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Adoption and impacts of sustainable intensification practices in Ghana

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ABSTRACT
Sustainable agricultural intensification requires the use of multiple agricultural technologies in an integrated manner to enhance productivity while conserving the natural resource base. This study analyses the adoption and impacts of sustainable intensification practices (SIPs) using a dataset from Ghana. A multivariate probit (MVP) model was estimated to assess the adoption of multiple SIPs. Moreover, we used a multivalued semi-parametric treatment effect (MVTE) model to estimate the effects of adopting multiple SIPs on maize productivity. The MVP model results show, among others, that access to market, capital, and information/knowledge would enhance the adoption of SIPs. The MVTE model results show that a higher number of SIPs is associated with higher productivity which is more visible when commercial inputs are used in combination with cultural practices. These results have the following policy implications. First, they imply that good rural infrastructure and agricultural services such as rural road network, village-level input delivery system, input credit, and multiple information/knowledge sharing approach (instead of the conventional singular formal information/knowledge sharing approach) can enhance adoption. Second, the results suggest that promoting an integrated use of technologies, instead of a single technology, would have a positive impact on farm productivity and farm household income.

KEYWORDS
Sustainable intensification practices; adoption; impacts; Ghana

1. Introduction

It is becoming more and more difficult nowadays for many African countries to realize agricultural growth by putting more land under cultivation. On the one hand, uncultivated agricultural land has declined over time due to increasing cultivation, rapid urbanization, and land degradation (Clay, Reardon, & Kangasniemi, 1998; Jayne, Chamberlin, & Headey, 2014). For instance, the total area under annual and perennial crops has expanded by about 50% or more within the last two decades in some countries such as Ghana, Mali, Sierra Leone, Burkina Faso, Malawi, Niger, Ethiopia, and Mozambique (Alliance for Green Revolution in Africa [AGRA], 2013). On the other hand, population has been increasing rapidly in Sub-Saharan Africa in the past five decades resulting in higher food demand (Muyanga & Jayne, 2014). For instance, the population of West Africa, Eastern Africa, and Middle Africa have been growing faster than that of any other region in the world, and this situation is expected to continue through 2100, even if fertility rate equals replacement rate by 2050 (United Nations, 2004). Such a perturbing situation and the remarkable success of the Asian Green Revolution have contributed to the wider acceptance of agricultural intensification as a strategy to enhance food production in Africa (Hazell, 2009; Jayne et al., 2014; Pretty, Toulmin, & Williams, 2011; The Montpellier Panel, 2013).

The Green Revolution, which is a typical example of agricultural intensification in the developing world, involved a widespread adoption of high yielding varieties, chemical fertilizers (CF), and irrigation (Hazell, 2009; Shiva, 1991). The widespread adoption of

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scientific agricultural techniques and inputs during that time resulted in the rise of labour productivity, thereby increasing income and reducing poverty (Hazell, 2009). However, this approach had several negative consequences as well (Alauddin & Quiggin, 2008; Shiva, 1991). For instance, it has contributed to the reduction of crop biodiversity and increased soil erosion (Altieri & Nicholls, 2005; Shiva, 1991). Moreover, the emphasis on a few staple cereals has reduced the diversity of macro- and micronutrients available for human consumption, thereby contributing to malnutrition among the poor and the wider public (Graham et al., 2007).

The concept of 'sustainable intensification' has been getting attention since the early 1980s in response to the adverse effects of the Green-Revolution-type intensification on agro-ecosystems and human health (Amekawa, 2010; Pretty et al., 2011). Sustainability implies both high yields that can be maintained, even in the face of major shocks, and agricultural practices that have acceptable environmental impacts (Pretty et al., 2011; Tilman, Cassman, Matson, Naylor, & Polasky, 2002). It entails the use of multiple practices and inputs in an integrated manner on a durable basis. However, there are no blueprints on how multiple practices (technologies) should be integrated in sustainable intensification as different mixes may result in different environmental and agricultural outcomes depending on local contexts. In fact, a sustainable agricultural system is characterized by high use of improved crop varieties and livestock breeds (i.e. genetic intensification), application of agroecological processes such as nutrient cycling, biological nitrogen fixation, allelopathy, predation, and parasitism (ecological intensification), and creation of enabling environment such as better markets and institutions (socioeconomic intensification) (Pretty et al., 2011; The Montpellier Panel, 2013).

The components of sustainable intensification are potentially complementary to each other and, if integrated, they may produce an impact higher than what would be gained otherwise (Ruben & Lee, 2000). However, very few studies have analysed the simultaneous adoptions of sustainable intensification practices (SIPs) and their impacts on smallholders' farm productivity and income. Most of the previous studies focused on a separate analysis of these components (e.g. improved seeds, fertilizer). While useful, such an approach can only provide a partial view of the role of sustainable intensification in smallholder agriculture and its determinants. Moreover, most of the existing studies on adoption of SIPs have been conducted in Eastern and Southern Africa (ESA) regions while studies in the context of West Africa (WA) are quite limited (Kassie, Jaleta, Shiferaw, Mmbando, & Mekuria, 2013; Kassie, Teklewold, Jaleta, Marenya, & Erenstein, 2015; Manda, Alene, Gardebroek, Kassie, & Tembo, 2016; Teklewold, Kassie, Shiferaw, & Kohlin, 2013). This shows the existence of a considerable research gap as there are significant differences between ESA and WA in terms of agroecological and sociocultural conditions limiting the external validity of existing findings in the context of WA. This study aims to fill this gap based on recent survey data from northern Ghana. Examining the adoption and impact of SIPs within the context of northern Ghana is particularly important because of at least two reasons. First, farming systems in this region are characterized by complex problems such as land degradation, deteriorating agricultural biodiversity, scarcity of agricultural water, and limited use of modern inputs demanding a study that would address such complexity (Aniah, Wedam, Pukunyiem, & Yinimi, 2013; Ellis-Jones et al., 2012). Second, evidence shows that farmers in northern Ghana exercise various components of sustainable intensification (Dalton, Yahaya, & Naab, 2014), but little is known whether they are applying the practices in an integrated manner, to what extent they are integrating them, which factors trigger or motivate farmers to integrate various practices, and the effects of such efforts on productivity and income.

SIPs can be evaluated from several dimensions such as productivity (e.g. grain yield, gross margin), risk (production stability, resilience), environment (pollution, land degradation), and nutrition (dietary quality) (Pretty et al., 2011; The Montpellier Panel, 2013; Tilman et al., 2002). In this paper, we assess the impact of SIPs on two outcome variables (i.e. grain yield and net returns) which are important productivity indicators. In addition, we identify factors contributing to the simultaneous adoption of various SIPs. However, we do not consider risk-related variables because of lack of multi-season data to make a valid assessment. We would provide only indicative results in the Section 5.3.1 'comparing cumulative distributions'.

