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Impact of Rainwater Harvesting on Livelihood Outcomes in Northern Ghana

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ABSTRACT
At the heart of the global community, the commitment to end hunger, poverty, and malnutrition at all levels remains a dominant target. This remains a difficult task without improved livelihoods. However, improved livelihoods largely depend on climate-smart agricultural practices (CSAPs) that draw together sustainable productivity, resilience, and emissions reductions under one umbrella. Yet, empirical information focusing on how CSAPs affect livelihoods remains scanty despite its policy relevance. In this study, the perceived benefits, adoption, and effects of rainwater harvesting (RWH) - one of the CSAPs - on livelihood outcomes in northern Ghana are examined using a dataset from the Ghana Agricultural Production Survey. The results revealed diverse perceptions as the farmers associate RWH with production increase (68.4%), reduction of drought effects (36.6%), seasonal crop failure (24.6%), erosion from runoff (24.0%), and quantity of inputs used (13.1%) and thus, indicate the underlying reason behind the adoption of water harvesting as CSAPs. Further, the results revealed farm size, labour, gender of farmer, level of education, credit access, membership to FBO, extension access, tenure security, number of irrigation sites accessible to the farmer, soil type, and farmer's perception as the main factors influencing the uptake of RWH in northern Ghana. Concerning the livelihood effects of adoption, RWH was found to improve yields and food security. It is therefore recommended that CSAPs including RWH techniques should remain a policy focus in drought-prone areas of Ghana. Government can focus on developing or improving existing infrastructure for rainwater harvesting in these areas.

INTRODUCTION
Sustainable livelihood remains central to the Agenda 2030 for sustainable development (Zero Hunger Challenge, 2016). However, sustainable livelihood including improved food production, food security, nutrition, and zero hunger is not achievable without climate-smart agriculture practices (CSAPs). Adoption of CSAPs can maintain ecosystems, reduce the emission of greenhouse gas, improve land quality and food security. Thus, the bottom line is that CSAPs can enhance food security, adaptation, and mitigation (FAO, 2010; Arslan *et al*., 2015; Issahaku and Abdulai, 2019a; Teklewold *et al*., 2019; Tesfaye *et al*., 2020).

The agriculture sector is also a strong option for achieving sustainable livelihoods in Africa (Djurfeldt *et al*., 2010; Brooks, 2016; Scharlemann *et al*., 2020). However, Africa still faces several challenges. For example, food insecurity is still a challenge in Africa as 19.1% is food insecure (FAOSTAT, 2020). Further, the population of undernourished people increased from 199.7 in 2000 to 256.1 million in 2018 *(FAO et al*., 2020). These challenges are reflected in the low productivity for the agricultural sector *(Bjornlund et al*., 2020). Realizing the prospects of CSAPs, many governments and stakeholders have largely promoted the adoption of CSAPs to better rural livelihoods and as well save the environment. For instance, the Climate Policy

Initiative estimated that by 2017/2018, annual global financial flows for mitigation and adaptation of climate change ranged between US$564 and US$612 billion (Buchner *et al*., 2019). Several countries have also been able to access funds for CSAPs through the Food and Agriculture Organisation (FAO, 2023). Extension strategies are also developed by the Global Alliance for Climate-Smart Agriculture (GACSA) to guide the dissemination of information that will lead to the adoption of CSAPs (GACSA, 2016).

In the case of Ghana, significant investments have also been made by public and private institutions including the Ministry of Food and Agriculture (MoFA), Climate Change, Agriculture and Food Security, and Cooperative for Assistance and Relief Everywhere on the development and dissemination of CSAPs to reduce yield losses (Essegbey *et al*., 2015). Among the practices that have been developed and disseminated in the country include agroforestry, dry land farming, tied ridging, fertilizer banding, micro-dosing, conservation tillage, mulching, crop rotation, contour earth mounds, vegetative barriers, improved fallows, integrated nutrient management, intercropping, cultivation of drought-resistant crops and rainwater harvesting. The northern sector, in particular, remains the target destination for the development of these practices because of the short rainfall distribution, high average annual temperatures, and prolonged drought which consequently presents challenges to smallholder farmers during crop production in the area. However, the adoption of these techniques is far lower than what prevails elsewhere in the country despite their benefits and as well as institutional efforts to promote them (Abdallah, 2017). Moreover, whiles the performance of CSAPs is often discussed in policy documents in Ghana (e.g. Sarpong and Anyidoho, 2012) and the literature elsewhere in Africa (Harvey *et al.*, 2014; Arslan *et al.*, 2015; Bagley, Miller, and Bernacchi, 2015; Way and Long, 2015; Makate *et al*, 2016; Sikka, Islam, and Rao, 2017; etc.), the empirical studies on the perceived benefits of CSAPs and its livelihoods impacts are limited in the literature in Ghana. Thus, knowledge of CSAPs and its livelihoods impacts is scanty in northern Ghana even though such knowledge could be relevant for agricultural and environmental policies.

By way of contributing to the existing literature on CSAPs (Harvey *et al*., 2014; Arslan *et al*., 2015; Way and Long, 2015; Makate *et al*., 2016; Sikka *et al*., 2017), this paper provides evidence on the adoption and effects of CSAPs on livelihoods outcomes using a unique dataset from the Ghana Agricultural Production Survey (GAPS). In particular, the study focused on rainwater harvesting (RWH) since it has the potential to supplement water for continuous production and the adoption of other techniques. In addition, it is the only technique that directly addresses the unimodal rainfall distribution and the prolonged drought of the area. Specifically, the average rainfall of the area ranges between 1000 mm and 1100 mm annually, and last from 150-200 days. This has made RWH attain popularity and to most farmers, embracing it may significantly reduce losses resulting from water shortage and as well as improve the livelihoods of smallholder farmers. Additionally, RWH is the only technique that has the potential to achieve the triple wins of CSAPs, and thus, justifies the study's focus.

Specifically, the study examines households' perceptions of the benefits of RWH using bar charts with descriptive statistics. For the adoption of RWH and its impact on livelihood outcomes, this study modelled the adoption of RWH under utility theory where the net benefit of adoption of CSAPs influences farmers' decisions. Next, the study controlled for endogeneity in rainwater harvesting through joint estimation of adoption and each of the livelihood outcomes of interest using the framework of the Conditional Mixed Process (CMP) (Roodman, 2009). Further, the robustness of the results is assessed using the OLS.

MATERIALS AND METHODS

Study Area

The study was conducted in northern Ghana in three (3) regions namely; Northern, Upper East, and West Regions (Figure 1). This area is mainly guinea Savannah with grassland, woodland, and drought-resistant trees as the main vegetation. Most people in the area are farmers. However, production is largely dependent on rainfall which is characterised by a single and short rainy season (lasting between May and October). The area is also characterized by high temperatures and prolonged drought with consequences of poor soil moisture and yields. These challenges not only put food security under threat but also increases food expenditure and widen the poverty between farmers in this area and those in the southern part of Ghana. Available statistics showed that 36% of households in northern Ghana live with moderate hunger and also spend 36-42.6% of mean annual per capita expenditure on food (Abu *et al*., 2016; Ghana Statistical Service, 2019). In response to the aforementioned challenges in the area, CSAPs have been endorsed and promoted by the government as one of the best approaches to sustainable livelihood (Essegbey *et al*., 2015). In line with the endorsement by the government, several CSAPs including rainwater harvesting have been adopted by farm households in northern Ghana and SSA (Issahaku and Abdulai, 2019a, 2019b). In this study, the livelihoods impact of CSAPs is examined but from the perspective of how rainwater harvesting affects yields, net revenue, food self-sufficiency, and food security.

