (between 43 and 46 years). High adopters of SAPs have higher years of formal education (5 years) than non-adopters (3 years) and low adopters (4 years). About 85% more of the entire sampled farmers are married. Although the non-adopters have more household members, the level of dependents do not differ among the three categories.

The average farm size is 2.1 ha for all categories, and 61% of both non-adopters and high adopters own farmland and have about 21 years of farming experience. The majority of the adopters (over 46%) are engaged in other economic activities. Most of the farmers (more than 16%) in our sample do not engage in contract farming. Over 40% of the farmers have access to extension services. High adopters had two extension contacts per farming season. Migration of household members due to farming is high among non-adopters (61%) and relatively low for adopters (22%). Membership in farmer-based organizations and the total land under insurance program is higher for high adopters of SAPs than non-adopters and low adopters. On average, one household member seeks off-farm jobs to complement household farm income. Adopters recorded a higher total household income than non-adopters, but non-adopters use more family labour and less hired labour than adopters.

In relation to the COVID-19 shocks, about 72%, 67%, 70%, and 67% of the high adopters of SAPs perceive a decrease in output prices, increased input price, limited access to input and output markets, and loss of income, respectively. Similarly, most of the low adopters anticipated a decrease in output prices, increased input price, limited access to input and output markets, and loss of income than non-adopters.

3. Empirical strategy

This section presents the empirical model that identifies the potential possible combinations of SAPs and their relationship. We use the principal component analysis (PCA) to identify the possible combinations of SAPs and subsequently employ the multivariate probit model (MVP) to determine the relationships (complements or substitutes) among the SAPs based on farmers' projection of COVID-19 shocks. The data was further subjected to Poisson regression to ascertain the factors influencing the intensity of adoption of SAPs.

3.1. Principal component analysis

The PCA's detailed description and application in identifying the possible combinations of SAPs have been published elsewhere (Martey and Kuwornu, 2021). The PCA was applied to determine the possible combinations of all the SAPs that farmers adopted on their farm plots. The weights generated by the PCA is used to construct household-specific SAPs index.

3.2. Multivariate probit analysis of the adoption of SAPs

The study explores the heterogeneity of SAPs, emphasizing perceptions of COVID-19 shocks at the extensive margin. At the extensive margin, the study explores farmers adoption (binary indicator) of SAPs using the MVP model with emphasis on COVID-19 shocks in the agricultural sector. The MVP model allows for the control of the interdependence between the SAPs. Complementarity and substitute associations between SAPs are one of the primary sources of correlation (Green, 2012; Belderbos et al., 2004).

Table 3
Summary statistics of explanatory variables by adoption status.

Variables	Non-adopters		Low adopters		High adopters	
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
Gender (1 = male)	0.869	0.340	0.823	0.382	0.803	0.398
Age (years)	44.525	14.058	42.961	12.574	45.555	12.641
Years of education (years)	2.951	4.533	4.359	5.090	4.777	5.058
Marital status (1 = married)	0.918	0.277	0.854	0.353	0.858	0.349
Nativity (1 = household head is native)	0.820	0.388	0.802	0.399	0.838	0.369
Female household members (number)	6.508	6.959	4.938	4.915	5.284	5.390
Male household members (number)	7.525	7.226	5.423	5.855	5.380	4.461
Number of dependents (number)	7.541	6.862	7.137	4.988	7.664	6.251
Farm size (hectares)	2.059	1.865	2.117	2.224	2.149	2.567
Own farm land (1 = yes)	0.607	0.493	0.569	0.496	0.607	0.489
Farming experience (years)	21.262	13.393	20.358	12.155	21.430	12.304
Engaged in other economic activities (1 = yes)	0.262	0.444	0.457	0.499	0.477	0.500
Engaged in contract farming (1 = yes)	0.213	0.413	0.175	0.380	0.158	0.365
Access to extension services (1 = yes)	0.410	0.496	0.408	0.492	0.465	0.499
Number of extension access (number)	1.148	1.558	1.293	2.309	1.706	2.992
Migration due to farming (number)	0.607	1.370	0.216	0.660	0.216	0.650
Member of farmer-based organization (1 = yes)	0.164	0.373	0.216	0.412	0.294	0.456
Household members seeking non-farm jobs (number)	1.033	2.065	0.723	1.392	0.817	1.389
Farm area insured (hectares)	15.000	34.448	24.633	50.131	25.332	59.376
Total household income (Ghana cedi)	2015	5927	2417	4570	3218	4415
Number of family labour (number)	5.869	4.573	4.201	3.629	4.635	5.133
Number of hired labour (number)	4.852	6.633	5.518	9.068	8.310	12.359
COVID-19 shocks variables						
Decrease in output price (1 = yes)	0.623	0.489	0.687	0.464	0.722	0.448
Increase in input price (1 = yes)	0.541	0.502	0.561	0.497	0.667	0.472
Limited access to input and output markets (1 = yes)	0.475	0.504	0.651	0.477	0.696	0.460
Income loss (1 = yes)	0.541	0.502	0.579	0.494	0.674	0.469
Regions						
Northern (1 = yes)	0.230	0.424	0.127	0.333	0.113	0.317
North East (1 = yes)	0.049	0.218	0.104	0.305	0.155	0.362
Savannah (1 = yes)	0.262	0.444	0.209	0.407	0.026	0.160
Upper East (1 = yes)	0.082	0.277	0.085	0.279	0.168	0.374
Upper West (1 = yes)	0.131	0.340	0.159	0.366	0.090	0.286
Bono (1 = yes)	0.000	0.000	0.065	0.247	0.197	0.398
Bono East (1 = yes)	0.082	0.277	0.098	0.298	0.162	0.369
Ahafo (1 = yes)	0.164	0.373	0.153	0.360	0.088	0.284
Observations	61		697		692	

Notes: *Low adopters are statistically significant different from non-adopters* in terms of years of education (**), nativity (*), number female household members (**), farm size (*), participation in other economic activities (***), migration due to farming (**), farm area insured (**), total household income (**), family labour (***), limited access to input and output markets (**), and residence in Northern (*), North East (*), and Bono (***). *High adopters are statistically significant different from non-adopters* in terms of years of education (***), number female household members (**), participation in other economic activities (***), number of extension access (**), migration due to farming (**), member of FBO (**), farm area insured (**), total household income (***), family labour (**), hired labour (***), anticipated increase in input price (*), limited access to input and output markets (***), loss of income (**), and residence in Northern (**), North East (***), Savannah (***), Upper East (**), Bono (***), and Bono East (**). *High adopters are statistically and significant different from low adopters* in terms of age (***), marital status (*), male household members (*), access to extension services (**), number of extension visits (***), member of FBO (***), total household income (***), family labour (*), hired labour (***), anticipated increase in input price (***), limited access to input and output markets (*), loss of income (***), and residence in North East (***), Savannah (***), Upper East (***), Upper West (***), Bono (***), Bono East (***), and Ahafo regions (***). ***$\rho < 0.01$; **$\rho < 0.05$; *$p < 0.10$. Extension services include building farmers' capacity in good agronomic practices, business-oriented farming, and provision of market information.

