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**Article**

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RESEARCH

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# Effects of climate adaptation on technical efficiency of maize production in Northern Ghana

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## Abstract

Climate adaptation is an essential strategy for responding to climate change at local levels and required for sustainable food production to meet the growing food demand. In this light, this study analyzed the effects of climate adaptation strategies on technical efficiency of maize farmers in Northern Ghana. This involved a total of 619 maize farmers that were selected through a multistage sampling procedure. A Cobb-Douglas stochastic frontier was fitted to the data. From the result, the major climate adaptation strategies adopted by the farmers include row planting, changing planting date, mixed farming, refilling, and intercropping. The frontier result shows that while climate adaptation significantly leads to higher maize outputs, only crop rotation and row planting significantly improve technical efficiency of maize farmers. Other factors that significantly influence maize output are farm size, labor, seed, and chemicals. The study concludes that climate adaptation, particularly, crop rotation and row planting, remains essential adaptation strategies for sustainable food production in the region. However, further understanding of mechanisms through which majority of the climate adaptation strategies significantly reduce technical efficiency is required.

**Keywords:** Climate change, Climate adaptation, Technical efficiency, Maize production frontier, Northern Ghana

## Introduction

Agriculture has historically played an essential role in improving the livelihood of poor people especially in the now developed countries and remains an important sector in the now developing countries (Dorward et al., 2004). Nonetheless, its pivotal role in the growth and development of economies have been challenged in recent times (Loizou et al., 2019). For Diao et al. (2010), agriculture has had less impact on most African economies compared to many Asian economies, leading to the debate on the role of agriculture in African development. Whichever direction the debate is directed, the widespread poverty in Africa can be linked to the performance of the agricultural sector. In Ghana specifically, the agricultural sector is essential for the socioeconomic development of the country through employment generation and contribution to the

country's Gross Domestic Product (GDP). However, the global drive to attaining zero hunger can be interrupted by climate change (Wheeler and Braun, 2013).

Already, there is substantial evidence that temperature levels have increased while rainfall in the tropics have decreased over the years with associated negative impacts (WMO, 2018). In agrarian communities, these negative effects of climate change are noticed in reduction in yields, increase in food prices, land use changes, increase pest infestations, and difficulty in farm management (Lungarska & Chakir, 2018; Mu et al., 2017). Dinko (2017) and Wheeler and Braun (2013) expressed that all four food security pillars (food availability, accessibility, utilization, and stability) are under threat due to climate change. As a result, climate change and its induced stresses are putting more pressure on the ability to provide a food-secured society (de Gennaro and Forleo, 2019).

The effect of climate change on economies is not universal but depends on the economic characteristics of each country. Climate change has high risks to areas that are already vulnerable to hunger and undernourishment (Wheeler and Braun, 2013) and where agriculture is the backbone of their economy (Abdul-Razak & Kruse, 2017). Ghana's high dependence on rainfed agriculture increases its vulnerability to the impacts of climate change and variability (Dinko, 2017). Already, Ghana's crop production is below its potential yields due to factors such as deteriorating soil conditions. Thatsarani and Gunaratne (2018) argued that poor households with low resources are riskier to climate change irrespective of their location. It is thus clear that Ghana's food security status is dependent on the climate (Dinko, 2017; Issahaku and Maharjan, 2014). Current evidence shows the presence of climate shocks such as droughts and floods that affect farmlands across the country. These climate shocks have made households and communities in Ghana food insecure, reduces their social safety and resilience (Akudugu and Alhassan, 2012). In order to minimize the impacts of climate change, farmers engage in the adoption of several adaptation strategies. Investing in these climate adaptation strategies to obtain climate-smart food systems is required to enhance food security amidst climate change (Wheeler & Braun, 2013)

Climate adaptation involves the processes and actions of an agent such as households to cope, manage, or adjust to a changing climatic condition (Smit and Wandel, 2006). This requires adjustments of the agent to respond to actual or expected changes or enhance the resilience of the agent to climate change. As such, climate adaptation is a manifestation of the adaptive capacity of the system to climate change (Smit and Wandel, 2006)—the higher the adaptive capacity, the higher the adaptation. There is generally an increasing body of literature on climate adaptation. These climate adaptation studies on farming households have focused on exploring the adaptation strategies adopted by the farmers (Assan et al., 2018; Phuong et al., 2017; Denkyirah et al., 2017; Limantol et al., 2016; Knox et al., 2015; Tessema et al., 2013), the determinants of climate adaptation (Alhassan et al., 2019; Akrofi-Atitianti et al., 2018; Khanal et al., 2018a; Denkyirah et al., 2017; Niles et al., 2016; Tessema et al., 2013), and the impacts of climate adaptation on farm and livelihood outcomes (Martins et al., 2019; Khanal et al., 2018a; Abid et al., 2016; Issahaku and Maharjan, 2014). Others indicated that to minimize climate vulnerability, adaptation is required (Akudugu & Alhassan, 2012). There are also studies to suggest the spillover effects of adaptation since adaptation or maladaptation may create unintended outcomes such as redistribution of risks and vulnerability (Atteridge and Remling, 2018).