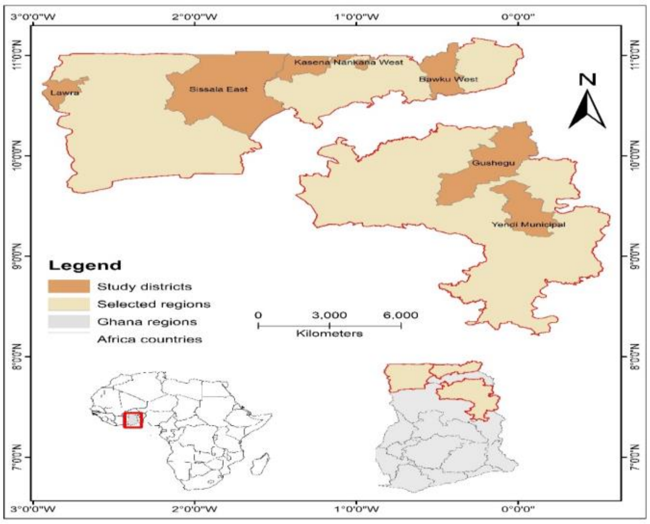

Figure 1: Map of study sites in northern Ghana

Estimation Techniques

This study aims to measure the effects of CSAPs (i.e., rainwater harvesting) on livelihood outcomes such as yields, net revenue, maize self-sufficiency, and food security. Hence, a multi-stage estimation procedure was employed.

Theoretical Basis for Modeling Adoption of Rainwater Harvesting

This study considered the adoption of rainwater harvesting (RHW) as a binary choice and thus, employs the rational choice behavior in modeling. In that regard, it is assumed that farmers are rational in their decision to practice the RWH technique as the main CSAPs and thus, weigh up the expected net utility from RHW against other options. If B_a is the actual benefit of the farmer in adopting rainwater harvesting and B_p is the perceived benefits of adopting the RHW, the net benefit B_n of adopting the same practice will be defined as:

$$B_n = B_p - B_a \qquad (1)$$

Econometrically, however, B_n cannot be directly observed but can be denoted as the choice of adoption Y defined as:

$$\mathrm{Y} = 1 \ \text{ if } B_n \leq 0 \qquad (2)$$

$$\mathrm{Y} = 1 \ \text{ if } B_n > 0 \qquad (3)$$

However, the adoption choice is also related to the observed farmer and other characteristics X in the specification:

$$Y = \delta' X_i + \varepsilon_i \qquad (4)$$

Where: δ' is a coefficient of X; and $\delta' X_i$ is the index function of the probability of adoption of RWH as CSAPs estimated as:

$$Pr[Y > 0] = Pr[\delta' X_i + \varepsilon_i > 0] \qquad (5)$$

If the error term ε_i has a mean of 0 and variance $\sigma^2_{U_n}$, then the probability of adoption can further be expressed as:

$$Pr(Y > 0) = f(\delta' X) \qquad (6)$$

Where: f is the cumulative distribution function of ε_i. The probability of adoption of RWH, Y is determined with the maximum likelihood function specified as:

$$\mathrm{lnL} = \sum_{\mathrm{y_i}=0} ln(1 - \Phi_{\mathrm{i}}) + \sum_{\mathrm{y_i}=1} ln(\Phi_{\mathrm{i}}) \qquad (7)$$

Where $\Phi_i = f(\delta' X)$.

Modelling the Links Between Adoption of Rainwater Harvesting and Livelihood Outcomes

The adoption of RWH is a means to an end. Thus, this study is not only interested in the adoption decisions of farm households, but also in the impact of such adoption decisions on their livelihood outcomes including yields, net returns, maize self-sufficiency, and food security. In this respect, the equation relating the adoption of RWH to livelihood outcomes is specified as:

$$Q_i = \beta_0 + \beta_1 Y_i + \beta_2 X_i + v_i \quad (8)$$

Where: Q_i represent the livelihood outcome of smallholder farmer *i* in this study; Y_i is rainwater harvesting; X_i is household, farm, and institutional indicator; and v_i is the error term. If a researcher can observe all factors in equation (8), the effects of rainwater harvesting Y_i on household livelihood outcomes would be β_1 without any form of selection bias. Unfortunately, all factors contained in equation (8) are not observable and are therefore captured v_i. For instance, the nature and some characteristics of rainwater harvesting which partly determine its adoption are sometimes not clear and are therefore captured in v_i. Aside from these problems, adoption of the rainwater harvesting is also partly determined by the characteristics of innovators. For instance, adoption could be triggered by innovators' ability to promote rainwater harvesting. However, such information may be unobservable to the researcher and may correlate with the variables X_i and thus, result in selectivity bias. In this regard, $E(X_i{}' v_i) \neq 0$, and OLS estimation of equation (8) will produce biased estimates if the potential endogeneity resulting from unobserved variables is not controlled for. Consequently, the endogeneity between livelihood outcomes and the practice of rainwater harvesting is a major methodological concern. To estimate the adoption of RWH and its effects on livelihood outcomes, the Conditional Mixed Process (CMP) was employed (Roodman, 2009). With the CMP, instruments are not necessary for the identification of the equations. However, since it is important to include instruments, this study used the perception of the farmer about rainwater harvesting; a dummy variable which is measured as 1 if perceived as highly beneficial and 0 otherwise. Unlike the instrumental variable estimation, the CMP controls for endogeneity and allows for the mixing of both continuous and limited dependent variables models in multi-equation systems. However, this approach is computationally cumbersome, especially, for a large number of equations involved in the estimation. To avoid this problem, a maximum of two equations are estimated for rainwater harvesting and each of the livelihood outcomes.