Following from theory, adoption of SAPs is realized when the net benefit is greater than zero, $K_{ij}^{*} = E[U(\pi_A)]\rangle E[U(\pi_N)]$. The net benefit K_{ij}^{*} derived by a farmer from the adoption of *jth* SAPs is a latent variable determined by household and farm characteristics, COVID-19 shocks, institutional and regional level characteristics (X_i) (Table 3) and the error term (μ_i). The model is formally expressed as:

$$K_{ij}^{*} = X_i^{'}\beta_j + \mu_i (j = NT, M, MC, P, IF, OF) \tag{1}$$

where *NT* is no tillage, *M* is mulch, *MC* is mixed cropping, , *P* is pesticide, *IF* is inorganic fertilizer, and *OF* is organic fertilizer. The explanatory variables are motivated by the literature on SAPs adoption and COVID-19 shocks on agricultural production (Martey and Kuwornu, 2021; Liverpool-Tasie et al., 2020; Waldman et al., 2017; Meijer et al., 2015; Wise et al., 2014). The unobserved preferences in equation (1) translate into the observed binary outcome equation for each choice based on the indicator function as follows:

$$K_{ij} = \begin{cases} 1 \; if \; K_{ij}^{*} > 0 \\ \\ 0 otherwise \end{cases} \tag{2}$$

In the multivariate probit model, the error terms jointly follow a multivariate normal distribution (MVN) with zero conditional mean, and variance-covariance matrix V which is normalized to unity (for identification of the parameters). The non-zero off-diagonal elements in the covariance matrix represent the unobserved correlation between the stochastic components of the different SAPs. This correlation coefficient establishes the complementary (positive correlation) and substitution associations (negative correlation) among the SAPs.

3.3. *Poisson and negative binomial regression analysis of adoption intensity*

The study employs the Poisson and negative binomial regression models to analyze the factors influencing the intensity of SAPs adoption given the count nature of the data. The Poisson and Negative Binomial regression models are standard count models in the literature (Greene, 2000; Grogger and Carson, 1991; Cameron and Trivedi, 1986). A detailed description of the Poisson and negative binomial regression models have been published elsewhere (Martey and Kuwornu, 2021).

4. Empirical results

4.1. *Packages of SAPs: principal component analysis*

The PCA determined the packages of SAPs. Fig. 4 shows the plot of the eigen values against the number of components to include in the PCA. Six factors were considered in the PCA but only two components were retained although about three of the components had eigen values above one.

Table 4 shows the two component loadings of the SAPs and Kaiser-Meyer-Olkin (KMO) values for each SAPs. The estimated overall KMO measure was 0.605, indicating sampling adequacy of the PCA. Mulching and organic fertilizer contributed more in terms of the overall KMO. Twenty-eight percent (28%) and 48% of the variations in the use of inorganic fertilizer and pesticides, respectively, are unexplained by the retained components. About 54%, 59%, and 56% of the variations in the use of mulch, no tillage, and mixed cropping, respectively, are unexplained, while 75% of the variation in the use of organic fertilizer is unexplained by the retained components. No tillage, mulching, mixed cropping, pesticides, and organic fertilizer highly loaded on component one. No tillage, mulching, mixed cropping, pesticides, and inorganic fertilizer are highly loaded on component two. This indicates the pattern of SAPs adoption on farmers' plots, but there is limited information regarding the relationship among the SAPs.

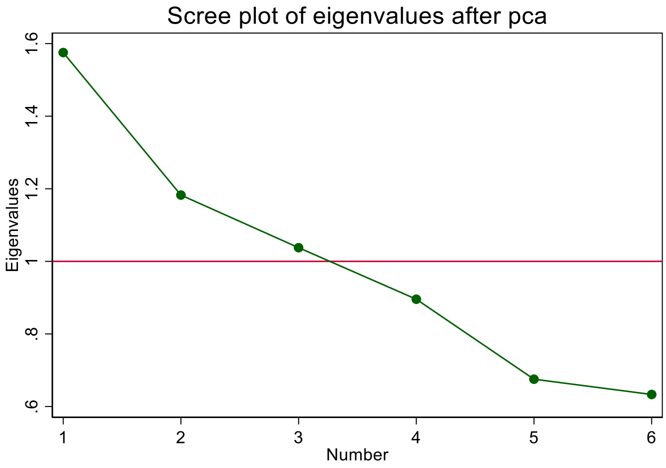

Fig. 4. Scree plot of eigenvalues.

Table 4
Component loadings of IPA practices.

Variable	Component 1	Component 2	Unexplained	KMO
No tillage	**0.449**	**0.252**	0.588	0.592
Mulching	**0.468**	**−0.276**	0.544	0.633
Mixed cropping	**0.445**	**−0.306**	0.561	0.581
Pesticides	**0.501**	**0.290**	0.481	0.592
Inorganic fertilizer	−0.067	**0.808**	0.282	0.473
Organic fertilizer	**0.355**	0.173	0.753	0.729
Overall				0.605

Fig. 5 presents the distribution of the SAPs index for the first (panel A) and second components (panel B). Panel A is more normally distributed than panel B. The majority of the respondents recorded SAPs index between −2 and −1.5 (panel A) and 0.5 to 1 (panel B). The distribution of panel B is more skewed towards the right, where the majority of the respondents recorded SAPs index between −1 and 1.5.

4.2. *Determinants of adoption of SAPs*

Table 5 presents the results of the MVP regression which measures the probability of adopting one of the SAPs. The Wald test suggests that the explanatory variables included in the MVP model provide a good explanation regarding the choice of SAPs. The results vary across the different SAPs. Farmers are 19 percentage points less likely to adopt mixed cropping and 48 percentage points more likely to adopt organic fertilizer. Older farmers are 2.4 and 0.9 percentage points more likely to adopt no tillage and mixed cropping, respectively. In contrast, older farmers are 1.6 percentage points less likely to adopt inorganic fertilizer. Nativity and number of dependents are associated with a 25.7 and 1.8 percentage points adoption of pesticides, respectively.

The probability of adopting no tillage and mixed cropping is 11.9 and 19.2 percentage points lower for farm households with migrants. Similarly, farm household members seeking off-farm jobs are 7.1 percentage points and 7.8 percentage points less likely to adopt no tillage and pesticides. Migration has both negative and positive effects on technology adoption. In our case, SAPs adoption is associated with high labour demand, and because migration reduces household family labour, it thus reduces the probability of adopting SAPs. Job seekers may reduce their labour effort in farming activities in anticipation of 'better' employment opportunities with high remuneration. The log of household income leads to 6.9 percentage points, 3.6 percentage points, 11.4 percentage points and 4.8 percentage points adoption no tillage, mulching, pesticide, and organic fertilizer, respectively. Statistically, the effect is higher for pesticide adoption relative to zero tillage. Farmers who earn more income are more likely to use pesticides to control pests than farmers with low income. For example, the fall armyworm is a typical example that requires pesticides to control. A study by Tambo and Kiru, (2021) finds that severe fall armyworm infestation reduced per capita household income by 44% and increased households' likelihood of experiencing hunger by 17%. To avert this negative effect of pests, farmers who earn more income will invest in pesticides.