2. The study areas

The study was conducted in three regions of northern Ghana namely, Northern Region, Upper West Region, and Upper East Region. These regions are mainly part of the Guinea Savanna agroecological zone which is locally known as the Northern Savanna. The Northern Savanna covers about 40% of the total area of the country (Ministry of Food and Agriculture [MoFA], 2010). It is characterized by unimodal and unpredictable rainfall distribution with the average annual amount of about 1000 mm. The growing season usually starts in May and ends in October. Cereals and legumes are dominant crops while root crops, vegetables, and fruits are cultivated to a lesser extent. Farmers produce most crops for both consumption and sale (Amanor-Boadu, Zereyesus, & Ross, 2015; United States Agency for International Development [USAID], 2012).

The three regions of Northern Savanna have generally similar farming systems. However, there is a slight variation among them in terms of cropping pattern and demography. Maize is among the three dominant crops in terms of volume of production in the Northern Region and the Upper West Region while it is less important in the Upper East Region although it is among the top five crops.[1] Sometimes maize is intercropped with grain legumes. The following cropping season maize is replaced by sorghum. Sorghum is the second most important crop in the Upper East and Upper West regions while it is the fourth crop in the Northern Region. Cowpea or groundnut is harvested first while sorghum remains in the field. The other important crop is rice which is mainly grown in the Upper East and Northern regions while it is less important in the Upper West. Rice is cultivated in lowlands basically through broadcasting. Groundnut is the most important legume in all of the three regions. The major trend across the three regions is increasing maize, decreasing sorghum and millet production with generally static legume production (Ellis-Jones et al., 2012). Rice production is also increasing, particularly in the Upper West due to the availability of improved varieties and management practices. Livestock is an important component of the farming system; the mode of livestock rearing is free ranching. Small ruminants (goat and sheep) and poultry production are very popular in large smallholder systems. They are increasing particularly in those areas where disease is not a major problem. Large ruminants (cattle) are also important. Cattle transhumance is common in the study regions. There is no much integration between crops and livestock. Crop–livestock integration is observed in some aspects. Oxen are used as a source of draught power for land preparation in all of the three regions and for weeding in some parts of the Upper East Region (Houssou, Kolavalli, Bobobee, & Owusu, 2013). Plots close to homesteads where cattle are housed can benefit from manure. However, outer fields do not benefit from manure as the quantity produced is often minimal.

3. The data and working variables

The study is based on the data collected in 2014 from 50 rural communities in the three regions described above with the purpose of establishing baseline data for the project 'Africa Research In Sustainable Intensification for the Next Generation (Africa RISING)'. A total of 1284 households operating more than 5500 plots were interviewed. The sampling strategy for the survey is a stratified two-stage random sampling which allows for statistical ex-post inferential analysis. Communities were selected in the first stage followed by households. Household interviews were guided by a structured questionnaire. Due to the complexity of the survey instrument and the need for minimizing possible non-sampling errors (e.g. data entry error), data collection was conducted using Computer Assisted Personal Interviewing (CAPI) supported by Survey CTO software on tablets. The survey captured all the data domains necessary for this study including data on various SIPs, household demographic characteristics, agricultural land holdings, crop outputs and sales, livestock production, farmers' access to agricultural information and knowledge, access to credit and markets, household assets, and income. More information about this data can be found at http://data.ilri.org/portal/dataset/gha_arbes.

We considered six SIPs in our analysis namely, cereal–legume intercropping, cereal–legume rotation, organic fertilizers, soil and water conservation (SWC) practices, chemical fertilisers, and improved seeds. All are dummy variables take on 1 if a farmer undertakes the practice and 0 otherwise. Intercropping involves the cultivation of cereals and any of the legumes grown in the areas (including groundnut, cowpea, and soybean) in the same field either at random or in alternate rows. Similarly, rotation involves the cultivation of cereals and legumes in sequence on the same plot of land over the years.[2] Soil and water management practices include contour ploughing, contour bunds, grass strips, drainage/ditches, and stone terraces. Organic fertilizers include animal manure, household wastes, and crop residues. CF are any of the industrially produced fertilizers such as such urea, DAP, sulphate-ammonia, and NPK. Improved seeds are seeds purchased from commercial sources and do not include recycled ones.

The above SIPs are expected to increase productivity and income either directly or indirectly through their effects on soil health. Evidence shows that practices such as crop rotation (CR) and intercropping would enhance farmers' adaptation to weather fluctuations as they involve the cultivation of multiple crops having different risk-response properties (Ndiritu, Kassie, & Shiferaw, 2014; Teklewold, Kassie, Shiferaw, & Kohlin, 2013; Tilman et al., 2002). Moreover, these practices are useful to improve soil fertility and to control pests and diseases, thereby increasing crop yield (Flint & Roberts, 1988; Ijoyah, 2014; Liebman & Dyck, 1993; Mousavi & Eskandari, 2011). Organic fertilizers improve soil structure and add organic carbon to the soil which can serve as the energy source for useful soil microbes (Zingore, Delve, Nyamangara, & Giller, 2008). Similarly, SWC practices can increase crop yield and reduce the impacts of weather fluctuation by increasing soil water availability, decreasing soil erosion, and ensuring the availability of nutrients to crops while, in the mean time, maintaining the natural resource base (Delgado et al., 2011; Ndiritu et al., 2014). Furthermore, Green Revolution technologies, such as improved varieties and CF, are known for their substantial and immediate effects on crop productivity. For instance, the widespread adoption of improved seeds and CF during the period of the Green Revolution increased the average cereal yield from 1.3 t/ha in 1970 to 2.6 t/ha in 1995 (Hazell, 2009). The benefits of SIPs are summarized in the appendix based on earlier studies (Table A1).

A large number of factors were hypothesized to have correlations with the adoption of SIPs including plot characteristics, household demography, household economy, access to information, market and finance, and location. Plots are the action spots of agricultural production. Empirical studies show that plot ownership and characteristics are important determinants of the adoption of SIPs among smallholders in Africa (Kassie et al., 2013; Ndiritu et al., 2014; Teklewold, Kassie, & Shiferaw, 2013). Plot ownership reflects the degree of confidence in the long term (Clay et al., 1998), and hence we expect that the probability of adoption is higher on own plots than on rented in/borrowed plots. Soil physicochemical characteristics may affect farmers' decisions to adopt SIPs as they reflect the soil fertility level (Clay et al., 1998; Ndiritu et al., 2014; O'Geen, Elkins, & Lewis, 2006). Plot-slope shows the degree of susceptibility of the plot to soil nutrient loss through erosion and hence it influences farmers' decisions to adopt SIPs as prevention measures. We expect that farmers would implement SIPs on soils susceptible to erosion such as sandy soils and those soils located on a steeper slope (Clay et al., 1998; Kassie et al., 2013; O'Geen et al., 2006). The adoption of SIPs is also influenced by plot size, the direction of influence being determined by the type of the technology (Kassie et al., 2013; Kassie et al., 2015). This hypothesis holds in this study too. Home–plot distance can affect the adoption of SIPs through its effects on transaction costs of implementing the technologies (Clay et al., 1998; Kassie et al., 2013). Therefore, we expect that home–plot distance would be negatively associated with adoption of SIPs.