Data and Description of Variables

The study relied on a dataset from a survey of agricultural production conducted by the Ministry of Food and Agriculture in the 2011/2012 cropping season. The survey was conducted to provide reliable information about agricultural statistics to all stakeholders in production. A multi-sampling procedure was employed in sampling a total of 8000 households across the 10 regions for the survey. The sampling consisted of a random selection of 2 districts from each region in the first stage; 40 Enumeration Areas (EAs) from each district in the second stage; and 10 holders EA in the third stage. In all, a total of 8000 were sampled for the survey. In this study, 1,140 holders from the Northern, Upper East, and Upper West regions are employed for analysis. Figure 1 highlights the survey sites for this study. The data captured information on households 'adoption of CSAPs, reasons for adoption, production, and institutional characteristics. For perceived benefits of adoption, the survey asked to respondents about the main reason for adopting soil and water conservation practices in Ghana. The reasons provided were considered as the underlying perceptions for adopting each technology. Thus, the reasons associated with the adoption of rainwater harvesting were used as the perceptions about the benefit of adopting RWH. The perceived benefits capture includes (i) increase production (ii) reduce input use (iii) reduce erosion (iv) counter the effects of drought and (v) reduce crop failure as the reasons for adopting agricultural practices during crop production in Ghana. These were then analysed using descriptive statistics with bar charts. RWH is captured as a dummy variable representing 1 if the farmer practices the technique and 0 if otherwise and the statistics indicate that 51% of farmers adopted rainwater harvesting in the study area. For measuring the livelihood outcomes, four variables were employed. These included maize yields, net returns, self-sufficiency in maize production, and food security. Like in other studies (Abdulai and Buss, 2013; Ma and Abdulai, 2016), net returns are defined as the value of maize yields fewer inputs value per hectare. This is measured in Ghana Cedis and the statistics showed that on average, farmers obtained an amount of GH¢1,182.13 from production. Further, maze yields of the farmer in the 2011/2012 cropping season were captured in kilogram per hectare and the statistics indicated an average yield of 128.4 kg/ha. To measure food self-sufficiency, the study adopted the approach of Jolly and Gadbois (1996) with slight modifications. According to Jolly and Gadbois (1996), food self-sufficiency (FSS) is estimated as follows:

$$FSS = \frac{\text{Total available cereal}}{\text{Population of family unit}} \qquad (9)$$

Where: total available cereal is the sum of total refined cereal and cereal in maize equivalent basis purchased from all cash crops. In this study, however, production information about cash crops is limited and thus, restricts the calculation of FSS to self-sufficiency in maize production (SSM). Thus, the total available cereal becomes $(\text{CP}\times 0.85)$ and equation (9) is specified as:

$$SSM = \frac{CP \times 0.85}{\text{The population of the family unit}} \qquad (10)$$

The SSM was, however, subjected to the same rule of thumb of 170 kg of cereal per annual equivalent (Djurfeldt *et al.*, 2010) as in the estimation of FFS. Thus, a household is a maize self-sufficient if the calculated SSM is greater or equal to 170 kg (i.e., 1 if self-sufficient and 0 if deficient). By these statistics, the majority of households (i.e., about 73%) were shown to be maize deficient with only about 27% being self-sufficient in the production of maize. Concerning food security, different indicators have been proposed in literature (FAO, 2008; WFP, 2009) and applied in research studies in various countries (Maxwell et *al.*, 2014; Mango *et al.*, 2014; Bekele Shiferaw, Menale Kassie, 2014; Shete and Rutten, 2015; Makate *et al.*, 2016; Abdallah *et al.*, 2021; Abdallah *et al.*, 2022). These indicators include the household dietary diversity score, household food insecurity access score, and food consumption score. However, due to the lack of actual variables for calculating these indicators, this study resorted to two measures; the first measure of food security is captured as 1 if the household completely harvested the maize without partial or complete mortgaging of the crops for consumption in the 2011/2012 season, and 0 if otherwise (Smith and Wiesmann, 2007; Stamoulis and Zezza, 2003; Owusu *et al*., 2011). The second measure captured food security using the household's food gap which is the difference between the household food need and food possessed (Thomson and Metz, 1998). The difference was then compared with the expenditure share of food within the households (Ghana Statistical Service, 2014) to determine how much of this gap can be covered by the food share of the total household income. If that share of income meets this gap then the household has no food gap and hence is measured as 1 and if the share does not meet this gap, then the household is said to have a food gap and thus, capture as 0. Again, the results in Table 2 showed that less than one-quarter (i.e., about 28%) of the households have no food gap while 60% partially or completely mortgage field crops before harvest. To produce food, households need land; materials; and labor. Land and labor were respectively measured in the number of hectares and man-days use in producing maize. However, the GAPS database did not directly capture materials in production. Consequently, materials were proxied by fertilizer and chemicals. Fertilizer was captured in kilograms while chemicals were captured in liters. Concerning these inputs, the statistics indicate an average farm size of 3.44 ha, 9.44 man-days of labour, 152.20 kg of fertilizer, and 1.56 liters of chemicals per hectare during production. In addition, gender (a dummy assigned a value of 1 if the farmer is male and 0, otherwise), age of the farmer (in years), level of education (in years), credit access (captured as a dummy and 1 for credit access in the growing seasons under consideration and 0, otherwise), membership to FBO (1 for being a member of farmer-based organization and 0, otherwise), extension- captured as 1 if a farmer accessed extension services and 0, otherwise, tenure security represented by 1 if the farmer is secured and 0, otherwise, distance from farm to the market/motorable road (measured in km), Upper East Region (1 if farmer resides in Upper East Region and 0 if otherwise), Upper West Region (1 if the farmer resides in Upper West Region and 0 if otherwise) and Northern Region (1 if farmer resides in the Northern Region and 0 if otherwise) were included to measure the effects of household characteristics, infrastructure, institutions, information, social capital, liquidity constraint and location on adoption and the livelihood outcomes. The definitions and summary statistics of these variables are presented in Table 1.

Table 1: Variable description and summary statistics

Variable	Description	Mean	Std. Dev.
Yields	Maize output (kg/ha)	128.41	269.99
Net returns	Revenue minus the value of variable inputs per hectare (GH¢)	1182.13	1944.08
Food gap	Dummy (1= no food gap; 0=food gap)	0.28	0.45
Mortgage status	Dummy (1=complete harvested without mortgage; 0 otherwise)	0.60	0.49
Maize self-sufficiency	Dummy (1= self-sufficient; 0=deficient)	0.27	0.44
Rainwater harvesting	Dummy (1=farmer adopted rainwater harvesting; 0=otherwise)	0.51	0.44
Farm size	Total maize area (ha)	3.44	4.62
Labour	Labor application (person days)	9.40	16.72
Fertilizer	Application of nitrogen fertilizer (kg/ha)	152.20	704.38
Chemicals	Application of agro-chemicals (litres/ha)	1.56	4.84
Gender	Dummy (1= male; 0=female)	0.27	0.45
Age	Age of respondent (years)	49.52	14.22
Education	Formal schooling years	4.88	4.22
Credit	Dummy (1= received credit; 0=otherwise)	0.65	0.48
FBO	Dummy (1=farmer belongs to farmer-based organization; 0=otherwise)	0.72	0.45
Extension	Dummy (1=farmer received extension service; 0=otherwise)	0.38	0.48
Distance	Distance to the nearest market centre (km)		
Tenure	Dummy (1=full control over land, 0=otherwise)	0.58	0.49
Northern	Dummy (1=farmer resides in the Northern region; 0=otherwise)	0.37	0.48
Upper West	Dummy (1=farmer resides in the Upper West region; 0=otherwise)	0.29	0.45
Upper East	Dummy (1=farmer resides in the Upper East region; 0=otherwise)	0.33	0.47
Perception	Dummy (1=perceived rainwater harvesting as highly beneficial; 0=otherwise)	0.61	0.49
Irrigation	Number of accessible irrigation sites in the area	0.79	0.51
Sandy soil	Dummy (1=farm land has sandy soil; 0 otherwise)	0.47	0.50
Loam soil	Dummy (1=farm land has loam soil; 0 otherwise)	0.27	0.44
Clay soil	Dummy (1=farm land has clay soil; 0 otherwise)	0.26	0.44

Note: GH¢- Ghana cedis.