Notwithstanding the increasing research on adaptation, an important gap in the literature on the impacts of climate adaptation on crop production is the failure to incorporate the concept of efficiency into the analysis of climate adaptation. Instead, a large body of the existing studies has either deliberately or unintentionally assumed that climate adaptation affects observed farm outputs and not the efficiency of production. For instance, Khanal et al. (2018b) and Roco et al. (2017) examined the impact of climate adaptation on technical efficiency but assumed that climate adaptation only affects the position of the production frontier and not the position of the farmers on or beneath the frontier. This predefined assumption without test may be misleading. Therefore, this present study slightly differs from these previous studies by integrating the concept of efficiency analysis into the estimation of the stochastic production function of farmers. The advantage of this is that the research is able to isolate the effects of climate adaptation on the position of the farmers on or beneath the production frontier (the observed output) as well as the effects on the position of the production frontier. This is important because the agriculture sector needs to minimize its impacts on the environment while adapting to the environmental changes (Gennaro and Forleo, 2019). Primarily, therefore, the objective of this study is to analyze the effects of climate adaptation strategies such as conservative agriculture (CA), integrated soil fertility management (ISFM), integrated pest management (IPM), and changing planting dates on technical efficiency of maize production.

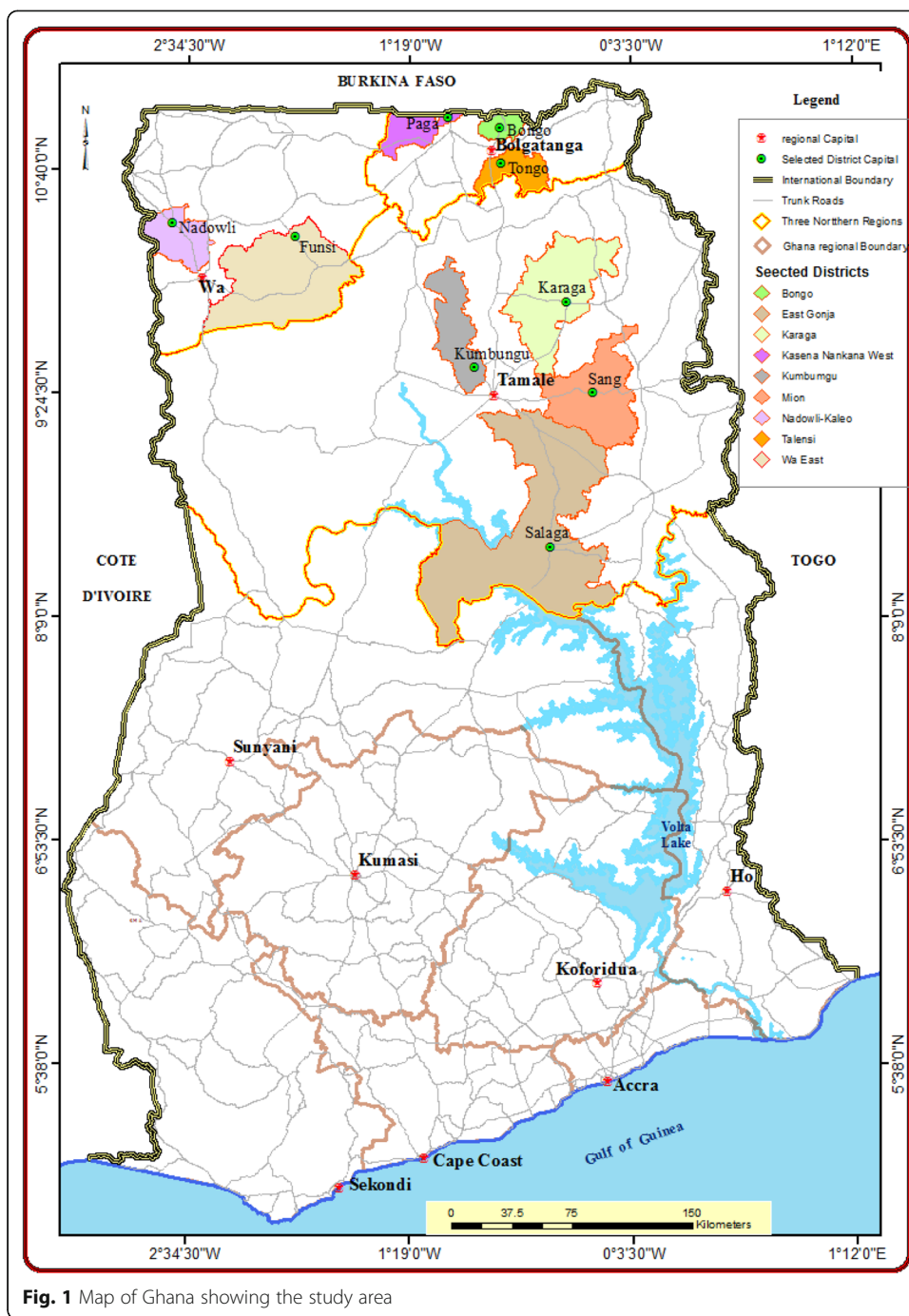
## **Methodology**

### **Study location**

The study was conducted in Northern, Upper East, and Upper West regions of Ghana. At the time of the design of this study, there were ten administrative regions of Ghana (now sixteen regions), and these three selected regions were collectively referred to in this study as the northern sector of the country. These three regions of Ghana covers 41% of Ghana's total landmass. This is shown in Fig. 1. Agriculture is the major occupation of most households in the area. And the farmers engage in the cultivation of crops such as maize, rice, millet, sorghum, cowpea, groundnut, and yam. Unlike the other parts of the county, the northern part experiences a single rainy season each year, and this has become more erratic in recent years. The effects of climate change on agricultural activities is increasingly becoming visible in the region. Therefore, farmers have over the years adopted a number of climate adaptation strategies such as drought-resistant and early maturing varieties, changing planting dates, banding and refilling in their quest to obtain higher yields and provide food for their families.