Household demography may also explain the adoption of SIPs as it implies the capability of households to implement the practices and their demand for intensification. Family size may imply households' demand for food and thus it may have a positive association with the adoption of SIPs. It may also have a negative association with the adoption of SIPs particularly when the household is characterized by high dependency ratio due to low capacity to generate income to cover cash outlays associated with SIPs. Thus, the direction of the relationship is indeterminate. The size of the active labour force shows the supply side potential to implement SIPs; thus, we expect a positive correlation with adoption. We expect that education would enhance adoption as it increases the capacity of farmers to acquire, process, and use information. Higher age may be associated with higher probability of adoption provided that older people have better confidence than younger people arising from their better farming experience and higher social capital. On the contrary, older age can be associated with lower probability of adoption as it implies shorter planning horizon and higher risk aversion. Women have lower access to critical farm resources and information than men in Africa which deters them from adopting modern technologies (De Groote & Coulibaly, 1998; Ndiritu et al., 2014). Empirical studies also show that women are more responsive to some technologies which do not require direct cash outlays (Kassie et al., 2013; Quisumbing et al., 1995).

Farm resources and income may influence the adoption of SIPs. Land is a critical resource for farming and in the context of high population pressure the Boserupean hypothesis may hold (Boserup, 1965; Headey, Dereje, & Taffesse, 2014; Josephson, Ricker-Gilbert, & Florax, 2014; Muyanga & Jayne, 2014). Off-farm activities may enhance adoption of SIPs as the cash generated through such activities can be used to purchase inputs and pay for related services (Barrett, Reardon, & Webb, 2001; Wouterse & Taylor, 2008). On the contrary, off-farm activities may divert time and effort away from agriculture, reducing the adoption of SIPs. Livestock may complement farming as a source of income, draught power, and manure, which may facilitate the adoption of SIPs.

Capital constraint is an important factor hindering the adoption of agricultural technologies among smallholder farmers (Feder, Lau, Lin, & Luo, 1990; Teklewold, Kassie, & Shiferaw, 2013; Teklewold, Kassie, Shiferaw, & Kohlin, 2013). The amount of input credit taken by farmers was included in our analysis with the expectation that it would be positively related to the dependent variables. Farmers' access to market can also affect the adoption of SIPs. We expect that farmers who live far away from market centres are less likely to adopt SIPs (particularly purchased inputs) since the transaction costs of accessing the inputs would be high.

Finally, we considered access to information in our analysis as it is necessary to make adoption decisions (Feder et al., 1990; Kassie et al., 2013; Kassie et al., 2015). While the conventional extension system is an important source of information for smallholder farmers in Africa, there are also other sources of information that can help farmers decide on technology adoption. We considered four sources of information other than the conventional extension: model farmers, farmers' research groups, farmers' training centres, and social groups. We expect all of these information sources will enhance the adoption of SIPs while the degree of influence may vary across the technologies.

4. Econometric framework and estimation strategy

4.1. Estimating the determinants of SIPs

When farmers' decisions involve the use of multiple technologies, adoption decisions can be better explained by multivariate models while univariate modelling may exclude part of the useful economic information. We used a multivariate probit (MVP) model to explain the adoption of SIPs. The MVP model enabled us to see the influence of a set of explanatory variables while accounting for a possible correlation among disturbance terms arising from the relationship between the adoption of multiple practices.

Our multivariate model consists of six potentially interrelated equations. Each of them is associated with one of the six SIPs we defined earlier. This is displayed as follows:

$$Y^*_{ij} = \beta_j X_{ij} + \varepsilon_{ij} \quad (j = 1, \ldots, 6), \tag{1}$$

where Y^*_{ij} is a latent variable associated with technology (SIP) j and individual i that can be translated into binary outcomes such that:

$$Y_{ij} = 1 \quad \text{if} \quad Y^*_{ij} > 0 \text{ and } 0 \text{ otherwise}. \tag{2}$$

ε_{ij} denotes error terms distributed as multivariate normal, each with zero conditional mean, and variance–covariance matrix Ω, where Ω has values of 1 on the leading diagonal and correlations $\rho_{jk} = \rho_{kj}$ as off-diagonal elements as presented below.

$$\Omega = \begin{bmatrix} 1 & \rho_{12} & \cdots & \rho_{16} \\ \rho_{21} & 1 & \cdots & \rho_{26} \\ . & . & \cdots & . \\ . & . & \cdots & . \\ \rho_{61} & \rho_{62} & \cdots & 1 \end{bmatrix}. \tag{3}$$

The off-diagonal elements of the variance–covariance matrix, ρ_{jk}, represent unobserved correlations between the disturbance terms associated with the j th and k th types of SIPs ($j = 1,2, \ldots 6$; $k = 1,2, \ldots 6$; $j \neq k$).

The model was estimated based on the Geweke-Hajivassilion-Keane (GHK) simulation method and maximum likelihood estimation (Cappellari & Jenkins, 2003). In order to increase model accuracy, we adjusted the default number of random draws to 50 which is approximately equal to the square root of the number of valid observations used for estimation.[3]

4.2. Estimating the effects of using multiple SIPs

A large number of impact studies have estimated treatment effects based on the assumption of binary treatment level, such as programme intervention vs non-intervention, or adoption of a technology vs non-adoption. These studies used the seminal work of Rosenbaum and Rubin (1983) as a framework to estimate the Average Treatment Effects (ATE) or ATE on the Treated (ATT). While there is a multitude of cases where impacts can be handled within the binary outcomes framework, there are also many other cases where treatments are multivalued. Multivalued treatments require the application of a broader framework than binary treatments. Though the literature is thin with regards to multiple treatment assignments, some studies indicate that the results of Rosenbaum and Rubin (1983) continue to hold when treatments are multivalued (Cattaneo, 2010; Imbens, 2000).