RESULTS AND DISCUSSION

Perceived Benefits of Rainwater Harvesting

The results of the perceived benefits of rainwater harvesting as the main CSAPs in northern Ghana are shown in Figure 2. The farmers reported a wide range of benefits as their perceptions about the use of rainwater harvesting in farming. However, most of the farmers, representing 68.4%, attributed the adoption of rainwater harvesting to the potential of increasing production. This is comparable to the findings of

Domènech *et al*. (2012) in Nepal where 77.3% of households were reported to have improved their kitchen garden using water harvested from rain. Farmers who associated the practice with the potential of countering drought effects were 36.6% and thus, represent the second majority. Further, about 24.6% of the farmers perceived rainwater harvesting as a practice that reduces seasonal crop failure in northern Ghana while 24.0% perceived it as a practice that reduces erosion caused by runoff from heavy downpours. This is similar to other studies that find water harvesting to reduce erosion from runoff and as well increase productivity (Sikka *et al*., 2017). Last and the least, about 13.1% of the farmers think the practice reduces the number of inputs used during sowing, especially when the germination percentage is not met.

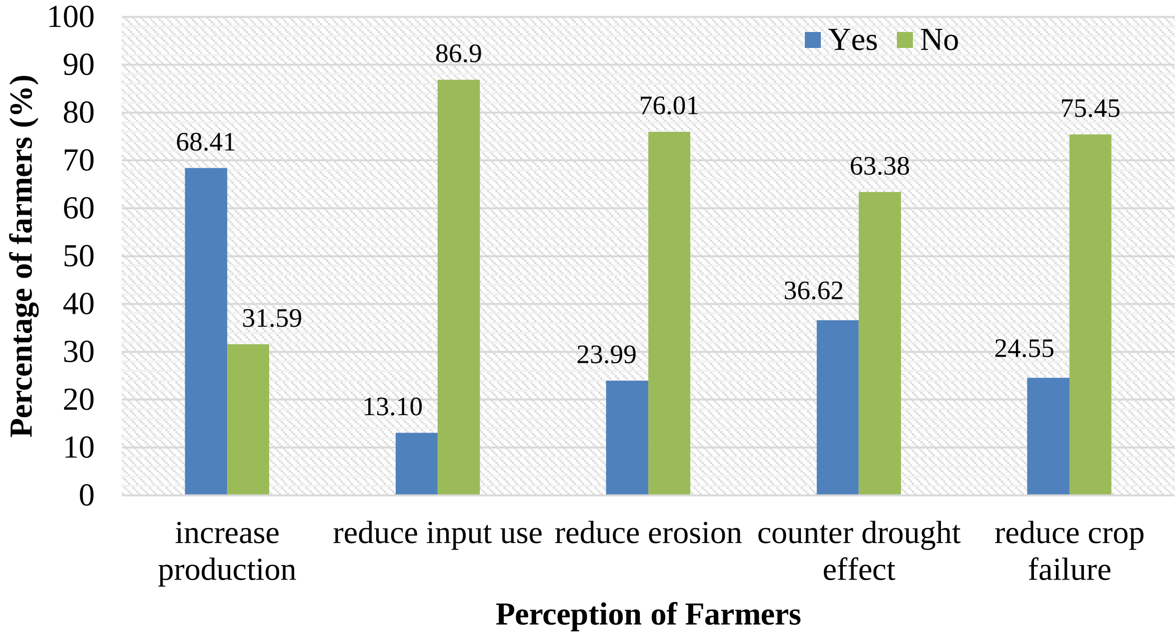

Figure 2: Perceived Benefits of Water Harvesting in Northern Ghana

Tests of Endogeneity of Rainwater Harvesting

The second objective of this study is to determine the drivers of the adoption of rainwater harvesting as the CSAPs and its impact on household maize yields, net revenue, self-sufficiency in maize production, and food security. However, as explained previously, rainwater harvesting may be endogenous in the outcome equation specified in equation (8). Thus, before the estimation of the drivers of the adoption of rainwater harvesting and its impact on household maize yields, net revenue, self-sufficiency in maize production, and food security, tests of endogeneity of rainwater harvesting were conducted. For self-sufficiency and food security, the marginal probabilities from the Heckman probit models with sample selection were compared with the predicted probabilities of normal probit models of self-sufficiency and food security. However, the marginal predicted probabilities from the probit models with sample selection were more accurate and thus, indicate the presence of selection bias. With regards to the yield and net-return models, the study tested for the null hypothesis that rainwater harvesting can be treated as exogenous using the Durbin-Wu–Haussmann tests. However, the null hypothesis of exogeneity was rejected in both models. Thus, the results, as shown in Table 2, indicated that rainwater harvesting is endogenous in the yields, net revenue, self-sufficiency, and food security models. Given that the RWH is endogenous, the conditional recursive mixed process (CMP) was employed to control for the endogeneity. The choice of the CMP over the instrumental variables (i.e., in the case of yields and net-revenue models) and probit model with sample selection (i.e., in the case of self-sufficiency and food security models) is associated with the difficulty of finding reliable instruments. The CMP jointly estimates the determinants of the adoption of RWH and its impact on the outcome of interest. The results are presented in the next sections. It is also important to note that the literature is not conclusive about the endogeneity of access to credit and extension services. While some consider these variables endogenous (Simtowe and Zeller, 2006; Abdallah, 2016a; Abdulai, 2016a;), others do not (e.g., Kousar *et al.*, 2014). For this study, similar endogeneity tests were conducted for these variables. However, the null hypotheses of the exogeneity of these variables were not rejected and thus, were therefore treated as exogenous variables.

Table 2: Tests of Endogeneity

Food security models	Mean	Std. Dev.
Marginal probabilities	0.6614	0.2923
True probability values	0.6167	0.3444
Normal Probit probabilities	0.6869	0.2837
Durbin-Wu–Hausman test statistics	F(1, 517)	$P-value$
Yield model	4.53	0.03
Net Returns model	12.31	0.00

Drivers of Adoption of Rainwater Harvesting

The joint estimations of the effects of rainwater harvesting (RWH) on livelihood outcomes are presented in Table 3 with *atanhrho* values (i.e., the primary measure of selection bias) reported at the bottom. It is observed that all the statistics (i.e., *atanhrho* values) are significant and positive and thus, indicate the absence of selectivity bias in the adoption of rainwater harvesting after controlling for endogeneity. These imply that there are no omitted variables affecting rainwater harvesting and each of the livelihood outcomes.

The results of the probit estimate of the drivers of the adoption of RWH in northern Ghana are presented in column 2 of Table 3. Farm size, labour, gender of farmer, number of years of schooling, credit access, membership to FBO, extension access, tenure security, number of irrigation sites accessible to the farmer, sand, and perception of the farmer were found to be the significant determinants of the adoption of RWH. Specifically, farm size displayed a negative relationship with the adoption of RWH and thus, implies that the adoption of RWH is likely to be lower for households with larger farm sizes as compared with households with smaller farm sizes. Though contradictory to some literature on the adoption of CSAPs (Solís *et al*., 2009; Abdulai and Huffman, 2014; Makate *et al*., 2016; Manda *et al*., 2016), the result is plausible for a technique like water harvesting which requires high labour for large farms. The result is perhaps explained more clearly by the labour variable which exerts a positive influence on adoption. Similar inconsistent results about the effects of farm size and labour on adoption are noted by recent studies in sub-Saharan Africa (Abdulai, 2016; Abdul-Hanan, 2016).