Apart from the demographic characteristics, an increase in farm size leads to 4.9 percentage points and 3.3 percentage points less likely to influence the adoption of no tillage and mixed cropping, respectively. The results also show that farmers who cultivated own land are 31 percentage points, 28 percentage points, and 25 percentage points more likely to adopt mulching, mixed cropping, and organic fertilizer, respectively but 17.4 percentage points less likely to use inorganic fertilizer. Experienced farmers are 2.3 percentage point less likely to adopt zero tillage but 1.7 percentage point more likely to adopt inorganic fertilizer. Farmers who engaged in contract farming are 35 percentage points, 19 percentage points, and 24 percentage points less likely to

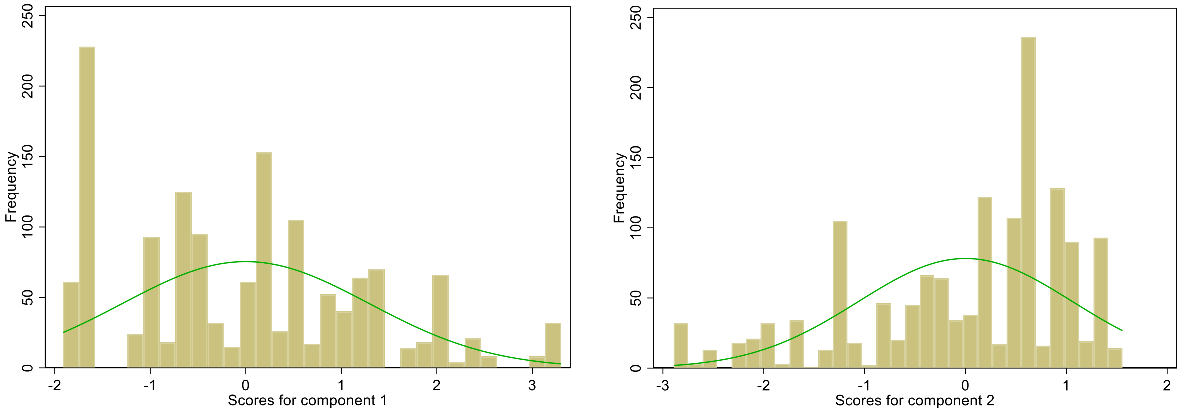

Fig. 5. Distribution of SAP index for the sample farmers.

adopt zero tillage, mixed cropping, and pesticides, while farmers who engaged in other economic activities apart from farming are 13.3 percentage points and 25.4 percentage points more likely to use pesticides and organic fertilizer. Contract farming specifies the terms of conditions of the contract which may not necessarily accommodate some SAPs. Participation in other economic activities improves household income which can be invested in protectants and soil fertility management practices to reduce pest infestations and enhance soil fertility. Farmers area under insurance program are 0.1 percentage points less likely to influence zero tillage and 0.2 percentage points more likely to use of inorganic fertilizer. The number of family labour is positively associated with all the SAPs except pesticide and inorganic fertilizer adoption. The effect is highest for organic fertilizer adoption. Organic fertilizer is bulky and requires more labour to transport and apply on the field. Consistent with family labour, the number of hired labour is positively associated with no tillage and mulching but negatively associated with pesticide adoption. The results suggest that hired and family labour is used for land management activities rather than for crop protection.

Institutional factors such as access to extension services are positively associated with no tillage, pesticide, and inorganic fertilizer. The positive association between extension and inorganic fertilizer use is consistent with the findings of Martey and Kuwornu (2021). This result is likely because SAPs are knowledge-based technologies and require demonstration to fully appreciate and adopt. Farmers who belong to farmer associations are 26.5 percentage points more likely to adopt pesticides. Our finding is consistent with previous studies that highlights the role of social learning and peer effect in terms of technology adoption (Krishnan and Patnam, 2014; Conley and Udry, 2010; Bandiera and Rasul, 2006). Farmers who belong to associations are more likely to learn from their peers and implement the knowledge gained on their own farm plots.

With reference to perception of COVID-19 shocks, farmers who anticipated a decrease in output price are 49.3 percentage points less likely to adopt mulching. The result suggests rationality in farmers' decisions, given that the level of farm investment may not be commensurate with crop income due to the decrease in output price. Farmers who reported an increase in input price are less likely to adopt no tillage but more likely to adopt mulching, mixed cropping, and pesticides. The adoption of mixed cropping could be a strategy to reduce cost as the same inputs may be applied to different crops on the same farm plot. Similarly, the adoption of mulching could be a strategy to minimize weed growth, thus reducing expenditure on the herbicide. Limited access to input and output markets reduced the adoption of no tillage but increased the adoption of pesticides and inorganic fertilizer by 35.9 and 17.3 percentage points, respectively. Given that market access is limited, farmers may buy inorganic fertilizer and protectants in bulk, assuming their income allows for such transactions. Income loss is negatively associated with no tillage and organic fertilizer adoption.

4.3. COVID-19 shocks and combinations of SAPs

Table 6 presents the correlation matrix of the MVP model for the entire sample and sub-sample of farmers based on their anticipated COVID-19 shocks on agriculture. The correlation coefficient is restricted to only significant combinations of SAPs. The full result is reported in Table A2 in the appendix. The first, second, third, fourth, and fifth columns show how farmers combine SAPs based on the entire sample and experiences regarding decreased output prices, increased input prices, limited access to input and output markets, and loss of income, respectively. A positive correlation coefficient between the error terms of two SAPs suggests complements and a negative correlation indicates substitutes. Our results indicate that most of the SAPs complement each other, with few substitutes.

Regarding the full sample, the highest complementarity relationship among the SAPs is observed between pesticide and no tillage (0.437) and is consistent for farmers who anticipated an increase in input prices (0.484) and income loss (0.496). Farmers who anticipated decrease in output price recorded the highest complementarity association (0.325) between pesticide and mixed cropping. In contrast farmers who projected limited access to input and markets recorded the highest complementarity association (0.405) between mixed cropping and mulching. The complementary pair of SAPs includes mulching and no tillage, mixed cropping and no tillage, pesticide and no tillage, mixed cropping and mulching, pesticide and mulching, pesticide and mixed cropping, and inorganic fertilizer and pesticide are common to all farmers. The results indicate that farmers combine these practices irrespective of their perceptions of COVID-19 shocks on agriculture. Adopting these practices generally improve soil structure, conserve moisture in the soil, reduces evapotranspiration, reduce risk of crop failure due to environmental stress, increases soil fertility, reduce pest infestation, and increases crop yield due to the complementary effects of each practice. We observed unique combinations of SAPs for farmers who projected limited access to input and output markets and loss of income due to COVID-19 pandemic.