### **Data and sampling procedure**

The study used a cross-sectional data from 619 maize farmers in Northern regions of Ghana. This data is a component of a wide study on gender perspectives of climate vulnerability and livelihood strategies among farming households in the region. The farmers for this study were selected through a multistage sampling procedure. In the first stage, maize farmers were purposively selected among all crops since maize is the number one crop cultivated and consumed by almost all households in Ghana. In the second stage, three districts were selected from each



of the three regions using stratified sampling procedure. In each selected district, simple random was used to select three maize-farming communities, given a total of twenty-seven communities. In the third stage, simple random was used to select 23 maize farmers from twenty-five communities and 22 farmers from the remaining two communities. The data was collected using a pre-tested questionnaire, and this included information on the socioeconomic characteristics of the farmers, farmers' perceptions on climate change, climate adaptation strategies adopted, maize production inputs and output, among others.

### Analytical framework and empirical models

The stochastic frontier analysis (SFA) method was used to analyze the technical efficiency of maize production. Efficiency analysis has become popular following the work of Farrell (1957) who defined three forms of efficiency: technical, allocative, and economic efficiencies. The focus of this study is on technical efficiency which simply refers to achieving the highest output with little effort. Unlike the classical production function, the stochastic production function assumes that the error component of the production function is not solely due to random and unmeasured factors. Therefore, it decomposes the error term into two—the random and nonrandom components. Farrell (1957) argued that there is an outer boundary of the production frontier and the inability of a firm to be on this boundary is due to inefficiency.

Generally, efficiency can be analyzed using parametric and nonparametric methods. Respectively, the SFA and data envelopment analysis (DEA) are the commonly used analytical methods. Both have their merits and weaknesses. For instance, the DEA requires information on only the inputs and outputs; it is deterministic and attributes all the deviations from the frontier to inefficiencies. Also, while the SFA considers random errors and allows for hypothesis testing on the production structure, it requires an implicit imposition of a functional form that describes the production technology (Hossain et al., 2012). However, the SFA best fits the objective of this study; hence, this was used. The SFA is given as:

$$Y_i = \beta_0 + \beta X_i + \varepsilon_i \quad (1)$$

where  $Y_i$  is the log of output and  $X_i$  is a  $1 \times Z$  vector of input quantities,  $\beta$  is a  $Z \times 1$  vector of parameters that are to be estimated, and  $\varepsilon_i = -u_i + v_i$ .  $v_i$  is assumed to be independently and identically distributed  $N(0, \sigma_v^2)$  and independent of the  $u_i$  while  $u_i$  is non-negative random variable, assumed to be independently and identically distributed as half-normal;  $u_i \sim iid N^+(0, \sigma_u^2)$ . Equation 1 can be redefined as:

$$Y_i = f(X_i; \beta) \exp(v_i - u_i) \quad (2)$$

where  $f(\cdot)$  can assume different production functional forms, mostly Cobb-Douglas or Translog functional forms. The Cobb-Douglas functional form is assumed in this study since it allowed to estimate input elasticities at constant levels. From equation 2, the technical efficiency of the farmers is defined as:

$$TE_i = \frac{Y_i}{Y_{i*}} = \frac{f(X_i; \beta) \exp(v_i - u_i)}{f(X_i; \beta) \exp v_i} \quad (3)$$

where the numerator is the frontier output (the outer boundary described by Farrell) and the denominator is the observed output of the farmer. Therefore:

$$TE_i = \exp(-u_i) \quad (4)$$

A further analysis is to regress a set of factors on  $-u_i$ . Thus,

$$-u_i = \delta_0 + \sum_{n=1}^k \delta_n Z_i + e_i \quad (5)$$

where  $Z_i$  is a vector of factors that influences technical inefficiency, and in this study, this includes climate adaptation strategies, and  $\delta_i$  is the parameter estimates of  $Z_i$ . The

method of maximum likelihood (ML) is used to obtain the estimates of the stochastic frontier and the inefficiency model in one step (Battese and Coelli, 1995).

Empirically, the output model and the inefficiency model are respectively given as:

$$\begin{aligned} \text{Maize output} = & \beta_0 + \beta_1 \text{Farm size} + \beta_2 \text{Family labour} + \beta_3 \text{Hired labour} \\ & + \beta_4 \text{Seed} + \beta_5 \text{Chemical} + \beta_6 \text{Fertiliser} + \beta_7 \text{Adaptation} + v_i \end{aligned} \quad (6)$$

and

$$\begin{aligned} \text{Inefficiency} = & \delta_0 + \delta_1 \text{Planting date} + \delta_2 \text{Early maturing variety} \\ & + \delta_3 \text{Drought resistant variety} + \delta_4 \text{Crop rotation} \\ & + \delta_5 \text{Land rotation} + \delta_6 \text{Mixed farming} + \delta_7 \text{Intercropping} \\ & + \delta_8 \text{Refilling} + \delta_9 \text{CA} + \delta_{10} \text{ISFM} + \delta_{11} \text{Mulching} \\ & + \delta_{12} \text{Row planting} + \delta_{13} \text{IPM} + \delta_{14} \text{Contour farming} + \delta_{15} \text{Age} \\ & + \delta_{16} \text{Education} + \delta_{17} \text{Home - farm} + \delta_{18} \text{Extension} \\ & + \delta_{19} \text{Farmer groups} + \delta_{20} \text{Credit access} + e_i \end{aligned} \quad (7)$$

The definition and measurement of the various factors are provided in Table 1.