Further, extension service access and tenure security which capture the effect of institutions are also positive and significant and thus, indicate that farmers with access to institutions are more likely to adopt rainwater harvesting as the main CSAPs. These particular findings lend credence to the notion that institutions are essential for the adoption of new technology and as well as transformation of subsistence-oriented smallholder agriculture (Zeller and Diagne, 2001; Teklewold *et al.*, 2013). In particular, the 'Six Is' framework, which promotes institutions as one of the best ways to rural transformation, is corroborated in this study and other studies (Johnston, 1989; Kibaara *et al*., 2008). Also, the finding concerning tenure security has settled the controversy concerning the role of tenure security in investing in agricultural production technologies (Goldstein, 2008; Asfaw *et al*., 2011; Arslan *et al*., 2015). A similar result is observed in a study by Abdul-Hanan (2016) in which tenure security is significant and positively related to adoption.

Membership in the farmer-based organization is also positively related to the adoption of RWH, suggesting RWH is more likely to be taken up by farmers who belong to farmer-based organizations in the area. The information-sharing that is characteristic of these groups might have helped relax some of the complexities in adopting rainwater harvesting. The social capital and networks literature (Teklewold *et al*., 2013) which treats membership to associations as a means of information access and asymmetries reduction is again corroborated in this study. Perhaps, this finding is re-echoed in the positive and significant relationship between education and water harvesting.

The importance of infrastructure in facilitating the adoption of livelihood-enhancing technologies is well documented in the development economics literature. Specifically, most studies find a positive relationship with the adoption of yield-enhancing techniques (Feder and Onchan, 1987; Binswanger *et al*., 1993; Pender and Kerr, 1998). In this study, however, infrastructure proxied by the number of irrigation sites accessible to the farmer is negatively related to rainwater harvesting. The inverse relationship between the number of accessible irrigation sites and rainwater harvesting is perhaps explained by similar roles played by irrigation and the rainwater harvesting technique. The option between the two might depend on the availability, accessibility, affordability, and possibly, the ease of use and hence calls for further investigation in that direction. The role of liquidity constraint is also manifested in this study as indicated by the positive and significant relation between credit access and rainwater harvesting. Specifically, the results suggest that liquidity-constrained farmers are less likely to adopt rainwater harvesting in northern Ghana. This finding shows the overwhelming role of credit in agricultural investment such as rainwater harvesting as the CSAPs. Similar results are observed in other agricultural investment and technology adoption literature (e.g. Mohamed and Temu, 2008). Similarly, soil type and location variables are positively related to the adoption of rainwater harvesting and thus indicate that the practice is more likely to increase among farmers producing in sandy soils and located in the upper regions than in the loam and northern regions respectively. Of particular interest is the positive sign exerted by the perception of rainwater harvesting, suggesting that the probability of the adoption of rainwater harvesting is more likely to increase among households that perceive the practice as highly beneficial. The negative sign of gender also suggests a decrease in the probability of the practice among male farmers. This is not surprising for the area under consideration. In northern Ghana, the practice is initially adopted at the household level by females who supplement the limited water from taps to perform household chores. This is later taken up by men who direct runoff to well-dug pits for productive purposes and to prevent erosion.

Effect of Rainwater Harvesting on Household's Livelihood Outcomes

Column 3, 4, 5, 6, and 7 of Table 3 presents the CMP results of the impact of rainwater harvesting on household livelihood outcomes such as maize yields, net revenue, maize self-sufficiency, and food security in northern Ghana. Robustness checks were conducted by simply regressing the covariates (including rainwater harvesting) on each of the livelihood outcomes using OLS (in the case of yields and net revenue) and probit (in the case of self-sufficiency, food gap, and mortgaging) without controlling for endogeneity. However, except for self-sufficiency in maize production, no significant associations between rainwater harvesting and any of the livelihood outcomes were observed. Further comparison with the results of joint estimations from CMP indicates significant differences in coefficients between the models. Specifically, the coefficient estimates from the CMP estimates were slightly smaller than those in the OLS and probit models and thus, pointing to an upward bias if the endogeneity of rainwater harvesting was not controlled for. The discussions, therefore, focused on the results of the CMP models.

Among the factors included in the model for maize yields in this study, are farm size, labour, gender, education, credit, membership to FBO, access to extension service, tenure security, number of accessible irrigation sites, soil types, and regional variables were found to exert a significant influence on maize yields in the area. Similar observations are noted about the household's net revenue model. In particular, it is observed that farm size, labour, chemicals, gender, age square, education, credit, distance to the nearest market, extension service, tenure security, and soil types significantly influence a household's net revenue. With regards to the results of the model for self-sufficiency in maize production, farm size, chemicals, gender, age, credit access, distance, extension service, tenure security, soil types, and regional variables were found to be the significant factors influencing the household's sufficiency in the production of maize. With regards to households' food security models, farm size, fertilizer, gender, age, credit access, tenure security, number of accessible irrigation sites, and soil type were noted to be significant determinants of food gap and mortgaging of crops on the fields, though the signs were inconsistent. Further, labour is found to have a significant influence on the food gap but not the mortgaging of standing crops on the field. A similar result is displayed by education. On the other hand, the square of age, distance, membership to FBO, access to extension service, and soil type exert significant influence on the mortgaging of field crops but not the household's food gap. For brevity, these results are not discussed in detail. Rather, only the results of the effects of rainwater harvesting on livelihood outcomes are discussed in detail.

Regarding the estimates of the impact of the adoption of rainwater harvesting on livelihood outcomes, the results showed a positive and significant influence of rainwater harvesting on household yields, suggesting that rainwater harvesting is a vital determinant of higher maize yields. This is an important finding because the negative effects of climate change reduce crop yields in the northern part of the country. Further, the results indicate a significant role played by rainwater harvesting in explaining the variations in maize net revenue of households. However, the two were inversely related, suggesting a decrease in net revenue for farmers who adopted rainwater harvesting. The decrease in net revenue is perhaps attributed to high expenditure which is probably not outweighed by the corresponding increase in yields. These results contradict other studies which found that CSAPs significantly increase both yields and net returns (Abdulai and Huffman, 2014). Similarly, an inverse and significant relationship is observed between rainwater harvesting and self-sufficiency in household maize production, indicating that the mere practice of rainwater harvesting as CSAPs alone does not enhance self-sufficiency but rather reduced the household's chances of attaining self-sufficiency in maize production. Also, while the practice is positive and significantly related to the household food gap, it is negatively related to the household mortgaging of food crops for food before harvesting. These results indicate that households adopting rainwater harvesting are less likely to have food gaps or mortgage food crops in northern Ghana. Thus, with the adoption of rainwater harvesting, households are more likely to enhance their chances of advancing toward food security than their non-adopting counterparts. This is plausible as households can supplement the minimal downpour with the harvested water and thus, sustain production throughout the year. These results corroborate the findings of Sikka *et al.* (2017) in India where rainwater harvesting was found to enhance cropping intensity. Similar findings have been reported by other studies for other CSAPs (Asfaw *et al.*, 2014; Arslan *et al.*, 2015; Makate *et al.*, 2016).