Farmers who anticipated a decrease in output price and an increase in input price are unique in their likelihood of complementing organic fertilizer with no tillage. The results indicate that these farmers are interested in the long-term benefit of soil productivity practices that are environmentally friendly given that no tillage protects the soil from erosion and helps retain soil moisture, organic matter, and nutrient cycling. In addition, organic fertilizer releases nutrients slowly into the soil to reduce losses. It ensures that nutrients are retained for longer periods, and improving soil structure to hold water and nutrients. Perception of a decrease in output price and limited access to input and output markets influences farmers' decision of substituting inorganic fertilizer for mulch or vice versa. The effect is higher for farmers who anticipated a decrease in output price relative to farmers who reported

Table 5
Coefficient estimates of the multivariate probit model of SAPs adoption.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	No tillage	Mulching	Mixed cropping	Pesticides	Inorganic fertilizer	Organic fertilizer
Gender of household head (1 = male)	−0.039	−0.064	−0.187*	0.114	−0.150	0.477***
	(0.105)	(0.111)	(0.100)	(0.104)	(0.120)	(0.153)
Age of household head	0.024***	0.002	0.009*	0.004	−0.016**	0.010
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.008)
Years of education	0.004	−0.011	0.003	−0.016*	−0.013	−0.033***
	(0.009)	(0.009)	(0.008)	(0.009)	(0.009)	(0.012)
Nativity (1 = household head is native)	0.027	−0.021	−0.056	0.257**	0.041	−0.054
	(0.102)	(0.119)	(0.102)	(0.109)	(0.115)	(0.149)
Female household members	0.006	−0.006	0.009	0.014	−0.010	−0.017
	(0.009)	(0.010)	(0.008)	(0.011)	(0.009)	(0.016)
Male household members	−0.001	0.008	−0.005	0.009	0.002	−0.002
	(0.010)	(0.011)	(0.009)	(0.009)	(0.010)	(0.012)
Number of dependents	0.004	−0.015	−0.002	0.018**	0.009	−0.001
	(0.009)	(0.010)	(0.009)	(0.009)	(0.009)	(0.013)
Household members migrated due to farming	−0.119**	−0.192***	−0.034	−0.083	−0.048	0.034
	(0.060)	(0.067)	(0.053)	(0.057)	(0.057)	(0.076)
Household members seeking off-farm jobs	−0.071**	0.049	−0.009	−0.078**	−0.021	−0.043
	(0.030)	(0.030)	(0.029)	(0.031)	(0.034)	(0.041)
Log of total household income	0.069***	0.036*	0.013	0.114***	0.015	0.048*
	(0.018)	(0.020)	(0.017)	(0.018)	(0.019)	(0.029)
Farm size	−0.049***	−0.006	−0.033*	0.019	−0.002	−0.004
	(0.018)	(0.019)	(0.017)	(0.018)	(0.019)	(0.024)
Marital status (1 = married)	−0.099	−0.099	0.007	−0.160	−0.008	−0.056
	(0.113)	(0.120)	(0.108)	(0.111)	(0.125)	(0.162)
Own farm land (1 = yes)	−0.038	0.310***	0.276***	0.047	−0.174*	0.249**
	(0.082)	(0.091)	(0.081)	(0.084)	(0.092)	(0.124)
Farming experience (years)	−0.023***	−0.008	−0.007	−0.009	0.017**	−0.003
	(0.006)	(0.006)	(0.006)	(0.006)	(0.007)	(0.008)
Engaged in contract farming (1 = yes)	−0.350***	0.072	−0.191*	−0.240**	0.047	−0.083
	(0.109)	(0.116)	(0.105)	(0.105)	(0.117)	(0.153)
Engaged in other economic activities (1 = yes)	0.014	0.039	0.039	0.133*	0.062	0.254**
	(0.079)	(0.084)	(0.075)	(0.078)	(0.086)	(0.107)
Farm area insured	−0.001**	0.001	−0.000	0.001	0.002*	0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Number of family labour	0.024**	0.039***	0.032***	−0.027**	−0.029**	0.053***
	(0.012)	(0.012)	(0.011)	(0.011)	(0.012)	(0.014)
Number of hired labour	0.009**	0.011***	0.001	−0.009**	0.002	−0.005
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.005)
Access to extension services (1 = yes)	0.172*	−0.024	0.003	−0.060	−0.093	−0.007
	(0.101)	(0.111)	(0.098)	(0.102)	(0.119)	(0.142)
Number of times of extension access	0.013	−0.013	−0.025	0.054***	0.102***	−0.012
	(0.018)	(0.021)	(0.018)	(0.019)	(0.028)	(0.029)
Member of FBO (1 = yes)	0.110	0.078	0.095	0.265***	−0.042	0.028
	(0.092)	(0.099)	(0.088)	(0.092)	(0.102)	(0.126)
COVID-19 shocks						
Decrease in output price	0.114	−0.493***	−0.058	0.039	0.141	−0.029
	(0.095)	(0.103)	(0.092)	(0.094)	(0.101)	(0.129)
Increase in input price	−0.163*	0.424***	0.214**	0.475***	−0.039	−0.083
	(0.092)	(0.103)	(0.091)	(0.094)	(0.101)	(0.132)
Limited access to input and output markets	0.022	−0.170*	−0.025	0.359***	0.173*	0.133
	(0.093)	(0.101)	(0.092)	(0.094)	(0.101)	(0.134)
Inability to maintain farm due to income loss	−0.184**	0.087	0.022	0.014	−0.032	−0.297**
	(0.088)	(0.096)	(0.085)	(0.087)	(0.095)	(0.125)
Constant	−0.853***	−0.561*	−0.572**	−1.509***	−0.505	−2.862***
	(0.282)	(0.293)	(0.272)	(0.286)	(0.314)	(0.439)
Region fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1444	1444	1444	1444	1444	1444
Wald chi2 (198)	1320***					
Log-likelihood	−4061.0538					

Notes: Robust standard errors are in parentheses. ***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

limited access to input and output markets. An expectation of a future output price decrease may influence farmers to adopt only inorganic fertilizer to improve land, and crop productivity to meet household consumption relative to commercialization.

Farmers who anticipated a decrease in output prices and limited market access shift production investment decisions from short-term SAPs (inorganic fertilizer) to long-term SAPs (mulch). Alternatively, farmers may opt for mulch to retain soil moisture to mitigate evapotranspiration and subsequently reduce yield losses. The substitution effect is consistent with the findings of Martey and Kuwornu (2021) and Waldman et al. (2017) who find that when farmers are faced with risks, they are more likely to make risk averse decisions (such as adopting practices that maintain soil moisture and reduce weed) that has the potential of influencing farm productivity. Our results further confirm the findings of Shikuku et al. (2017) that farmers are likely to invest in technologies with low associated risk compared to agricultural technologies with high level of associated risk.

Compared to perceptions such as decrease in output price, increase

Table 6
Correlation matrix derived from MVP model by perceptions of COVID-19 shocks.