Consider a standard cross-sectional setting where we observe a random sample of size n from a large population in which each individual has been assigned one of $J + 1$ possible treatment levels $j = 0, 1, \ldots, J$. For each individual $i = 1, 2, \ldots, n$, we observe the random vector $Z_i = (Y_i, W_i, X_i)$, where Y_i is the observed outcome variable, W_i denotes the treatment status, and X_i is a vector of covariates. Each individual is associated with $J+1$ potential outcome out of which only one, Y_{it}, is observed. Let $D_i(t)$ be the vector of receiving the treatment t for individual i such that:

$$D_i(t) = \begin{cases} 1, & \text{if} \quad T_i = t \\ 0 & \text{otherwise} \end{cases}. \tag{4}$$

Then, Y_i can be written in terms of $D_i(t)$ and Y_{it} as follows:

$$Y_i = \sum_{t=0}^{K} D_i(t) Y_{it}. \tag{5}$$

The interest is to estimate the average treatment effect of treatment j as defined as follows:

$$ATE_j = E((Y_j - Y_0)|D = 1) = E(Y_j|D = 1) - E(Y_0|D = 1). \tag{6}$$

We used two alternative treatment categories. The first category was based on the number of SIPs adopted by the farmers. This constitutes four mutually exclusive categories corresponding to (1) zero/one SIP, (2) two SIPs, (3) three SIPs, and (4) four/more SIPs. The second category was based on the type of SIPs adopted by the farmers. Here we grouped treatments also into four categories as follows: (1) commercial SIPs (consisting of CF and improved seeds), (2) non-commercial SIPs (consisting of intercropping, CR, SWC, and organic fertilizers), (3) a combination of commercial and non-commercial SIPs, and (4) none of the SIPs. Thus, variable '*j*' in Equation (6) would take on values one to four in both options of analysis. The *Y*s in that equation denote any of the two outcome variables namely, maize grain yield (kg/ha) and net income (Ghc/ha).

The difficulty with the identification of ATE from a random sample data is that the term $E(Y_0|D = 1)$ is not observable. Thus, we need to make further assumptions in order to identify it (Cattaneo, 2010; Imbens, 2000). The two most important assumptions are the conditional-independence (CI) assumption which restricts the dependence between the treatment model and the potential outcomes, and the overlap assumption which ensures that each individual could receive any treatment level (see Cattaneo, 2010 for details). These assumptions would help to fill the gap by allowing the estimation of the missing potential outcomes (Y_{it}) using relevant covariates, X:

$$E[Y_{it}|X_i] = E[Y_{it}|D_i(t) = 1, X_i] = E[Y_i|D_i(t) = 1, X_i] = E[Y_i|T_i = t, X_i]. \tag{7}$$

The unconditional means can be estimated by averaging these conditional means, i.e.

$$\mu_t \equiv E[Y_{it}] = E[E[Y_{it}|X_i]]. \tag{8}$$

Furthermore, Lechner (2001) defines the average effect of the treatment m relative to treatment l as follows, which has interesting interpretations in the multivalued treatment context.

$$\tau^{ml} = E[Y_{im} - Y_{il}], \tag{9}$$

where $m,l = 1,2,\ldots 4$; $m \neq l$.

The analytical support in this study is given by Cattaneo, Drukker, and Holland (2013). Their procedure is based on the inverse probability weighting (IPW) estimator and allows joint estimation of the average and the quantile treatment effects. Based on the suggestion in that work, we conducted a pre-estimation analysis to select equations necessary to specify the model for predicted probabilities and the model for conditional expectations for the means and quantiles.[4] Thereafter, we jointly estimated means and quantiles of the potential outcome distributions associated with multilevel adoption of SIPs.

5. Results and discussion

5.1. Descriptive statistics

The majority of the sample households (93%) apply at least one of the SIPs. CR and SWC practices are more widely used than others. They are practiced on 47% and 54% of the plots, respectively. The major SWC practice is contour ploughing (49.8%) which is practiced mainly by using tractors. Farmers also apply other SWC measures such as contour bunds (5.1%), grass strips (2.9%), drainage/ditches (2%), and stone terraces (1.3%). CF are also considerably abundant accounting for about 37% of the total number of plots. Organic fertilizers (OF) are applied on 16.5% of the plots. The main organic fertilizer is manure, while crop residues and household wastes are also used in a few cases. Intercropping (IC) is practiced on 12.3% of the total plots. Farmers intercrop maize with cowpea, soybean, and groundnut. Improved seeds (IS) are used on 6.1% of the total plots only. However, this figure shows the lower boundary of the adoption of improved seeds since we considered purchased improved seeds only while farmers may access the inputs through other means such as recycling and exchange.[5]

Farmers apply multiple SIPs in most of the cases. About two SIPs are applied on a typical plot constituting commercial inputs (i.e. CF and improved seeds), non-commercial inputs/practices (intercropping, crop rotation, organic fertilizers, and SWC practices), or both. Farmers use only non-commercial inputs/practices on about 46% of the plots, only commercial inputs on about 8% of the plots, and a combination of the two on about 30% of the plots.

The mean maize grain yield is about 836 kg/ha. Evidence implies that this yield level is lower than what farmers used to harvest. An official assessment report shows that the poor distribution of rainfall during the season adversely affected crop yields (MoFA, 2013). Actually, more than 80% of our sample farmers revealed that they had experienced reduction in crop yields as compared to the previous season due to the bad rainfall condition during the season. This situation may have also resulted in low net returns from maize production which is only about 270 Ghc/ha, on average.

5.2. Determinants of adoption

The results of the MVP model are presented in Table 1. The model fits the data fairly well. The model Chi square test is statistically significant asserting that the explanatory variables taken together are relevant to explain the variations in the adoption of the six SIPs considered in the study (Wald χ^2 (203) = 1625, p = 0000). The likelihood ratio test rejects the hypothesis that the agricultural practices under consideration are independent (χ^2 (21) = 287, p = 0000) which shows that the multivariate regression generates a more reliable information than separate univariate regressions. Plot size is positive and significant in most of the regressions, indicating that the probability of having SIPs increases as plot size increases; this is the case for cereal–legume intercropping (IC), cereal–legume rotation (CR), CF, and SWC practices. Perhaps larger plots are more convenient for some operations and use of inputs. For instance, operationally it is not convenient to use tractors for contour plowing (the common SWC practice in northern Ghana) on small plots. Similarly, some commercial inputs are not divisible (because of packaging style), and hence farmers may target crops planted on larger plots to efficiently use the purchased inputs. Our result is consistent with earlier studies (Clay et al., 1998; Kassie et al., 2013). For instance, Kassie et al. (2013) found that the probability of applying intercropping, SWC, conservation tillage, CR, and improved seeds increases as plot size increases.

It is more likely that farmers apply organic fertilizers on their own plots as compared to rented-in or borrowed plots. Organic fertilizers usually take several seasons to mineralize/oxidize which means that farmers who apply them on own plots are more likely to enjoy the full benefits than those who apply on rented plots due to the fact that rented-in/borrowed plots are characterized by lower tenure security.[6] Similar results have been reported by other researchers on adoption of SIPs (Kassie et al., 2013; Tenge, De Graaff, & Hella, 2004). However, farmers are less likely adopt CF and improved seeds on own plots. This may be due to the fact that these inputs are associated with short-term benefits and hence farmers could be tempted to exploit rented-in/borrowed plots by applying them (Kassie et al., 2013; Kassie & Holden, 2007).

Plot characteristics including soil properties and slope correlate with farmers' adoption decisions. It is less likely that farmers adopt CR and SWC on clay soils as compared to sandy or sandy-loam soils while it is more likely that they adopt CF on clay soils. Loam soil types are more preferred to other soil types to practice IC and apply OF, but they are less preferred for CR and IS. The probability of adoption of

Table 1. MVP regression estimates of adoption of SIPs in Ghana.