Table 3: Joint estimation results of the effect of rainwater harvesting in northern Ghana

Variable	RWH	Log Yields	Log Net revenue	Self-sufficiency	Food gaps	Mortgage
Constant	0.33***	4.61***	12.70***	2.80*	0.57***	9.22***
	(0.09)	(1.12)	(1.35)	(1.64)	(0.18)	(1.68)
Farm size	-0.10***	-0.07***	-0.10***	-0.03***	0.13***	-0.07***
	(0.01)	(0.01)	(0.02)	(0.02)	(0.02)	(0.02)
Labour	0.41***	0.20***	-0.01**	0.01	0.01*	0.01
	(0.12)	(0.04)	(0.00)	(0.00)	(0.01)	(0.01)
Fertilizer	0.01	0.90	0.00**	0.00	0.31***	0.00*
	(0.16)	(0.07)	(0.00)	(0.00)	(0.05)	(0.00)
Chemicals	0.07	-0.01	0.09***	0.04**	-0.01	0.05***
	(0.05)	(0.01)	(0.02)	(0.02)	(0.01)	(0.02)
Gender	-0.10*	0.23**	-0.32*	-0.61***	-0.10*	-0.55***
	(0.05)	(0.12)	(0.17)	(0.18)	(0.05)	(0.18)
Age	0.01	-0.01	0.00	0.05**	0.02*	-0.05***
	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)	(0.02)

Age square	0.03	0.00	0.00**	0.00	0.03	0.00***
	(0.04)	(0.00)	(0.00)	(0.00)	(0.09)	(0.00)
Education	0.22**	0.23***	0.03**	-0.01	0.05**	-0.02
	(0.11)	(0.01)	(0.02)	(0.02)	(0.01)	(0.02)
Credit	0.12***	0.12***	1.11***	0.42**	-0.18*	0.57***
	(0.02)	(0.03)	(0.18)	(0.19)	(0.09)	(0.19)
Distance	-0.02	-0.01	0.06*	0.08**	0.01	0.07*
	(0.02)	(0.02)	(0.03)	(0.04)	(0.03)	(0.04)
FBO	0.36***	0.18*	0.14	-0.16	0.06	-0.34**
	(0.12)	(0.09)	(0.14)	(0.14)	(0.13)	(0.16)
Extension	0.27**	0.17***	-1.78***	-0.88***	-0.02	-1.18***
	(0.11)	(0.02)	(0.29)	(0.34)	(0.33)	(0.34)
Tenure	0.21*	-0.19**	-1.06***	-0.62***	0.23***	-1.21***
	(0.11)	(0.09)	(0.23)	(0.27)	(0.06)	(0.27)
Irrigation	-0.12*	-1.00***	0.26	-0.06	0.07**	-0.45***
	(0.06)	(0.10)	(0.16)	(0.14)	(0.14)	(0.17)
Sand	0.23*	-0.17	0.91***	0.84***	-0.11	2.33***
	(0.12)	(0.20)	(0.26)	(0.29)	(0.28)	(0.31)
Clay	-0.15	0.08	-0.49**	-1.80***	-0.06	-1.61***
	(0.13)	(0.15)	(0.20)	(0.26)	(0.20)	(0.23)
RWH		0.98***	-0.75***	-0.76***	0.89***	-0.36***
		(0.05)	(0.12)	(0.03)	(0.20)	(0.02)
Perception	0.12*					
	(0.06)					
atanhrho_12		-0.07**	-0.13***	-0.23***	-0.14**	-0.17*
		(0.03)	(0.05)	(0.08)	(0.07)	(0.09)
Observations	537	537	537	537	537	537
Log-likelihood	-361.24	-1086.40	-639.04	-637.72	-703.66	-610.58

*Note: *, **, and *** indicate 10%, 5%, and 1% levels of significance. Also, standard errors are in parentheses. Loam as the reference point in soil type*

CONCLUSION

This study sought to determine farmers' perceptions about the benefits of rainwater harvesting, its drivers, and its effects on household livelihood outcomes such as yields, net revenue, self-sufficiency in maize production, and food security. Given the diverse nature of the objectives, the study employed different analytical approaches on a unique dataset collected by the Ministry of Food and Agriculture in Ghana. The target population was smallholder maize farmers in northern Ghana and thus, necessitates the use of such a dataset as time and resource constraints would not have permitted an individual to collect data of such quantity and quality for the analysis.

With regards to the perception of farmers about the benefits of rainwater harvesting as CSAPs, the study employed descriptive statistics and found that a variety of perceptions drive the farmers' choice of rainwater harvesting as CSAPs during production in drought-prone areas. Specifically, the study revealed that majority of the farmers (68.4%) perceived rainwater harvesting as a practice that increases the production of maize while about 36.6% perceive it as a practice that counters drought effects from climate change. Further, about 24.6%, 24.0%, and 13.1% of the farmers perceived rainwater harvesting as a practice that respectively reduces crop failure, erosion, and quantity of input used.

Concerning determinants of adoption and effects of rainwater harvesting on livelihood outcomes, the study employed conditional recursive mixed-process models to control for endogeneity in the adoption of rainwater harvesting. For the adoption of water harvesting, the analysis revealed farm size, labour, gender of farmer, education implied in formal schooling years, credit access, membership to FBO, extension access, tenure security, number of irrigation sites accessible to the farmer, soil type and perception of the farmer as the significant factors determining the adoption of rainwater harvesting in the area. This emphasizes the role of household characteristics, infrastructure, institutions, information, social capital, liquidity constraint, and location in the adoption of agricultural technologies. Concerning the effects of rainwater harvesting on livelihood outcomes, the analyses revealed that rainwater harvesting plays a vital role in the livelihoods of smallholder farmers. However, the results are mixed. Whereas maize yields and food security were found to be enhanced by the adoption of rainwater harvesting, net revenue and self-sufficiency in maize production were found to decrease with the adoption of rainwater harvesting in northern Ghana.

Further, the study revealed other factors that also play significant and mixed roles in the livelihood outcomes of smallholder maize farmers in the area. Among these factors are farm size, labour, fertilizer, chemicals, gender, age, education, credit, nearest market distance, FBO membership, extension service access, tenure security, accessible irrigation sites, soil types, and regional variables. Based on these results, the study, therefore, concludes that greater water supplement from harvested rainwater can enhance some livelihood outcomes in northern Ghana. Further, the perceived benefits of rainwater harvesting found in this study are likely to lead to increased adoption, which will consequently reduce poverty and enhance the well-being of the farmers in northern Ghana. It is therefore recommended that climate-smart agricultural practices including rainwater harvesting techniques should remain a policy focus in drought-prone areas of Ghana. Government can focus on developing or improving existing infrastructure for rainwater harvesting in these areas.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

REFERENCES

Abdallah, A.-H. (2017). Determinants of adoption of soil and water and conservation techniques: evidence from Northern Ghana. *Int. J. Sustainable Agricultural Management and Informatics*, *3*(1), 31–43.