## Results and discussions

### Socioeconomic characteristics and production inputs used by farmers

Table 2 shows the descriptive statistics of the output of the farmers, the inputs used for production, and the socioeconomic characteristics of the farmers. From the result, an average maize farmer had obtained about 426 kg of maize grains in the 2017 production season. This was obtained by cultivating an average farm of 3.44 acres, sowing about 7 kg of seeds, and using about 5 and 3 hired and family labor respectively, applying 179.44 kg of fertilizer and 4 L of chemicals. The average farm size of the farmers showed that the sampled farmers are smallholder crop farmers, a typical characteristic of farming in Ghana.

The socioeconomic characteristics of the farmers shows that the average farmer was about 47 years old at the time of data collection. The educational level of the respondents was low as the average farmer had only 4 years of formal education (primary education), although there are few with graduate degrees. The low education observed among the farmers is typical of Ghanaian farming communities where an increase in education push the desire for white collar jobs. The average farmer had to travel for 1.57 km from home to farm while the farthest farm is 10 km away from the farmer's home. Farmers cultivate their maize farms distanced from home because most of them also engage in extensive livestock keeping. However, where farmers have to walk to their farms, longer distance can affect their efficiencies on the farm as they may get tired before reaching the farm. The majority (58%) of the farmers had no access to extension services during the cropping season. Extension service remains one of the crucial and farmer-trusted means by which technology, including new climate adaptation strategies, can be introduce to the farmers. Therefore, the low extension access among the farmers could suggest low access to current production information by the farmers. Also, while 47% of the farmers belonged to an FBO, the majority (53%) were not members of any FBO. Farmers in FBOs provide social capital and other mutual benefits to each other. The transfer of technology in recent times has also been channeled through groups. Access to agricultural credit is low as only 27% of the sampled farmers had access to credit. Generally, access to credit is a major challenge in the agricultural sector; hence, this is not an isolated finding.

**Table 1** List and definition of variables

Variable	Definition/measurement
Output	The total kilograms of maize grains obtained by a farmer
Farm size	The total acres of land cultivated by a farmer
Hired labor	The total of people hired during the production season on maize farm
Family labor	The number of family members who assisted for any activity on the farm.
Seed	The total kilogram of seed sown on farm.
Chemical	The total liter of herbicides plus pesticides.
Fertilizer	The total kilogram of organic and inorganic fertilizer used by a farmer.
Adaptation	The number of the fourteen climate adaptation strategies adopted by a farmer. Expectedly, climate adaptation should improve crop production.
Planting date	Dummy: 1 if a farmer adopted the climate adaptation strategy and 0 if not.
Early maturing variety	Dummy: 1 if a farmer adopted the climate adaptation strategy and 0 if not.
Drought-resistant variety	Dummy: 1 if a farmer adopted the climate adaptation strategy and 0 if not.
Crop rotation	Dummy: 1 if a farmer adopted the climate adaptation strategy and 0 if not.
Land rotation	Dummy: 1 if a farmer adopted the climate adaptation strategy and 0 if not.
Mixed farming	Dummy: 1 if a farmer adopted the climate adaptation strategy and 0 if not.
Intercropping	Dummy: 1 if a farmer adopted the climate adaptation strategy and 0 if not.
Refilling	Dummy: 1 if a farmer adopted the climate adaptation strategy and 0 if not.
CA	Dummy: 1 if a farmer adopted the climate adaptation strategy and 0 if not.
ISFM	Dummy: 1 if a farmer adopted the climate adaptation strategy and 0 if not.
Mulching	Dummy: 1 if a farmer adopted the climate adaptation strategy and 0 if not.
Row planting	Dummy: 1 if a farmer adopted the climate adaptation strategy and 0 if not.
IPM	Dummy: 1 if a farmer adopted the climate adaptation strategy and 0 if not.
Contour farming	Dummy: 1 if a farmer adopted the climate adaptation strategy and 0 if not.
Age	The total number of years of a farmer from birth to the time of interview. Age is expected to be positively related to inefficiency since younger farmers should be able through their energy produce maize more efficient.
Education	The total number of years of formal education by a farmer. Expectedly, higher education should improve efficiency through better understanding of production information.
Home-farm	The distance between the home of the farmer and the farm in kilometers. Farmers with short distance to farm are expected to be more efficient since they do not walk longer distance to their farms.
Extension	Dummy: 1 if a farmer had access to extension service during the cropping season and 0 if not. Extension service improves efficiency through the provision and training on production technologies.
Farmer group	Dummy: 1 if a farmer belonged to a farmer group and 0 if not. Group membership is a source of social asset to rural farmers; hence, membership is expected to improve efficiency.
Credit access	Dummy: 1 if a farmer had accessed credit during the cropping season and 0 if not. Access to credit is expected to enhance the use of production inputs, hence, improve efficiency.