	IC		CR		SWC		OF		CF		IS	
	Coef.	SD	Coef.	SD	Coef.	SD	Coef.	SD	Coef.	SD	Coef.	SD
Plot characteristics and location												
Plot size (ln)	0.190***	0.057	0.313***	0.039	0.065*	0.039	0.048	0.049	0.137***	0.038	0.016	0.058
Farmer owns the plot	0.147	0.187	0.197	0.133	−0.147	0.140	0.519***	0.193	−0.310**	0.126	−0.383**	0.167
Moderate to steep slope or depression	0.051	0.105	0.106	0.136	0.478***	0.153	0.237	0.149	−0.023	0.124	−0.022	0.195
Gentle slope	−0.051	0.105	0.222***	0.079	0.158*	0.081	−0.229**	0.101	0.047	0.076	0.136	0.111
Type of soil is clay	0.248	0.156	−1.066***	0.109	−0.183	0.108	−0.144	0.172	0.441***	0.100	0.030	0.157
Type of soil is loam	0.307***	0.078	−0.251***	0.059	0.029	0.059	0.245***	0.072	−0.057	0.057	−0.158*	0.089
Proportion of plot with crusted soils (%)	−0.001	0.003	0.004*	0.002	0.009***	0.002	−0.016***	0.005	0.002	0.002	−0.000	0.005
Farmer perceives soil erosion on [PLOT]	0.401***	0.113	0.233***	0.090	1.637***	0.146	0.238**	0.107	0.026	0.085	−0.155	0.142
Plot is located adjacent to homestead	0.383**	0.184	−0.087	0.132	−0.118	0.135	1.322***	0.177	0.275**	0.126	0.271	0.201
It takes less than 15 minutes to reach plot	0.180	0.170	0.042	0.117	−0.299**	0.120	0.756***	0.169	0.095	0.111	0.293*	0.180
It takes 15–30 minutes to reach plot	0.213	0.147	−0.119	0.101	−0.204**	0.103	0.514***	0.156	0.008	0.097	−0.001	0.164
It takes 30–60 minutes to reach plot	0.261*	0.146	0.120	0.101	0.052	0.104	0.453***	0.157	0.012	0.098	0.203	0.161
Demographic characteristics												
Number of household members	0.131	0.146	−0.232**	0.107	−0.054	0.112	−0.100	0.134	−0.299***	0.104	−0.013	0.165
Number of household members in active labour category (15–64 years)	−0.108	0.118	−0.070	0.089	0.032	0.093	0.174	0.113	0.052	0.087	0.136	0.139
Household head can at least read and write	−0.046	0.093	−0.075	0.070	−0.040	0.071	−0.002	0.085	0.072	0.067	0.035	0.101
Household head is male	−0.206**	0.100	0.229***	0.085	−0.008	0.087	0.103	0.101	−0.022	0.080	−0.277**	0.113
Age of household head	−0.096	0.128	0.127	0.096	0.130	0.098	0.176	0.120	0.075	0.093	−0.046	0.145
Resource ownership and access												
Percapita household landholding (ha)	0.021	0.074	−0.272***	0.053	0.018	0.053	−0.011	0.067	−0.141***	0.051	−0.045	0.077
Total livestock owned (TLU)	−0.023	0.026	0.052***	0.020	0.052***	0.020	0.117***	0.026	−0.032*	0.019	0.012	0.030
Total off-farm income (GHS)	−0.011	0.012	0.029***	0.009	0.007	0.009	0.039***	0.012	0.022**	0.009	0.019	0.014
Distance from nearest market centre (minutes)	−0.001	0.003	−0.003	0.002	−0.001	0.002	−0.016***	0.003	−0.005**	0.002	−0.013***	0.004
Amount of input credit received (GHC)	−0.031	0.025	−0.024	0.017	−0.013	0.017	−0.121***	0.025	0.027	0.017	0.071***	0.021
Access to information and knowledge												
Received advise from extension agents	0.020	0.089	−0.059	0.066	−0.341***	0.068	0.240***	0.088	0.039	0.064	0.220**	0.106
Received advice from a model farmer	0.282**	0.128	0.295***	0.093	0.384***	0.093	−0.014	0.121	0.020	0.088	−0.145	0.139
Participates in trainings	−0.166**	0.084	0.507***	0.064	0.429***	0.064	−0.132*	0.078	0.141**	0.061	0.040	0.097
Farmer is a member of community's farmer research group	0.074	0.088	−0.140**	0.065	0.074	0.066	0.402***	0.077	0.028	0.063	0.375***	0.093
Farmer participates in local social groups	−0.133	0.090	0.521***	0.067	−0.054	0.067	0.323***	0.090	0.047	0.063	−0.047	0.103
Location dummies												
Northern region	−0.720***	0.104	0.540***	0.073	0.530***	0.072	−0.290***	0.091	0.566***	0.070	0.021	0.108
Upper east region	0.036	0.133	−0.404***	0.105	0.748***	0.107	0.296**	0.119	0.716***	0.100	0.034	0.152
Constant	−0.952*	0.548	−1.403***	0.417	−0.724*	0.422	−3.111***	0.531	−0.413	0.398	−1.063*	0.613
Number of observations											2545	
Log likelihood											−6611.57	
Wald χ^2 (203)											1625	
Likelihood ratio test for regression interdependence (χ^2 (21))											287***	

Notes: *,**,*** significant at the 10%, 5%, and 1% levels. Figures in parenthesis are standard errors.

SWC practices and CR increases as the proportion of crusted soils increases. However, plots with high level of crusted soils are less likely to receive OF. The perception of soil erosion enhances the application of SWC practices, OF, CR, and IC. Moreover, there is a strong positive association between the slope of land and application of SWC practices – i.e. plots with steep to moderate slopes are more likely to receive SWC practices than flat plots. The latter finding corroborates the findings of earlier studies (Clay et al., 1998; Kassie et al., 2013). However, a higher slope tends to discourage the application of OF which is similar to the results of Teklewold, Kassie, and Shiferaw (2013).

Home–plot distance affects the decision of farmers to adopt SIPs perhaps through its effects on the level of effort needed to accomplish the practices. Plots located adjacent to the residence more likely receive OF, CF, and IS as compared to distant plots (i.e. more than one hour away from home). They are also more likely to be intercropped. On the contrary, we found that plots that are closer to the residence (i.e. less than 30 minutes away) are less likely to receive SWC practices than the more distant ones. This is similar to the results of earlier studies such as Teklewold, Kassie, and Shiferaw (2013).

Most of the socioeconomic variables are significantly related to farmers' decisions to adopt SIPs. Distance to nearest market is negatively associated with applications of CF, IS, and OF. Farmers purchase commercial inputs from input dealers who are mostly located in major towns, and hence distance may matter for adoption as it could affect the transaction costs of acquiring the inputs. These results are in line with the results of some earlier studies (Kassie et al., 2013; Pender & Gebremedhin, 2007). We also found that the probability of adoption of improved seeds increases with the availability of input credit.