Variables	(1)	(2)	(3)	(4)	(5)
	Full sample	Decrease in output price	Increase in input price	Limited market access	Income loss
Mulching and no tillage	0.273***	0.137**	0.236***	0.165***	0.215***
	(0.047)	(0.063)	(0.064)	(0.060)	(0.074)
Mixed cropping and no tillage	0.167***	0.118**	0.200***	0.105*	0.231***
	(0.043)	(0.055)	(0.057)	(0.055)	(0.063)
Pesticides and no tillage	0.437***	0.299***	0.484***	0.390***	0.496***
	(0.040)	(0.056)	(0.057)	(0.053)	(0.064)
Inorganic fertilizer and no tillage	0.133***				
	(0.051)				
Organic fertilizer and no tillage	0.141**	0.161*	0.319***		
	(0.063)	(0.085)	(0.084)		
Mixed cropping and mulching	0.302***	0.265***	0.267***	0.405***	0.390***
	(0.043)	(0.056)	(0.059)	(0.053)	(0.064)
Pesticides and mulching	0.134***	0.136**	0.379***	0.315***	0.281***
	(0.048)	(0.057)	(0.060)	(0.057)	(0.074)
Inorganic fertilizer and mulching	−0.115**	−0.174***		−0.144**	
	(0.054)	(0.064)		(0.067)	
Organic fertilizer and mulching	0.195***			0.287***	
	(0.063)			(0.075)	
Pesticides and mixed cropping	0.258***	0.325***	0.309***	0.347***	0.368***
	(0.043)	(0.052)	(0.056)	(0.052)	(0.063)
Inorganic fertilizer and mixed cropping	−0.151***				−0.181**
	(0.047)				(0.083)
Organic fertilizer and mixed cropping	0.173***				
	(0.058)				
Inorganic fertilizer and pesticides	0.130**	0.211***	0.167**	0.214***	0.237***
	(0.051)	(0.062)	(0.069)	(0.063)	(0.077)
Organic fertilizer and pesticides	0.265***	0.250***			0.296***
	(0.060)	(0.074)			(0.109)
Likelihood ratio test of correlation terms: chi2 (15)	263.80***	120.67***	163.49***	186.27***	220.98***

Notes: Numbers in parentheses are the standard errors. ***$p < 0.01$, **$p < 0.05$, *$p < 0.10$.

in input price, and loss of income, perception of limited access to input and output markets is associated with unique complementarity association of organic fertilizer and mulch. The result is consistent with our expectation, given that farmers with limited market access will rely on readily available factor inputs to enhance soil fertility and maintain soil moisture for optimum crop yield. Similarly, farmers who experienced income loss uniquely substitute inorganic fertilizer for mixed cropping. The inorganic fertilizer is costly, but when applied appropriately using site-specific recommended rate, the economic reward especially yield gains is high. However, income loss may reduce farm investment in terms of input purchase but increase the likelihood of farmers engaging in crop diversification strategy to reduce the high risk of income loss. The result suggests that farmers sacrifice short-term benefits of crop yield for crop diversification as a mechanism for reducing risks of crop and income loss.

Finally, framers who reported decreased output price and income loss complemented organic fertilizer with pesticides. The highest complementary association is observed for farmers who reported income loss due to the COVID-19. Consistent with the earlier findings, farmers who experienced a decrease in output price are more willing to make an investment that will benefit household consumption relative to commercialization. Similarly, farmers who reported income loss are more likely to invest in long-term soil fertility (organic fertilizer) and protectants to avoid losses that negatively impact crop income and household welfare. Organic fertilizers may be readily available at a reduced or no cost for households keeping livestock. Protectants may also be applied as a risk-reducing strategy against crop losses due to pest infestation. Generally, the responses of farmers to perceptions of COVID-19 shocks indicate a trade-off among SAPs taking into consideration the impact on soil fertility and environmental impact. The responses provide a basis for enhancing sustainable productivity and addressing environmental challenges.

4.4. *Intensity of SAPs adoption*

The results of the Poisson model employed to measure the extent or the number of SAPs adopted are reported in Table 7. Models 1 and 3 are the Poisson and the negative binomial regression models that include non-adopters of SAPs. In contrast, models 2 and 4 are the Poisson and the negative binomial regression models that exclude non-adopters of SAPs. Comparing the AIC values across models, models 2 and 4 recorded lower AIC than models 1 and 3. In the interest of brevity but without loss of generalizations for the conclusions, we discuss the restricted Poisson model (model 2), which is similar in terms of the magnitude of effect to the negative binomial regression model. Our result is consistent and robust across model specifications.

The intensity of SAPs adoption is significantly determined by age, years of formal education, farm size, ownership of farmland, farming experience, contract farming, migration, membership of FBO, household income, family labour, and increase in input price due to COVID-19 pandemic. Age of farmer is positively associated with the intensity of SAPs adoption. This indicates that older household heads are more likely to adopt multiple SAPs. Older farmers may have experimented with SAPs in the past based on which they make their adoption decisions. Educated household heads are 1.4 percentage points less likely to adopt multiple SAPs. The result is consistent with Martey and Kuwornu (2021) who find that education reduces the intensity of adopting soil fertility management practices. The result indicates that education enables farmers to make an informed decision given that multiple adoptions of SAPs which are labour intensive.

Farmers with smaller farm sizes are 2.8 percentage points more likely to adopt multiple SAPs than those with large farms. Most smallholder farmers are resource-poor; thus, they are more likely to adopt multiple SAPs on a small parcel of farmland for effective management (Martey and Kuwornu, 2021). The result suggests farm intensification, which has been proven to positively impact yield and household welfare (Shew et al., 2019; Varma, 2019; Van Campenhout and Bizimungu, 2018;

Table 7
Poisson and Negative binomial regression estimate of the number of IPA adoption.

Variables	Poisson regression models				Negative binomial regression models			
	Model 1		Model 2		Model 3		Model 4	
	Marginal Effect	Robust Std. Err.	Marginal effect	Robust Std. Err.	Marginal effect	Robust Std. Err.	Marginal effect	Robust Std. Err.
Gender of household head (1 = male)	−0.009	0.092	−0.003	0.089	−0.009	0.092	−0.003	0.089
Age of household head	0.009**	0.005	0.010**	0.004	0.009**	0.005	0.010**	0.004
Years of education	−0.014*	0.008	−0.014*	0.008	−0.014*	0.008	−0.014*	0.008
Nativity (1 = household head is native)	0.040	0.088	0.048	0.085	0.040	0.088	0.048	0.085
Female household members	0.002	0.007	0.004	0.006	0.002	0.007	0.004	0.006
Male household members	0.002	0.008	0.008	0.008	0.002	0.008	0.008	0.008
Number of dependents	0.003	0.008	−0.002	0.007	0.003	0.008	−0.002	0.007
Farm size	−0.026*	0.015	−0.028*	0.015	−0.026*	0.015	−0.028*	0.015
Marital status (1 = married)	−0.141	0.095	−0.087	0.094	−0.141	0.095	−0.087	0.094
Own farm land (1 = yes)	0.193***	0.072	0.168**	0.068	0.193***	0.072	0.168**	0.068
Farming experience (years)	−0.011**	0.005	−0.012***	0.004	−0.011**	0.005	−0.012***	0.004
Engaged in other economic activities (1 = yes)	0.111*	0.066	0.064	0.064	0.111*	0.066	0.064	0.064
Engaged in contract farming (1 = yes)	−0.239**	0.095	−0.187**	0.090	−0.239**	0.095	−0.187**	0.090
Access to extension services (1 = yes)	0.046	0.084	0.037	0.081	0.046	0.084	0.037	0.081
Number of times of extension access	0.020	0.015	0.021	0.014	0.020	0.015	0.021	0.014
Migrated due to farming	−0.146**	0.062	−0.100*	0.057	−0.146**	0.062	−0.100*	0.057
Member of FBO (1 = yes)	0.168**	0.076	0.141*	0.073	0.168**	0.076	0.141*	0.073
Non-farm jobs	−0.048	0.030	−0.036	0.027	−0.048	0.030	−0.036	0.027
Farm area insured	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Log of total household income	0.086***	0.017	0.064***	0.015	0.086***	0.017	0.064***	0.015
Number of family labour	0.025***	0.009	0.031***	0.008	0.025***	0.009	0.031***	0.008
Number of hired labour	0.002	0.003	0.002	0.003	0.002	0.003	0.002	0.003
Decrease in output price	−0.044	0.090	−0.052	0.088	−0.044	0.090	−0.052	0.088
Increase in input price	0.267***	0.083	0.281***	0.081	0.267***	0.083	0.281***	0.081
Limited access to input and output markets	0.131	0.085	0.048	0.082	0.131	0.085	0.048	0.082
Income loss	−0.088	0.078	−0.070	0.075	−0.088	0.078	−0.070	0.075
Region fixed effects	Yes		Yes		Yes		Yes	
Pearson goodness-of-fit (Prob > Chi2)	824 (1.000)		661 (1.000)		–		–	
AIC	4826		4572		4826		4572	
BIC	5005		4750		5005		4750	
Pseudo R-squared	0.053		0.043		0.053		0.043	