### Climate adaptation strategies adopted by the farmers

Fourteen on-farm climate adaptation strategies were identified based on existing literature and during pre-test of the research questionnaire used. These strategies were provided to the respondents and asked to indicate which of the strategies they adopted. The result is shown in Table 3. Although this is not to suggest that there are only these 14 strategies adopted by farmers, these remain the major climate adaptation strategies in the region.



**Table 2** Descriptive statistics of output, inputs, and socioeconomic characteristics

Variable	Mean	Std. Dev.	Min	Max
Output	425.93	731.52	25	7500
Farm size	3.44	5.39	0.5	90
Hired labor	5.39	6.72	0	50
Family labor	3.01	2.67	0	35
Fertilizer	179.44	479.04	0	6100
Chemicals	3.66	4.05	0	40
Seed	7.18	6.53	0.76	60
Age	47.15	13.13	20	100
Education	3.97	5.19	0	18
Home-farm	1.57	1.37	0.001	10
Extension	0.42	0.49	0	1
FBO	0.47	0.50	0	1
Credit access	0.27	0.45	0	1

The result shows that only four of the strategies were adopted by more than half of the farmers. These strategies included changing planting date (82.6%), mixed farming (54.8%), refilling (51.4%), and planting in rows (52.8%). Generally, farmers have changed their time of sowing maize from May to June as a way of responding to the changes in the onset of the rains. This is consistent with the result in Khanal et al. (2018b), Alemayehu and Bewket (2017), and Roco et al. (2017) where these authors found that changing planting and harvesting date recorded the highest adoption rate among various adaptation strategies. Also, majority of the farmers engaged in refilling due to low germination rate of seeds particularly due to failure of rains that would enable germination and the early growth stage of the maize plants. As such, farmers have to refill the empty seed spots on their farms early enough to ensure there is uniformity in the growth and maturity of the plants.

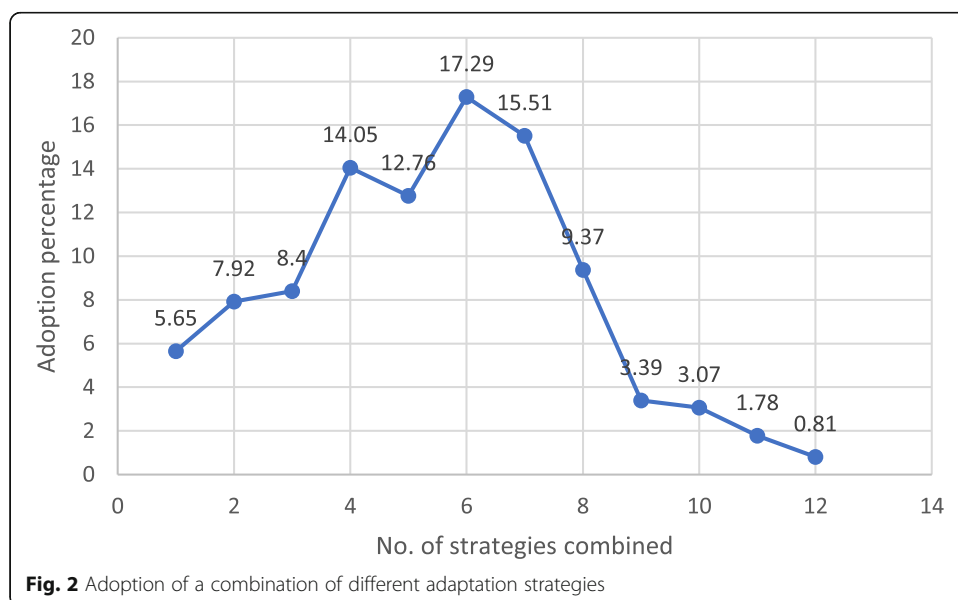
Row planting involves the cultivation of maize seeds in lines. According to the farmers, the major reason for planting in rows is to ease farm operations; ensure

**Table 3** Climate adaptation strategies adopted by the farmers

Adaptation strategy	Freq.	% out of 619
Planting date	511	82.6
Early maturing variety	290	46.8
Drought-resistant variety	173	27.9
Crop rotation	200	32.3
Land rotation	155	25.0
Mixed farming	339	54.8
Intercropping	272	43.9
Refilling	318	51.4
CA	190	30.7
ISFM	140	22.6
Mulching	170	27.5
Row planting	327	52.8
IPM	159	25.7
Contour farming	126	20.4

appropriate spacing of seeds, efficient use of sunlight, and soil nutrients; and ultimately, for higher yields. Although other adaptation strategies were adopted by less than half of the farmers, their adoption levels were reasonably remarkable. For instance, about 47% of the farmers adopted early maturing maize seed varieties while 28% adopted drought-resistant maize varieties. These indicate that the farmers are becoming more conscious of the effects of erratic rainfall patterns on their yields and gradually shifting towards the cultivation of these improved seed varieties. Also consistent with national estimates, 44% of the sampled farmers engaged in inter-crop farming system. This farming system was adopted to maximize the use of farm lands and other farm inputs such as labor and to ensure that there is no total crop failure on a particular farm land. The adoption of contour farming, IPM, mulching, CA, land rotation, and crop rotation are however low (Table 3). In their study, Khanal et al. (2018a) found that the major adaptation strategies adopted by farmers involve varietal adjustment such as planting drought/pest-resistant varieties and soil and water conservation practices such as mulching.