Abdallah, A.-H., Michael, A., & Awuni, J. A. (2022). Impact of land grabbing on food security: evidence from Ghana. *Environment, Development and Sustainability*. https://doi.org/10.1007/s10668-022-02294-7

Abdallah, A. (2016a). Agricultural credit and technical efficiency in Ghana : is there a nexus ? *Agricultural Finance Review*, *76*(2), 309–324. https://doi.org/10.1108/AFR-01-2016-0002

Abdallah, A. (2016b). Does credit market inefficiency affect technology adoption ? Evidence from Sub-Saharan Africa. *Agricultural Finance Review*, *76*(4), 494–511. https://doi.org/10.1108/AFR-05-2016-0052

Abdallah, A. H., Abdul-Rahaman, A., & Issahaku, G. (2021). Sustainable agricultural practices, farm income and food security among rural households in Africa. *Environment, Development and Sustainability*, *23*(12), 17668–17701. https://doi.org/10.1007/s10668-021-01407-y

Abdulai, A., & Huffman, W. (2014). The Adoption and Impact of Soil and Water Conservation Technology: An Endogenous Switching Regression Application. *Land Economics*, *90*(1), 26–43.

Abdulai, A. N. (2016a). Impact of conservation agriculture technology on household welfare in Zambia. *Agricultural Economics (United Kingdom)*, *47*(6), 729–741. https://doi.org/10.1111/agec.12269

Abu, B. M., Issahaku, H., & Nkegbe, P. K. (2016). Farmgate versus market centre sales: a multi-crop approach. *Agricultural and Food Economics*, *4*(1), 21. https://doi.org/10.1186/s40100-016-0065-6

Arslan, A., Mccarthy, N., Lipper, L., Asfaw, S., Cattaneo, A., & Kokwe, M. (2015). Climate Smart Agriculture? Assessing the Adaptation Implications in Zambia. *Journal of Agricultural Economics*, *66*(3), 753–780. https://doi.org/10.1111/1477-9552.12107

Asfaw, S., Mccarthy, N., Lipper, L., Arslan, A., Cattaneo, A., & Kachulu, M. (2014). Climate variability , adaptation strategies and food security in Malawi ESA Working Paper No . 14-08. *ESA Working Paper No. 14-08.*, *14*.

Asfaw, S., Shiferaw, B., Simtowe, F., & Hagos, M. (2011). Agricultural technology adoption, seed access constraints and commercialization in Ethiopia. *Journal of Development and Agricultural Economics*, *3*(9), 436–447.

Bagley, J. E., Miller, J., & Bernacchi, C. J. (2015). Biophysical impacts of climate-smart agriculture in the Midwest United States. *Plant, Cell and Environment*, *38*(9), 1913–1930. https://doi.org/10.1111/pce.12485

Bekele Shiferaw, Menale Kassie, M. J. & C. Y. (2014). Adoption of improved wheat varieties and impacts on household food security in Ethiopia. *Food Policy*, *October 2015*, 1–13. https://doi.org/10.1016/j.foodpol.2013.09.012

Binswanger, H. P., Khandker, S. R., & Rosenzweig, M. R. (1993). How infrastructure and financial institutions affect agricultural output and investment in India. *Journal of Development Economics*, *41*(2), 337–366. https://doi.org/10.1016/0304-3878(93)90062-R

Bjornlund, V., Bjornlund, H., & Van Rooyen, A. F. (2020). Why agricultural production in sub-Saharan Africa remains low compared to the rest of the world–a historical perspective. *International Journal of Water Resources Development*, *36*(sup1), 1–34. https://doi.org/10.1080/07900627.2020.1739512

Brooks, J. (2016). Food security and the Sustainable Development Goals. In P. Love (Ed.), *Debate the Issues: New Approaches to Economic Challenges* (pp. 143–146). OECD Publishing. https://doi.org/10.1787/9789264264687-27-en

Buchner, B., Clark, A., Falconer, A., Macquarie, R., Tle, C. M.-, Tolentino, R., & Wetherbee, C. (2019). *Global Landscape of Climate Finance 2019* (Issue November). https://climatepolicyinitiative.org/publication/ global-climate-finance-2019/

Cooperation, I. (2016). *Research Center on International Cooperation of the University of Bergamo Giordano Dell-Amore Foundation ACCESS TO CREDIT AND ITS EFFECT ON THE ADOPTION OF AGRICULTURAL TECHNOLOGIES : THE CASE OF ZANZIBAR Author (s): Khalid S . Mohamed and Andrew E . Te*.

Djurfeldt, G., Aryeetey, E., & Isinika, A. C. (2010). *African Smallholders: Food Crops, Markets and Policy* (G. Djurfeldt, E. Aryeetey, & A. C. Isinika (eds.); 1st ed.). CAB International CABI. https://doi.org/10.1079/9781845937164.0000

Domènech, L., Heijnen, H., & Saurí, D. (2012). Rainwater harvesting for human consumption and livelihood improvement in rural Nepal: Benefits and risks. *Water and Environment Journal*, *26*(4), 465–472. https://doi.org/10.1111/j.1747-6593.2011.00305.x

Essegbey, G. O., Nutsukpo, D., Karbo, N., & Zougmoré, R. (2015). *National Climate-Smart Agriculture and Food Security Action Plan of Ghana (2016-2020)* (No. 139; Issue 139). https://cgspace.cgiar.org/bitstream/handle/10568/69000/CCAFS_WP139_CSA_Ghana_nov.pdf?sequence=3&isAllowed=y

FAO. (2008). *Report on use of the Household Food Insecurity Access Scale and Household Dietary Diversity Score in two survey rounds in Manica and Sofala Provinces, Mozambique, 2006-2007. FAO food security project GCP/MOZ/079/BEL* (Vols. 2006-2007,).

FAO. (2010). “Climate-Smart” Agriculture. *The Hague Conference on Agriculture, Food Security and Climate Change*, 41. https://doi.org/10.1111/j.1467-6346.2009.02662.x

FAO. (2023). *International fora | Climate-Smart Agriculture | Food and Agriculture Organization of the United Nations*. FAO. https://www.fao.org/climate-smart-agriculture/international-fora/en/

FAO, ECA, & AUC. (2020). *Africa Regional Overview of Food Security and Nutrition 2019: Containing the Damage of Economic Slowdowns and Downturns to Food Insecurity in Africa*. FAO, AU & UN. https:/doi.org/10.4060/CA7343EN

Feder, G., & Onchan, T. (1987). Land Ownership Security and Farm Investment in Thailand. *American Journal of Agricultural*