Notes: ***ρ < 0:01; **ρ < 0:05; *ρ < 0:1.

Garnett et al., 2013). Farmers who own land are 16.8 percentage points more likely to adopt multiple SAPs relative to farmers who rent land. Land productivity investment is highly correlated with land ownership. Farmers that own land are more likely to make long-term investments to improve their welfare, unlike renters who may invest in short-term land productivity enhancing practices to fulfill their contractual requirements from the land returns. Farming experience is negatively associated with the adoption of multiple SAPs. Comparing the results with age suggest that the elderly may increase the adoption of SAPs but years of farming experience reduces the intensity of adoption of SAPs. Farmers who engage in contract farming are 18.7 percentage points less likely to adopt multiple SAPs relative to farmers who do not engage in contract farming. Contract farming is associated with specifications that require strict compliance with little or no shirking. The migration of household members reduces the intensity of the adoption of SAPs by 10 percentage points due to the reduction in family labour to support the implementation of SAPs. Consistently, family labour increases the intensity of SAPs adoption.

Membership of FBO is positively associated with the adoption of SAPs. Membership of FBO enhances knowledge sharing, learning, and support services to members. The positive association between membership of FBO and technology adoption is consistent with previous studies that find that member of FBO increases the adoption of maize and cowpea technologies, use of inorganic fertilizer, crop rotation, and adoption of improved cassava varieties (Adams et al., 2021; Manda et al., 2020; Wossen et al., 2017). Household income is positively associated with multiple SAPs adoption. The result is consistent with expectations due to the costly nature of the SAPs. Farmers who projected an increase in input price due to the COVID-19 are 28.1 percentage points more likely to adopt multiple SAPs. The anticipated price increase coupled with the ravages of the pandemic on the rural economy may influence households to adopt strategies such as the adoption of SAPs to ensure sustainable food production.

5. Conclusion

Sustainable agricultural practices have long been studied and proven to positively impact yield, welfare, and environmental outcomes. However, there is no empirical evidence on how perceptions of exogenous shock such as the novel COVID-19 pandemic influences the adoption and combinations of SAPs. Our study assessed how farmers adapt and combine SAPs in response to their anticipation of COVID-19 shocks such as decrease in output price, increase in input price, limited access to input and output market, and loss of income. The shocks are linked directly with the synergistic and trade-offs associations in the combinations of SAPs with subsequent effect on environmental outcomes.

The main results of the study lead to two major conclusions. First, the intensity of SAPs adoption is significantly influenced by age, years of education, farm size, ownership of farmland, farming experience, contract farming, migration, membership of FBO, household income, family labour, and COVID-19 shocks. These findings indicate that the promotion of SAPs among farm households must prioritize these factors to ensure broad and sustained adoption of SAPs. Second, we find heterogeneity in the combinations of SAPs adopted by farmers based on their experience of COVID-19 shocks. The adaptive response to these shocks is expressed in the combinations of the SAPs. Farmers who reported a decrease in output price, and an increase in input prices are unique in their likelihood of complementing organic fertilizer with no tillage. Decrease in output price and limited access to input and output markets influences farmers' decision of substituting inorganic fertilizer for mulch or vice versa. The correlation effect is higher for farmers who reported a decrease in output price relative to farmers with limited access to input and output markets. Farmers who reported a decline in output price and loss of income complements organic fertilizer with pesticides. In contrast, limited access to input and output markets is associated with unique complementary combinations of organic fertilizer and mulch. Income loss due to COVID-19 is associated with a substitution effect between inorganic fertilizer for mixed cropping. The results imply a trade-off decision in terms of soil and plant protection and environmental impact. Furthermore, the results suggest that farmers are adjusting appropriately to the COVID-19 shocks to enhance their resilience.

The importance of this finding is that the adoption and combinations of SAPs recommended for increasing yield are less likely to be implemented if economic agents' experience of external shocks are ignored. This indicates a need for more effective design and promotion of SAPs among farmers to enhance effective uptake, implementation, and sustainability without a disruptive effect on environmental sustainability. Discussing the role of COVID-19 shocks on other SAPs and their impact on household welfare and the environment will contribute immensely to the literature on sustainable agricultural intensification. Therefore, more research is needed on the influence of COVID-19 shocks on the adoption and combinations of SAPs and the consequent environmental and welfare effects.

Declarations

Availability of data and manual

The authors do not have the right to share the data but available upon request.

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.

Acknowledgement

This study was made possible through data support from the International Fertilizer Development Centre (IFDC) as part of the project "Fertilizer Research and Responsible Implementation" (FERARI). The authors express their appreciation for the administrative support offered by the CSIR-Savanna Agricultural Research Institute. Finally, we wish to express our profound gratitude to the anonymous reviewers whose contribution has led to a major improvement of this manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2022.115810.

References

Adams, A., Jumpah, E.T., Caesar, L.D., 2021. The nexuses between technology adoption and socioeconomic changes among farmers in Ghana. Technol. Forecast. Soc. Change 173, 121–133.

Afridi, F., Dhillon, A., Roy, S., 2020. How Has Covid-19 Crisis Affected the Urban Poor? Findings from a Phone Survey. *Ideas For India* (Accessed 15th July, 2020). https://www.ideasforindia.in/topics/poverty-inequality/how-has-covid-19-crisis-affected-the-urban-poor-findings-from-a-phone-survey.html.

Ahmed, F., Islam, A., Pakrashi, D., Rahman, T., Siddique, A., 2021. Determinants and dynamics of food insecurity during COVID-19 in rural Bangladesh. Food Pol. 101, 102066.

Akter, S., 2020. The impact of COVID-19 related 'stay-at-home' restrictions on food prices in Europe: findings from a preliminary analysis. Food Secur. 12 (4), 719–725.

Amare, M., Abay, K.A., Tiberti, L., Chamberlin, J., 2021. COVID-19 and food security: panel data evidence from Nigeria. Food Pol. 101, 102099.

Arndt, C., Davies, R., Sherwin, G., Harris, L., Anderson, L., 2020. Covid-19 lockdowns, income distribution, and food security: an analysis for South Africa. Global Food Secur. 26, 100410.