Since climate adaptation strategies are mostly complementary and adopted simultaneously, the study proceeds from Table 3 to further analyze the distribution of the percentage of strategies simultaneously adopted (Fig. 2). This demonstrates that the climate adaptation strategies are mostly complementary and not substitutes. The higher the adoption intensity, the higher the likelihood of complementarity of the strategies. This shows that while the adoption of many technologies simultaneously increased up to six combinations, the percentage of farmers that simultaneously adopted more than six technologies decreases with the number of strategies. For instance, while the highest percentage (17.29%) of the farmers adopted six of the strategies simultaneously, 5.65% and 0.81% adopted only one and twelve strategies, respectively. There is no zero (none) and complete adaptation (all fourteen) by the farmers. In a similar study, Khanal et al. (2018b) found that 91% of their farmers adopted at least one climate adaptation strategy.



### Model selection and diagnosis of the SFA

As discussed under data analysis, technical efficiency is defined by two separate equations. Also, the literature on efficiency analysis shows that socioeconomic factors can have effects on the efficiency levels of the farmers. Therefore, three different models were estimated and subjected to the Aikake Information Criterion (AIC) and Bayesian Information Criterion (BIC) tests. Model 1 involves SFA with adaptation in one part, model 2 involves SFA with adaptation in both parts, and model 3 involves adaptation in both parts with socioeconomic characteristics. The test results (Table 4) suggest that model 2 had the lowest AIC, hence, best fits the data followed by models 3 and 1. However, since the signs in models 2 and 3 are similar and based on the fact that previous studies showed a significant effect of socioeconomic factors on technical efficiency, this study proceeded with the discussion of model 3. The full result of models 1 and 2 are provided in the Appendix 1. In this study, the test of functional form was ignored since the Cobb-Douglas functional form provides basic features that are relevant for the novelty in this research.

### Determinants of maize production

Table 5 shows the set of factors that influenced maize output and the effects of climate adaptation on technical efficiency of the farmers. From the result, the estimated returns to scale (RTS) was more than one, suggesting that there is an increasing return from maize production. Thus, an increase in the use of production inputs would lead to a more than proportionate increase in the output of farmers. In a similar study, Roco et al. (2017) estimated an RTS of 0.9870. Similarly, Table 6 shows that all the factors of production as well as climate adaptation had positive significant effect on maize output, except hired labor which had negative significant effect and fertilizer which had a positive insignificant effect on maize output.

The positive effect of farm size on output means that there is an increasing return from larger farm sizes. Thus, a 100% increase in farm size results to about 63% increase in output. Farm size had the highest elasticity of production, implying that an increase in maize output can be more achieved through an increase in farm size. Fortunately for the studied regions, there are vast unexploited arable lands for cultivation. Generally, farming in Ghana is on small scale with over 80% of farmers operating on less than 2 ha of farm land. However, this result demonstrates the economic merits of economies of scale in crop production and justifies the need for farmers to invest more lands into maize production. Previously, Khanal et al. (2018b), Roco et al. (2017), and Bempomaa and Acquah (2014) used Cobb-Douglas SFA and found positive effects of land on agricultural productivity.

**Table 4** Model selection and diagnosis of the SFA

Model	ll (model)	df	AIC	BIC
Model 1	- 570.891	23	1187.782	1289.628
Model 2	- 567.287	24	1182.574	1288.849
Model 3	- 561.911	30	1183.822	1316.666

**Table 5** Estimates of Cobb-Douglas stochastic frontier

Variable	Coef.	Std. Err.	P>z
<b>Output model</b>			
Farm size	0.625***	0.06	0.000
Hired labor	− 0.103***	0.026	0.000
Family labor	0.098**	0.045	0.031
Seed	0.470***	0.055	0.000
Chemical	0.189***	0.035	0.000
Fertilizer	0.003	0.031	0.928
Adaptation	0.150***	0.048	0.002
Constant	3.706	0.115	0.000
<b>Inefficiency model</b>			
Planting date	3.345	2.18	0.125
Early maturing variety	1.679	1.101	0.127
Drought-resistant variety	3.573**	1.778	0.044
Crop rotation	− 4.959**	2.139	0.02
Land rotation	1.124	1.009	0.265
Mixed farming	0.382	1.024	0.709
Intercropping	0.956	0.895	0.285
Refilling	− 0.324	0.799	0.685
CA	1.911**	0.931	0.04
ISFM	2.846**	1.379	0.039
Mulching	2.689*	1.6	0.093
Row planting	− 4.752**	1.956	0.015
IPM	− 1.759	1.356	0.194
Contour farming	− 0.479	1.084	0.658
Age	0.063	0.046	0.174
Education	0.213**	0.103	0.039
Home-farm	0.329	0.207	0.113
Extension	− 1.399	1.075	0.193
Farmer groups	− 2.993*	1.655	0.071
Credit access	2.006	1.41	0.155
Constant	− 13.44	5.729	0.019
Sigma (v)	0.593	0.017	
RTS	1.431		