Land is a major factor of production in agriculture and, hence, its availability may affect the adoption of SIPs. Our result shows a negative correlation between per capita land size and adoption of CR and CF. This could be because of the fact that, within the setting of land scarcity, farm households have no option but to intensify farming in order to satisfy increasing food demand for their members and beyond (Boserup, 1965). Earlier adoption studies also found that the probability of applying SIPs would be high for households with smaller land holdings (Kassie et al., 2013; Ndiritu et al., 2014; Pender & Gebremedhin, 2007; Teklewold, Kassie, & Shiferaw, 2013).

Livestock husbandry and the off-farm economy are important complements of farming which may enhance the adoption of SIPs. Livestock holding is positively correlated with the use of organic fertilizers justifying the role of livestock as a source of manure. Moreover, households with more livestock holdings are more likely to apply SWC practices; this could be related to the fact that livestock are a source of draught power and finance which are necessary to these practices (Kassie et al., 2013; Pender & Gebremedhin, 2007; Teklewold, Kassie, & Shiferaw, 2013). Similarly, off-farm income is positively related to the application of CF suggesting the existence of synergy between crop production and the off-farm economy.

Intercropping and improved seeds are more likely to be adopted by female-headed households than male-headed ones. Intercropping attracts women more than men perhaps because it can buffer production risks as it allows them to grow multiple crops having different risk-response characteristics while increasing dietary diversification. The positive correlation between female-headed households and adoption of improved seeds was not expected. This may be due to interventions targeting women which have improved their access to improved seeds in recent years.

Farmers' access to information and knowledge emanating from their connections to the formal and the informal systems is important in explaining adoption. Farmers who received advice from model farmers have higher probability of adopting IC, CR, and SWC than those who did not receive any advice. Contact with extension agents has a mixed effect on the adoption of SIPs; consistent with earlier studies it has positive effects on the adoption of improved seeds and organic fertilizers (e.g. Clay et al., 1998; Ndiritu et al., 2014) while it has a negative effect on the application of SWC. Farmers' participation in training at farmers' training centres enhances the adoption of CR, CF, and SWC. However, it is negatively related to the adoption of IC and OF. Furthermore, farmers' participation in a research group enhances the adoption of OF and IS, while it reduces the adoption of CR which implies that active involvement of farmers in monitoring the impacts of technologies would allow farmers to make decisions on which technologies to adopt. Farmers who participate in various social groups are more likely to adopt CR and OF. These results suggest that the positive contribution of information and knowledge sharing systems on some practices has a crowding out effect on the others by diverting farmers' attention. However, most of them have a positive association with the adoption of SIPs and the apparent differences in the degree of association may suggest the existence of differentiated access of farmers to agricultural information sources and the existence of complementarity and substitutability among them.

Location dummies were considered at the regional level. The results show that farmers in the Northern Region more likely adopt CR, CF, and SWC as compared to those in the Upper West Region (the base region). However, the Upper West Region is better than the Northern Region in terms of the probability of adoption of IC and OF. On the other hand, the probabilities of adoption of OF, CF, and SWC are significantly higher in the Upper East Region than the Upper West Region while the latter is better in terms of CR.

5.3. Effects of SIPs on productivity and income

5.3.1. Comparing cumulative distributions

Prior to the MVTE analysis, we conducted analysis of stochastic dominance with respect to a function (SDRF) to compare cumulative distributions of maize grain yield and net monetary value (net income) associated with different situations of agricultural practices (i.e. treatments) (Meyer, 1977). Figure 1(a, b) shows that farmers who apply a higher number of SIPs are more likely to generate higher benefits in terms of grain yield and net income. The probability of getting the highest benefits is associated with the ≥4SIP category whereas the 3SIPs, the 2SIPs, and the ≤1SIP categories follow in that order. The results also indicate that the pattern of preferable categories would remain the same for different risk aversion coefficients which means that farmers' perceptions towards risk would not affect the adoption of any one of them.[7] The pattern of the cumulative distributions is by and large similar across regions except that there are only a few observations corresponding to the ≤1SIP category in the Upper East Region to see a smoother cumulative density function.

We also assessed how different types of SIPs and combinations affect the outcome variables. We rebundled the SIPs into commercial SIPs (CS) and non-commercial SIPs (NCS) and looked into the separate and combined effects of these categories on grain yield and net income. The SDRF results show that combining both commercial inputs and non-commercial inputs always dominates over the cases of using the inputs separately or using none of them in terms of grain yield (Figure 1(c)). This shows the existence of complementarity between CS and NCS. The result with respect to net income shows that the CS+NCS category dominates over the CS category and that the NCS category dominates overthe 'None of the SIPs' (NS) category (Figure 1(d)). However, the CS +NCS category is not always dominant over the others in terms of net income, implying that the marginal costs of commercial inputs are higher than the marginal returns for some farmers. The patterns are by and large similar across the three regions for both outcome variables.

5.3.2. MVTE model results

The MVTE model results show that the mean grain yield increases monotonically across treatment levels as one goes from the ≤1SIP category through to the ≥4SIP category (Table 2). That means, for example, adopting three sustainable practices instead of two increases maize grain yield while adopting four or more SIPs instead of two increases it even more. The highest mean effect is 296 kg/ha which would happen when one goes from the ≤1SIP category to the ≥4SIPs category. Changing from the ≤1SIP category to the 2SIPs category does not have significant effects on maize grain yield at mean as well as quantile levels although the figures are apparently positive (Table 2). However, all other pairwise differences are statistically significant at least at the mean level. The effects of changing from the ≤1SIP category to the ≥4SIPs category are statistically significant at the mean level and for all quantiles which show that using four or more SIPs instead of one or none can benefit farmers at all productivity levels. Similar results are observed when the ≥4SIPs category is compared to the 2SIPs category. Contrasts of 3SIPs vs ≤1SIP, 3SIPs vs 2SIPs, and ≥4SIPs vs 3SIPs also show that integrating higher number of SIPs would increase grain yield at the mean level although the positive impact may not be visible for lower end farmers.

The mean figures for net income are positive for all treatment levels varying from 233 GhC/ha to 270 GhC/ha. However, pairwise contrasts of the treatment levels show that none of the differences are statistically significant, indicating that the effects of using SIPs are not visible at any level of integration when major external costs are considered.[8] The exceptions are the 50th and 75th quantiles in the case of the 3SIPs vs. 2SIPs contrast and the 75th quantile in the case the ≥4SIPs vs. 2SIPs contrast which show positive and significant effects of applying higher number of SIPs on net income.