Ayanlade, A., Radeny, M., 2020. COVID-19 and food security in Sub-Saharan Africa: implications of lockdown during agricultural planting seasons. Sci. Food 4 (1), 1–6.

Bandiera, O., Rasul, I., 2006. Social networks and technology adoption in northern Mozambique. Econ. J. 116 (514), 869–902.

Barrett, C.B., 2020. Actions now can curb food systems fallout from COVID-19. Nat. Food 1 (6), 319–320.

Belderbos, R., Carree, M., Diederen, B., Lokshin, B., Veugelers, R., 2004. Heterogeneity in R&D cooperation strategies. Int. J. Ind. Organ. 22 (8–9), 1237–1263.

Bellemare, M.F., 2015. Rising food prices, food price volatility, and social unrest. Am. J. Agric. Econ. 97 (1), 1–21.

Cameron, A.C., Trivedi, P.K., 1986. Econometric models based on count data. Comparisons and applications of some estimators and tests. J. Appl. Econom. 1 (1), 29–53.

Chen, C.Y.C., Byrne, E., Vélez, T., 2022. Impact of the 2020 pandemic of COVID-19 on Families with School-aged Children in the United States: Roles of Income Level and Race. Journal of Family Issues 43 (3), 719–740.

Conley, T.G., Udry, C.R., 2010. Learning about a new technology: pineapple in Ghana. Am. Econ. Rev. 100 (1), 35–69.

Dang, H.A., Nguyen, C.V., 2021. Gender inequality during the COVID-19 pandemic: income, expenditure, savings, and job loss. World Dev. 140, 105296 https://doi.org/10.1016/j.worlddev.2020.105296.

Elleby, C., Dominguez, I.P., Adenauer, M., Genovese, G., 2020. Impacts of the COVID-19 pandemic on the global agricultural markets. Environ. Resour. Econ. 76 (4), 1067–1079. https://doi.org/10.1007/s10640-020-00473-6.

FAO, 2020. Impact of COVID-19 on agriculture, food systems and rural livelihoods in Eastern Africa: policy and programmatic options. Accra. https://doi.org/10.4060/cb0552en.

Ferreira, F.H., Fruttero, A., Leite, P.G., Lucchetti, L.R., 2013. Rising food prices and household welfare: evidence from Brazil in 2008. J. Agric. Econ. 64 (1), 151–176. https://doi.org/10.1111/j.1477-9552.2012.00347.x.

Garnett, T., Appleby, M.C., Balmford, A., Bateman, I.J., Benton, T.G., Bloomer, P., Godfray, H.C.J., 2013. Sustainable intensification in agriculture: premises and policies. Science 341 (6141), 33–34.

Gatto, M., Islam, A.H.M.S., 2021. Impacts of COVID-19 on rural livelihoods in Bangladesh: evidence using panel data. PLoS One 16 (11), e0259264.

Greene, W.H., 2000. Econometric Analysis, fourth ed. Prentice Hall, New Jersey.

Greene, W.H., 2012. Econometric Analysis, seventh ed. Prentice Hall, New York.

Grogger, J.T., Carson, R.T., 1991. Models for truncated counts. J. Appl. Econom. 6 (3), 225–238.

Hadley, C., Stevenson, E.G.J., Tadesse, Y., Belachew, T., 2012. Rapidly rising food prices and the experience of food insecurity in urban Ethiopia: impacts on health and well-being. Soc. Sci. Med. 75 (12), 2412–2419. https://doi.org/10.1016/j.socscimed.2012.09.018.

Headey, D., Fan, S., 2008. Anatomy of a crisis: the causes and consequences of surging food prices. Agric. Econ. 39, 375–391. https://doi.org/10.1111/j.1574-0862.2008.00345.x.

Kabir, H., Maple, M., Usher, K., 2020. The impact of COVID-19 on Bangladeshi readymade garment (RMG) workers. J. Publ. Health 43 (1), 47–52.

Kansiime, M.K., Tambo, J.A., Mugambi, I., Bundi, M., Kara, A., Owuor, C., 2021. COVID-19 implications on household income and food security in Kenya and Uganda: findings from a rapid assessment. World Dev. 137, 105199 https://doi.org/10.1016/j.worlddev.2020.105199.

Karim, M.R., Islam, M.T., Talukder, B., 2020. COVID-190 s impacts on migrant workers from Bangladesh: in search of policy intervention. World Dev. 136, 105123 https://doi.org/10.1016/j.worlddev.2020.105123.

Krishnan, P., Patnam, M., 2014. Neighbors and extension agents in Ethiopia: who matters more for technology adoption? Am. J. Agric. Econ. 96 (1), 308–327.

Kumar, P., Singh, S.S., Pandey, A.K., Singh, R.K., Srivastava, P.K., Kumar, M., Dubey, S. K., Sah, U., Nandan, R., Singh, S.K., Agrawal, P., Kushwaha, A., Rani, M., Biswas, J. K., Drews, M., 2021. Multi-level impacts of the COVID-19 lockdown on agricultural systems in India: the case of Uttar Pradesh. Agric. Syst. 1.

Laborde, D., Martin, W., Swinnen, J., Vos, R., 2020. COVID-19 risks to global food security. Science 369 (6503), 500–502.

Liverpool-Tasie, L.S., Pummel, H., Tambo, J.A., Olabisi, L.S., Osuntade, O., 2020. Perceptions and exposure to climate events along agricultural value chains: evidence from Nigeria. J. Environ. Manag. 264, 110430.

Manda, J., Khonje, M.G., Alene, A.D., Tufa, A.H., Abdoulaye, T., Mutenje, M., Manyong, V., 2020. Does cooperative membership increase and accelerate agricultural technology adoption? Empirical evidence from Zambia. Technol. Forecast. Soc. Change 158, 120160.

Martey, E., Kuwornu, J.K., 2021. Perceptions of climate variability and soil fertility management choices among smallholder farmers in northern Ghana. Ecol. Econ. 180, 106870.

Meijer, S.S., Catacutan, D., Ajayi, O.C., Sileshi, G.W., Nieuwenhuis, M., 2015. The role of knowledge, attitudes and perceptions in the uptake of agricultural and agroforestry innovations among smallholder farmers in sub-Saharan Africa. Int. J. Agric. Sustain. 13 (1), 40–54.

MoFA, 2017. Agriculture in Ghana: Facts and Figures. http://www.sridmofaghana.com/sites/default/files/Agric%20in%20Ghana%20F%26F%202016.pdf, 2016.

MoFA, 2019. Ministry of Food and Agriculture Operational Performance (2017-2018). https://mofa.gov.gh/site/images/pdf/PFJ.pdf.

Owusu, K., 2018. Rainfall changes in the savannah zone of northern Ghana 1961–2010. Weather 73 (2), 46–50.

Paganini, N., Adinata, K., Buthelezi, N., Harris, D., Lemke, S., Luis, A., et al., 2020. Growing and eating food during the COVID-19 pandemic: farmers' perspectives on local food system resilience to shocks in Southern Africa and Indonesia. Sustainability 12 (20), 8556. https://doi.org/10.3390/su12208556.