\*Statistically significant at 10%

\*\*Statistically significant at 5%

\*\*\*Statistically significant at 1%

The effect of labor on maize production is mixed. While family labor had a positive significant effect on output, hired labor had a negative significant effect on output. These imply that while increasing family labor for maize production would lead to an increase in output, an increase in hired labor would lead to a decrease in output. The positive effect of family labor on output can be due to its constant availability and the fact that it is the basic labor for most farm operations, especially subsistence farms. Family members may also work on the farms of their colleague members with full commitment, knowing the benefits from a higher output on such farms to their families. On the other hand, not only is hired labor readily unavailable but also there are no

measures to check and pay for labor based on the quality of work done. Rather, hired labor is paid based on daily wage or the level of farm operation performed. Generally, the elasticity of hired labor was higher than for family labor. Hence, the net effect of labor on maize output is negative. Consistently, Abawiera and Dadson (2016) estimated that an increase in labor would reduce maize production. Using man days per hectare, Karimov (2014) estimated a positive effect of labor on cotton frontier.

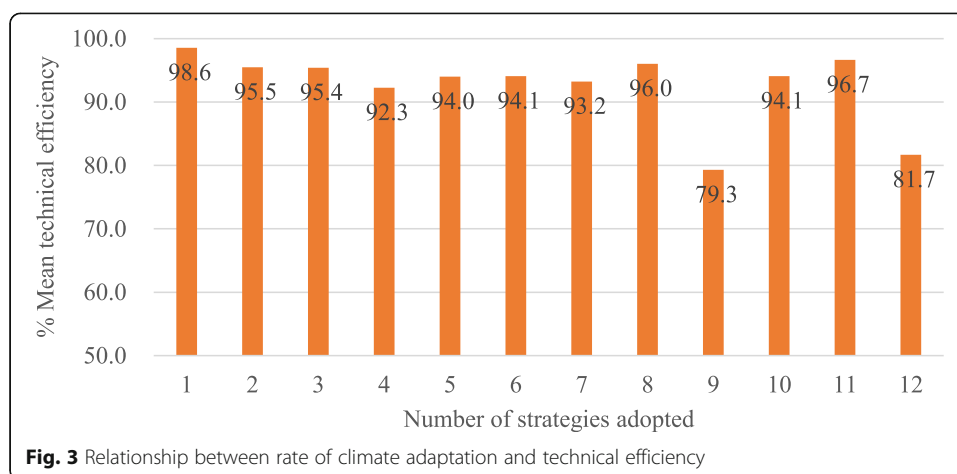
One of the basic inputs of production is seed. From Table 6, seed had a positive significant effect on maize output, with an elasticity of 0.470. This means that the farmers have currently planted seeds at lower rates than required for higher output. This can be attributed to the fact that nearly half of the farmers do not plant in line but randomly where they do not use any standard distance measure between or within stands but based on their sight. In order to obtain the positive effect of seed on maize output, there is the need for farmers to adhere to planting standards. Although insignificant, Abawiera and Dadson (2016) also estimated a positive effect while Kuwornu et al. (2013) estimated a negative insignificant effect of seed quantity on maize output in Ghana.

The effect of chemicals is positive with an elasticity of 0.189. Thus, a 100% increase in the use of herbicides and pesticides could lead to about 19% increase in maize output. In recent maize production, pest and weed control are major activities and challenges in the region. The increasing resistant of weeds and insects have led to their control difficult for farmers who mostly rely on manual control measures. It is therefore consistent that using more chemicals on farm would improve maize output. Abawiera and Dadson (2016) also estimated that an increase in use of both pesticides and herbicides would increase maize production in Ghana. Contrary to this finding, Bempomaa and Acquah (2014) estimated a negative effect of agrochemicals on maize production in Ghana.

As indicated from the model selection result in Table 4, climate adaptation is an essential factor that determines maize output. Already, studies such as Lungarska and Chakir (2018) and Mu et al. (2017) have observed a negative effect of climate change on crop yields and recommended the adoption of climate adaptation strategies. From Table 5, climate adaptation had a positive significant effect on maize output in northern Ghana. This implies that maize farmers who adopted more on-farm climate adaptation strategies had more output than those who adopted few strategies. Consistently, Roco et al. (2017) estimated a positive effect of climate adaptation on agricultural productivity.

#### **Effects of climate adaptation strategies on technical efficiency of maize production**

The second part of Table 5 shows the effect of climate adaptation strategies and socio-economic factors that influenced the technical inefficiency of maize production. From the theoretical notation of the stochastic frontier model, the dependent variable in the model are the levels of technical inefficiency of individual farmers and not technical efficiency. This means that positive estimated coefficients have positive relationship with inefficiency but a negative relationship with efficiency, vice versa. Expectedly therefore, climate adaptation strategies should have negative estimated coefficients. From the result, six out of the fourteen adaptation strategies had significant effect on efficiency levels, out of which only two had negative coefficients. Among the socioeconomic factors, education and farmer group membership had significant effects on technical inefficiency. Before proceeding with the discussion of these significant variables, Figure 3 was determined to show the relationship between the number of adaptation strategies



adopted by farmers and their mean technical efficiency scores. Surprisingly, farmers who adopted a single adaptation strategy had higher average efficiency score, followed by those who adopted eleven and eight strategies while those who adopted nine and 12 strategies had the lowest mean technical efficiencies. Juxtaposing this finding with the positive effect of adaptation on maize output in Table 4, it is imperative that farmers adopt eight or eleven strategies in order to ensure that higher outputs are efficiently produced.