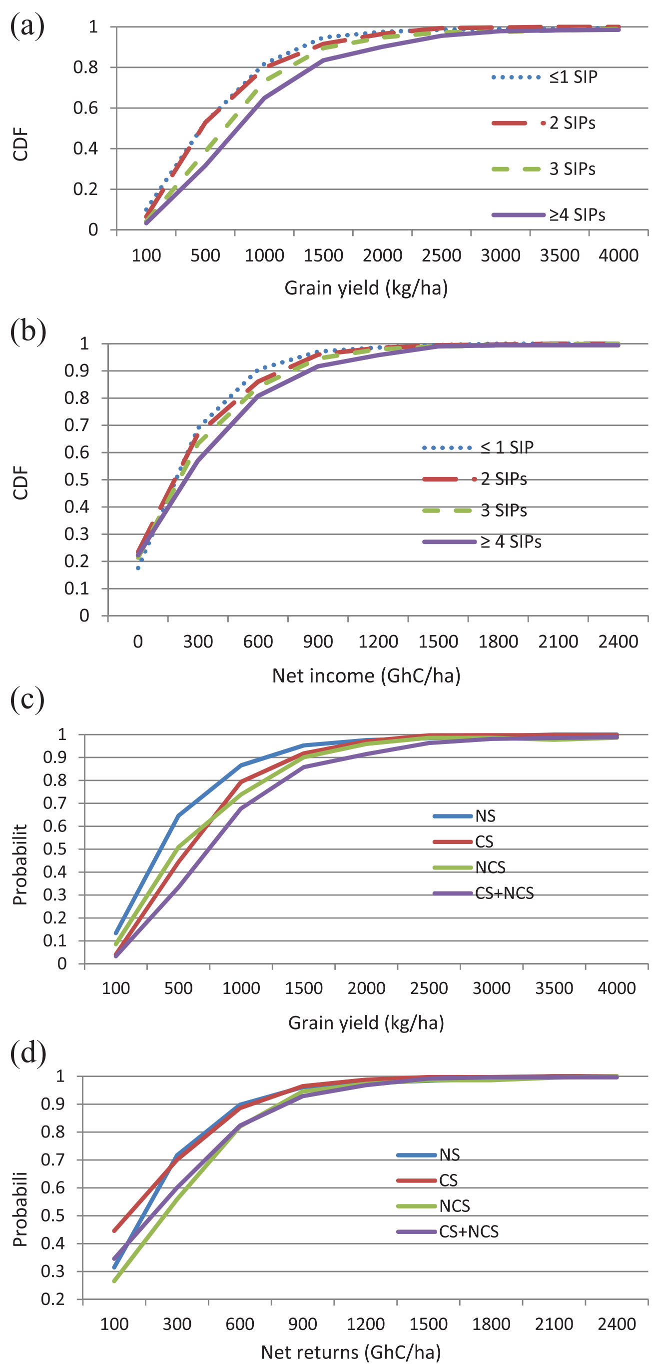

Figure 1. (a)–(d) Impacts of SIPs on maize grain yield and net income.

The alternative MVTE analysis shows that combining commercial SIPs and NCS would provide the highest mean grain yield which is 930 kg/ha whereas applying none of the inputs would provide the lowest mean grain yield (554 kg/ha). Pairwise comparisons of linear predictions show that using commercial SIPs and NCS separately or combined would produce higher grain yield than using none of them (Table 3). The highest mean difference is 376 kg/ha (68%) which would be realized when the inputs are combined. Combining

Table 2. Average treatment effect of SIPs on grain yield and net income, number of SIPs.

		Grain yield			Net income		
	Mean/Quantile	Contrast	Std. Err	95% Conf. interval	Contrast	Std. Err	95% Conf. interval
2 vs. 0	Mean	23	55	[55, −85]	−37	31	[−98, 24]
	25	49	58	[−65, 163]	−51	29	[−107, 5]
	50	0	75	[−148, 148]	−19	48	[−113, 74]
	75	55	125	[−189, 299]	−87	52	[−189, 14]
3 vs. 0	Mean	185*	57	[73, 297]	−13	30	[−72, 46]
	25	106	61	[−15, 226]	−40	31	[−102, 20]
	50	124	86	[−44, 291]	43	45	[−46, 132]
	75	329*	130	[74, 584]	11	58	[−103, 125]
4/more vs. 0	Mean	296*	59	[180, 413]	−3	31	[−64, 58]
	25	190*	64	[64, 316]	−55	33	[−119, 9]
	50	247*	81	[88, 406]	13	46	[−77, 103]
	75	417*	120	[181, 654]	9	55	[−99, 117]
3 vs. 2	Mean	162*	49	[67, 257]	24	27	[−29, 77]
	25	56	38	[−19, 132]	10	23	[−34, 54]
	50	124*	48	[29, 218]	62*	28	[7, 118]
	75	275*	92	[93, 456]	98*	45	[11, 186]
4/more vs. 2	Mean	273*	52	[172, 374]	34	28	[−21, 89]
	25	141*	41	[61, 220]	−4	24	[−52, 43]
	50	247*	41	[166, 328]	33	29	[−25, 90]
	75	362*	79	[207, 518]	96*	41	[17, 176]
4/more vs. 3	Mean	111*	53	[7, 216]	10	26	[−41, 62]
	25	84	45	[−4, 173]	−14	26	[−65, 36]
	50	124*	56	[14, 233]	−30	25	[−80, 20]
	75	88	88	[−84, 259]	−2	48	[−96, 92]

Note: *Statistically significant.

commercial and non-commercial inputs can also produce higher grain yield than using commercial inputs alone. The results of quantile estimations show, by and large, similar patterns although not all differences which are significant at the mean level are significant at the quantile level and vice versa. The differences become apparently higher as one goes from the 25th quantile through to the 75th quantile.

Table 3. Average treatment effect of SIPs on grain yield and net income, category of SIPs.

		Grain yield			Net income		
	Mean/Quantile	Contrast	Std. Err	95% Conf. Interval	Contrast	Std. Err	95% Conf. Interval
Commercial SIPs vs. None of the SIPs	Mean	169*	82	[61, 278]	−68	55	[−139, 3]
	25	205*	57	[93, 316]	−71	50	[−175, 40]
	50	206*	66	[76, 336]	−30	41	[−169, 27]
	75	309*	142	[30, 588]	8	85	[−111, 50]
NCS vs. None of the SIPs	Mean	279*	104	[125, 434]	117*	58	[38, 195]
	25	148*	64	[24, 273]	81	51	[4, 230]
	50	222*	88	[49, 395]	133*	39	[−19, 182]
	75	469*	162	[152, 787]	225*	99	[56,209]
Combined SIPs vs. None of the SIPs	Mean	376*	83	[264, 488]	12	53	[−55, 79]
	25	253*	59	[138, 368]	−29	49	[−92, 116]
	50	350*	63	[228, 472]	47	37	[−125, 67]
	75	568*	136	[302, 835]	122	85	[−25, 119]
NCS vs. commercial SIPs	Mean	110	79	[−29, 248]	184*	35	[121, 248]
	25	−56	48	[−150, 37]	152*	29	[116, 253]
	50	16	72	[−125, 158]	163*	34	[95, 210]
	75	161	108	[−51, 372]	217*	61	[96, 230]
Combined SIPs vs. commercial SIPs	Mean	207*	46	[119, 295]	80*	27	[31, 129]
	25	49	40	[−29, 126]	42	24	[28, 132]
	50	144*	38	[70, 219]	78*	31	[−7, 91]
	75	259*	64	[135, 384]	114*	36	[16, 140]
Combined SIPs vs. NCS	Mean	97	79	[−44, 238]	−105*	32	[−164, −45]
	25	105*	49	[9, 201]	−110*	28	[−168, −41]
	50	128	68	[−7, 262]	−85*	28	[−165, −56]
	75	99	100	[−98, 296]	−103	60	[−140, −31]

*Statistically significant.