Economics, *69*(2), 311–320.
GACSA. (2016). Compendium on Climate-Smart Agriculture & Extension. In *Supporting agricultural extension towards Climate-Smart Agriculture An overview of existing tools* (pp. 1–87). Global Alliance for Climate-Smart Agriculture. www.fao.org/gacsa/en/
Ghana Statistical Service. (2014). *Ghana Living Standards Survey Round 6: Main Report*.
Ghana Statistical Service. (2019). *Nation Report: 207/2018 Ghana Census of Agriculture*.
Goldstein, M. (2008). *The Profits of Power : Land Rights and Agricultural Investment in Ghana Christopher Udry*. *116*(6).
Harvey, C. A., Chacón, M., Donatti, C. I., Garen, E., Hannah, L., Andrade, A., Bede, L., Brown, D., Calle, A., Chará, J., Clement, C., Gray, E., Hoang, M. H., Minang, P., Rodríguez, A. M., Seeberg-Elverfeldt, C., Semroc, B., Shames, S., Smukler, S., … Wollenberg, E. (2014). Climate-Smart Landscapes: Opportunities and Challenges for Integrating Adaptation and Mitigation in Tropical Agriculture. *Conservation Letters*, *7*(2), 77–90. https://doi.org/10.1111/conl.12066
Issahaku, G., & Abdulai, A. (2019a). Adoption of climate-smart practices and its impact on farm performance and risk exposure among smallholder farmers in Ghana. *Australian Journal of Agricultural and Resource Economics*, 1–25. https://doi.org/10.1111/1467-8489.12357
Issahaku, G., & Abdulai, A. (2019b). Can Farm Households Improve Food and Nutrition Security through Adoption of Climate-smart Practices? Empirical Evidence from Northern Ghana. *Applied Economic Perspectives and Policy*, 1–22. https://doi.org/10.1093/aepp/ppz002
Jolly, C. M., & Gadbois, M. (1996). The effect of animal traction on labour productivity and food self-sufficiency: The case of Mali. *Agricultural Systems*, *51*(4), 453–467.
Kleemann, L., Abdulai, A., Mareike, B. (2014). Is Organic Farming Worth its Investment? The Adoption and Impact of Certified Pineapple Farming in Ghana. *World Development*, *64*(1856), 79–92.
Kousar, R., Abdulai, A., & Society, A. E. (2014). *Impact of non-farm work and land tenancy contracts on soil conservation measures Impact of non-farm work and land tenancy contracts on soil conservation measures*. *April*. https://doi.org/10.13140/2.1.4505.9842
Ma, W., & Abdulai, A. (2016). Does cooperative membership improve household welfare? Evidence from apple farmers in China. *Food Policy*, *58*(January), 94–102. https://doi.org/10.1016/j.foodpol.2015.12.002
Makate, C., Wang, R., Makate, M., & Mango, N. (2016). Crop diversification and livelihoods of smallholder farmers in Zimbabwe: adaptive management for environmental change. *SpringerPlus*, *5*(1), 1–18.
Manda, J., Alene, A. D., Gardebroek, C., Kassie, M., & Tembo, G. (2016). Adoption and Impacts of Sustainable Agricultural Practices on Maize Yields and Incomes: Evidence from Rural Zambia. *Journal of Agricultural Economics*, *67*(1), 130–153.
Manfred Zeller, Aliou Diagne, and C. M. (2001). Market access by smallholder farmers in Malawi: Implication for technology adoption in agricultural productivity and crop income. *Journal of Agricultural Science*, *19*(35), 219–229.
Mango, N., Zamasiya, B., Makate, C., Nyikahadzoi, K., & Siziba, S. (2014). Factors influencing household food security among smallholder farmers in the Mudzi district of Zimbabwe. *Development Southern Africa*, *31*(4), 625–640.
Maxwell, D., Vaitla, B., & Coates, J. (2014). How do indicators of household food insecurity measure up? An empirical comparison from Ethiopia. *Food Policy*, *47*(4), 107–116.
Owusu, V., Abdulai, A., & Abdul-Rahman, S. (2011). Non-farm work and food security among farm households in Northern Ghana. *Food Policy*, *36*(2), 108–118.
Pender, J. L., & Kerr, J. M. (1998). *Determinants of farmers ' indigenous soil and water conservation investments in semi -arid India*. *19*, 113–125.
Roodman, D. (2009). *Working Paper Number 168 April 2009*. *168*.
Scharlemann, J. P. W., Brock, R. C., Balfour, N., Brown, C., Burgess, N. D., Guth, M. K.,

Ingram, D. J., Lane, R., Martin, J. G. C., Wicander, S., & Kapos, V. (2020). Towards understanding interactions between Sustainable Development Goals: the role of environment–human linkages. *Sustainability Science*, *15*(6), 1573–1584. https://doi.org/10.1007/s11625-020-00799-6

Shete, M., & Rutten, M. (2015). Impacts of large-scale farming on local communities ' food security and income levels – Empirical evidence from Oromia Region , Ethiopia. *Land Use Policy*, *47*(1), 282–292.

Sikka, A. K., Islam, A., & Rao, K. V. (2017). Climate-Smart Land and Water Management for Sustainable Agriculture. *Irrigation and Drainage*. https://doi.org/10.1002/ird.2162

Simtowe, F., & Zeller, M. (2006). *The Impact of Access to Credit on the Adoption of hybrid maize in Malawi: An Empirical Test of an Agricultural Household Model under credit market failure*. *January 2008*.

Smith, L. C., & Wiesmann, D. (2007). *Is Food Insecurity More Severe in South Asia or Sub-Saharan Africa ? August*.

Solís, D., Bravo-Ureta, B. E., & Quiroga, R. E. (2009). Technical efficiency among peasant farmers participating in natural resource management programmes in Central America. *Journal of Agricultural Economics*, *60*(1), 202–219. https://doi.org/10.1111/j.1477-9552.2008.00173.x

Stamoulis, K., & Zezza, A. (2003). A Conceptual Framework for National Agricultural , Rural Development , and Food Security Strategies. *ESA Working Paper*, *03*.

Teklewold, H., Gebrehiwot, T., & Bezabih, M. (2019). Climate smart agricultural practices and gender differentiated nutrition outcome : An empirical evidence from Ethiopia. *World Development*, *122*, 38–53. https://doi.org/10.1016/j.worlddev.2019.05.010

Teklewold, H., Kassie, M., & Shiferaw, B. (2013). Adoption of multiple sustainable agricultural practices in rural Ethiopia. *Journal of Agricultural Economics*, *64*(3), 597–623.

Tesfaye, W., Tirivayi, N., Blalock, G., Bageant, L., Boone, C., Mcbride, L., Mulu, Y., Gebremariam, G., Zewdie, T., Yitbarek, E., Kebede, K., Mccullough, E., Mali-, E., & Lybbert, T. (2020). *Climate-Smart Innovations and Rural Poverty in Ethiopia: Exploring Impacts and Pathways*. *00*(00), 1–22. https://doi.org/10.1111/ajae.12161

Thomson, A., & Metz, M. (1998). *Implications of Economic Policy for Food Security: A Training Manual*. Training Materials for Agricultural Planning 40. http://www.fao.org/3/X3936E/X3936E03.htm#self

Way, D. a, & Long, S. P. (2015). Climate-smart agriculture and forestry : maintaining plant productivity in a changing world while minimizing. *Plant Cell and Environment*, *38*, 1683–1685. https://doi.org/10.1111/pce

WFP. (2009). Emergency Food Security Assessment Handbook. *WFP, Rome*, 296. https://doi.org/http://www.wfp.org/content/emergency-food-security-assessment-handbook

Zero Hunger Challenge. (2016). Partnering for Nourishing our People, Nurturing our Planet, Growing Prosperity, Harvesting Peace Transforming our Food Systems to Transform our World Background. *Zero Hunger Challenge*, *2*(6), 1–5.