Ravallion, M., 2020. Could Pandemic Lead to Famine? Project Syndicate. Online; Published. https://www.project-syndicate.org/commentary/covid19-lockdowns-threaten-famine-in-poor-countries-by-martin-ravallion-2020-04/.

Roussi, A., 2020. Kenya farmers face uncertain future as Covid-19 cuts exports to EU. Financ. Times.

Ruan, J., Cai, Q., Jin, S., 2021. Impact of COVID-19 and nationwide lockdowns on vegetable prices: evidence from wholesale markets in China. Am. J. Agric. Econ. 1–21. https://doi.org/10.1111/ajae.12211, 00(00):

Shew, A.M., Durand-Morat, A., Putman, B., Nalley, L.L., Ghosh, A., 2019. Rice intensification in Bangladesh improves economic and environmental welfare. Environ. Sci. Pol. 95, 46–57.

Shikuku, K.M., Winowiecki, L., Twyman, J., Eitzinger, A., Perez, J.G., Mwongera, C., Läderach, P., 2017. Smallholder farmers' attitudes and determinants of adaptation to climate risks in East Africa. Clim. Risk manag. 16, 234–245.

Sumner, D.A., 2021. Impact of COVID-19 and the lockdowns on labor-intensive produce markets, with implication for hired farm labor. Choice 36 (3).

Tambo, J.A., Kirui, O.K., 2021. Yield effects of conservation farming practices under fall armyworm stress: The case of Zambia. Agriculture, Ecosystems & Environment 321, 107618.

Tripathi, H.G., Smith, H.E., Sait, S.M., Sallu, S.M., Whitfield, S., Jankielsohn, A., Nyhodo, B., 2021. Impacts of COVID-19 on diverse farm systems in Tanzania and South Africa. Sustainability 13 (17), 9863. https://doi.org/10.3390/su13179863.

Van Campenhout, B., Bizimungu, E., 2018. Risk and returns of sustainable crop intensification: the case of smallholder rice and potato farmers in Uganda. Dev. Pol. Rev. 36, 605–633.

Varma, P., 2019. Adoption and the impact of system of rice intensification on rice yields and household income: an analysis for India. Appl. Econ. 51 (45), 4956–4972.

Waldman, K.B., Blekking, J.P., Attari, S.Z., Evans, T.P., 2017. Maize seed choice and perceptions of climate variability among smallholder farmers. Global Environ. Change 47, 51–63.

Wang, L., Wang, J., Fang, C., 2020. Assessing the impact of lockdown on atmospheric ozone pollution amid the first half of 2020 in Shenyang, China. International Journal of Environmental Research and Public Health 17 (23), 9004.

Wise, R.M., Fazey, I., Smith, M.S., Park, S.E., Eakin, H.C., Van Garderen, E.A., Campbell, B., 2014. Reconceptualising adaptation to climate change as part of pathways of change and response. Global Environ. Change 28, 325–336.

World, Bank, 2020. COVID-19 to Add as Many as 150 Million Extreme Poor by 2021. Press Release. https://www.worldbank.org/en/news/press-release/2020/10/07/covid-19-to-add-as-manyas-150-million-extreme-poor-by 2021#:~:text=The%20COVID%2D19%20pandemic%20is,severity%20of%20the%20economic%20contraction. (Accessed 7 October 2020), 2020 March 2021.

Wossen, T., Abdoulaye, T., Alene, A., Haile, M.G., Feleke, S., Olanrewaju, A., Manyong, V., 2017. Impacts of extension access and cooperative membership on technology adoption and household welfare. J. Rural Stud. 54, 223–233.

Zabir, A.A., Mahmud, A., Islam, M.A., Antor, S.C., Yasmin, F., Dasgupta, A., 2021. COVID-19 and food supply in Bangladesh: a review. South Asian J. Soc. Stud. Econ. 10 (1), 15–23. https://doi.org/10.9734/sajsse/2021/v10i130252.

Edward Martey (Email: eddiemartey@gmail.com; ORCID ID: 0000-0002-6933-3685) is an Agricultural and Applied Economist at the CSIR-Savanna Agricultural Research Institute and a visiting scholar at the University of Illinois at Urbana-Champaign. He received his BSc (Agricultural Economics), MPhil (Agricultural Economics) and PhD (Agricultural and Applied Economics) degrees from the University of Ghana and University of Illinois at Urbana-Champaign, respectively. He is currently the Head of the Socio-economic Section of CSIR-SARI. His key research interests are in the areas of agricultural technology adoption, impact evaluation of development projects, agricultural commercialization, time poverty, institutional and energy economics.

Prince M. Etwire (Email: ; ORCID ID: 0000-0002-6533-2538) is a Research Scientist (Agricultural Economist) at the CSIR-Savanna Agricultural Research Institute, Tamale, Ghana where he has been a faculty member of the Socio-economic Section since 2009. He received his BSc (Agricultural Technology), MPhil (Agricultural Economics) and PhD (Economics) degrees from the University for Development Studies, University of Ghana, and University of Otago, respectively. His research interests are in the areas of modelling climate change adaptation, productivity studies, general microeconomic modelling, monitoring and evaluation of agricultural projects, and building organizational capacity.

William Adzawla (Email: ; ORCID ID: 0000-0002-6938-0625) holds PhD in Economics, Master of Philosophy (MPhil) in Agricultural Economics and BSc Agricultural Technology. He has very good understanding of agricultural and climate change economics, and an in-depth knowledge in policy analysis and socioeconomic research. Currently, he is the Economist at IFDC Ghana. He has published journal articles especially in the areas of climate change and adaptation, gender, poverty, livelihoods and crop production. His research goal is to identify how inequality in all forms can be addressed and how smallholder agriculture can be transformed for an all-inclusive development.

Williams Atakora (Email: ; ORCID ID: 0000-0003-3526-333X) holds a PhD in Soil Science and MPhil in Soil Science from the Universities of Cape Coast and Kwame Nkrumah University of Science and Technology, respectively. He is the National Coordinator of the Fertilizer Research and Responsible Implementation Project (FERARI) since January 2020. Prior to joining IFDC, Dr Atakora has over 11 years of research experience in soil fertility management and improvement. His research focus includes crop-soil-water-fertilizer interaction using models, assessment of greenhouse gases emissions emanating from agricultural practices, on-farm and on-station trials, and training of smallholder farmers and agricultural extension agents.

Prem S. Bindraban (Email: ; ORCID ID: 0000-0001-5221-8763) is Program Director of the program Fertilizer Research and Responsible Implementation (FERARI) at the International Fertilizer Development Center. He obtained his Master and Doctorate at Wageningen University (WUR), was research team leader on Food Security and Natural Resources and Director of ISRIC – World Soil Information at WUR. He was a researcher at the CGIAR centers CIMMYT and IRRI, and has been teaching at WUR, Univ. Amsterdam, and Univ Sao Paulo. He is an expert in sustainable use of natural resources, design and development of production systems, and on policies on global development issues. Publications refer to: https://www.researchgate.net/profile/PS_Bindraban. His area of specialties is World Food Security, Agricultural Development, Climate Change, Water for Food, Soil Fertility, Biofuels, and Innovative fertilizers.