However, the confidence intervals are overlapping for all possible pairs, suggesting that we will not reject the null hypothesis that the treatment effects have the same value.

The results with respect to net income show that using NCS alone would generate the highest benefit (374 GhC/ha) while using none of the SIPs would generate the lowest net returns (190 GhC/ha). The results also show that the comprehensive package constituting both commercial and non-commercial inputs is not the first best as it is the case for grain yield. It takes the second rank in terms of net returns. The change in the pattern of ranking could be related to the relatively high costs of accessing commercial inputs. Indeed, the marginal benefit of commercial inputs could not compensate for the increased cost. This is expected given the low yield in the season which has shifted the economic optima to the left of the production curve. However, the comparison should be interpreted cautiously for the reason that some of the inputs associated with cultural practices (e.g. organic fertilizers) have not been considered in calculating the net return as they are not tradable in the study areas. While the opportunity costs of these non-tradable goods are supposed to be small but positive, the inclusion of such costs can change the results in favour of using a combined use of commercial and non-commercial inputs.

6. Conclusions and implications

Sustainable agricultural intensification entails the adoption of modern technologies and cultural practices in an integrated manner. This study discusses the integration of SIPs by smallholder farmers in northern Ghana and its impacts on productivity and income. The MVP regression result shows that multiple factors would explain the adoption of SIPs which include access to market, access to credit, access to information, asset ownership, participation in off-farm activities, plot characteristics, and demographic factors, although the degree and direction of influence varies among the type of SIPs.

While all of the results provide useful information, the significance of access to information, market, and credit has important policy implications. Distance to the nearest market is negatively correlated with application of CF and improved seeds while access to input credit is positively associated with these inputs. The implication is that policies which would reduce the transaction costs of farmers by improving the road network, village-level input delivery system, and access to credit are important to enhance adoption. Moreover, supporting complementary income sources such as off-farm activities and livestock will relax the financial constraints of farmers, thereby enhancing adoption of SIPs. Furthermore, farmers' access to information and knowledge emanating from their connections to the formal and the informal systems have positive effects on adoption of SIPs. This implies that it would be necessary to use multiple knowledge sharing strategies to promote technology adoption instead of following the conventional singular formal information sharing approach.

We found that adoptions of SIPs are interdependent and that farmers more likely adopt agricultural practices as a package. A higher number of SIPs is associated with higher grain yield. The impact is apparently the highest in terms of grain yield when commercial inputs are used in combination with cultural practices. These results suggest that promoting integrated use of technologies, instead of a single technology, would have positive impacts on farmers' productivity and support the principles of sustainable agricultural intensification which are being promoted by many agricultural research and development programmes such as Africa RISING.

Our results also show that comprehensive packages that constitute both commercial SIPs and NCS would not always result in the highest net returns. This could be partly attributable to the high costs related to commercial inputs. Working to improve the efficiency of input markets is one way to minimize the costs related to commercial inputs.[9] Moreover, it is important for actors involved in the design, promotion, and dissemination of SIPs to find a suitable mix of these practices that will ensure higher productivity and income while minimizing the adverse effects of weather variability. This may require a well-designed research programme to review existing recommendations which are based on conventional input response trials that ignore potential complementarities among different practices.

Notes

1. Data from the Ministry of Food and Agriculture, http://mofa.gov.gh/site (last accessed on 16 July 2016).
2. The time frame is five years before the survey time.
3. The default number of random draw is 5 and the adjustment was made as suggested by Cappellari and Jenkins (2003).
4. We used a conventional count model (Poisson) for the pre-estimation analysis related to the number of SIPs.

For the other option (i.e. category of SIPs), we used the multinomial logit model.
5. We could not report the other alternatives of accessing improved seeds because of lack of detailed data on this.
6. Decomposability of organic fertilizers varies from 10% to 60% during the first year which shows that they can serve as a reservoir of minerals for multiple seasons (van Opheusden, van der Burgt, & Rietberg, 2012).
7. This is based on the analysis of stochastic efficiency with respect to a function (SERF) (Hardaker, Richardson, Lien, & Schumann, 2004). The risk aversion coefficients we considered varies from 0 (corresponding to a risk-neutral person) to 0.0001 (corresponding to a risk-averse person).
8. We considered costs of seeds, chemical fertilizers, pesticides, and other costs such as payments for tractor services.
9. Farmers mostly pay higher than official prices. For instance, during the season under consideration, farmers actually paid on average GhC110 for 100 kg of NPK fertilizer although the official price was pegged at GhC71.5. This might be because of inefficient input markets characterized by high transaction and transport costs.

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Appendix

Table A1. Benefits of sustainable intensification practices (SIPs).

SIPs	Benefits	Sample references
Cereal–legume CR	• Improve soil fertility by enhancing nutrient recycling and improved soil physical properties • Control pests and diseases, thereby increasing crop yield and reducing crop failure	Ijoyah (2014), Liebman and Dyck (1993), Flint and Roberts (1988), Mousavi and Eskandari (2011)
Cereal–legume intercropping	• Improve soil fertility by enhancing nutrient recycling and improved soil physical properties • Control pests and diseases, thereby increasing crop yield • Enhance farmers' adaptation to weather fluctuations as they involve the cultivation of multiple crops having different risk-response properties • Enhance dietary diversification; improve health	Teklewold, Kassie, Shiferaw, and Kohlin (2013), Ndiritu et al. (2014), Tilman et al. (2002), Ijoyah (2014), Liebman and Dyck (1993), Flint and Roberts (1988), Mousavi and Eskandari (2011)
Physical SWC	• Reduce the impacts of drought spells by increasing soil water availability or maintaining soil moisture • Decreasing soil erosion and ensuring the availability of nutrients to crops	Delgado et al. (2011), Ndiritu et al. (2014)
Organic fertilizers (manure, crop residue)	• Improve soil structure and add organic carbon to the soil which can serve as the energy source for useful soil microbial	Zingore et al. (2008)
CF	• Add nutrients to the soil and increase yield	Hazell (2009), Shiva (1991)
Improved seeds	• Increase yield • Enhance yield stability (reduce risk of crop failure) • Improve nutrition	Hazell (2009), Shiva (1991)