Crop rotation had a negative significant effect on technical inefficiency. This means that farmers who engaged in crop rotation were more technically efficient than those farmers who did not. Crop rotation involves the cultivation of more than one crop on different plots in a rotation. This is an effective way of improving the quality, both the structure and fertility, of the soil. For instance, while some farmers include fallow in their crop rotation strategy, others include leguminous crops or crops from different families into their strategy. The advantage is that while the fallow allows to regain organic matter in the soil, the leguminous crops fix atmospheric nitrogen into the soils while other family crops may also have different rooting and nutrient requirement systems. This ensures that maize farmers are able to efficiently manage their farms, hence the higher efficiency.

Expectedly, farmers who planted maize in rows had higher efficiency than those who planted randomly. Planting in row is one of the recommended agronomic practices in maize production since it leads to proper utilization of nutrient by crops, efficient weed control, proper aeration, effective application and utilization of fertilizer, and general ease in the management of farm. For instance, farmers who planted in rows can easily move on their farms to observe the performance of each plant and are able to detect deficiencies, pests, and diseases easily. It is therefore consistent that row planting improves technical efficiency.

Contrary to expectations, the adoption of drought-resistant varieties, CA, ISFM, and mulching leads to an increase in technical inefficiency. Drought-resistant varieties are widely promoted climate adaptation strategy due to the erratic supply of rainfall in recent years. However, some of these varieties are new to the farmers and may require that proper education is given to the farmers on such varieties prior to their introduction in order to avoid maladaptation. For instance, there is the need to have demonstration farms to give farmers enough education on these varieties. However, the farmers indicated that these drought-resistant varieties were only obtained from the input shops based on recommendations from colleague farmers and extension officers. Since the farmers are more knowledgeable in the

production of their own local seeds and not the drought-resistant varieties, it was clear that the efficiency for the former farmers would be higher than for the latter group of farmers. This finding does not downplay the role of drought-resistant varieties in the crop production climate of the area but to reaffirm the need for effective information and communication on these varieties to the farmers. Also, CA involves minimal to zero tillage of the farm. However, in northern Ghana, due to the high and fast compaction of the lands, it has become practically impossible for farmers to cultivate the lands without tillage, either with tractor or by animal plough. Therefore, it is plausible that zero tillage of the farms may reduce the efficiency of the farms. Marenya et al. (2017) also argued that there are unaddressed concerns on the adoption, diffusion, and scaling of minimum tillage at farm levels, and that the practice is faced with micro and macro challenges that are not different from other agricultural technologies. Admittedly, it is not clear the mechanisms through which ISFM and mulching led to a decline in the technical efficiencies of the farmers, hence, requires further exploration. Contrary to the result of this study, Karimov (2014) estimated a positive effect of organic manure on technical efficiency.

Among the socioeconomic variables, education and farmer group membership had significant effects on technical efficiency of the farmers. While higher formal education led to a reduction in technical efficiency, farmer group membership led to an increase in technical efficiency. Farming in Northern Ghana and Ghana as a whole is mostly done by the less educated. Even so, persons who are well-educated and engage in farming does so as a secondary occupation. Therefore, their time dedication to farming is less and this could reflect in their high technical inefficiencies. The estimated positive coefficient of education is contrary to the result of Khanal et al. (2018b). Also, farmer groups are avenues for sharing of production ideas and a source of labor for most farmers. Therefore, it is consistent that membership in such groups improve technical efficiency. The positive effect of group membership was consistent to the findings of Khanal et al. (2018b) but contrary to that observed by Roco et al. (2017) and Kuwornu et al. (2013). Upon estimating a positive effect of cooperatives on technical efficiency, Linn and Maenhout (2019) argued that farmers have to organize themselves into groups to increase scale of operations and access to information.

#### **Technical efficiency levels of the farmers**

Table 6 shows the technical efficiency scores of the farmers. It can be argued that farmers were highly technically efficient, with an estimated average efficiency of 93.8%, a minimum of 18.1% and a maximum of 100%. This implies that the average farmer requires 6.2% improvement in technical efficiency to be on the maximum production frontier. In fact, only 2.6% of the farmers had efficiency level lower than 61% while 90.3% of the farmers had efficiency levels more than 80%. The efficiency distribution from Models 1 and 2 are presented in Table 8 in the Appendix 2. The observed average technical efficiency score in this study is high relative to most previous studies on maize production in Ghana. For instance, Abawiera and Dadson (2016), Bempomaa and Acquah (2014), and Kuwornu et al. (2013) estimated a mean technical efficiency of 58.1%, 67%, and 51%, respectively. A similar study that examined the impact of climate adaptation on agricultural productivity in Chile by Roco et al. (2017) found that farmers were averagely 76.4% technically efficient. With a similar objective, Khanal et al. (2018b) estimated a technical efficiency of 71.5% while Linn and Maenhout (2019) estimated 22.5% and 61.0% under constant and variable returns to scale respectively. The implication is that although the farmers of northern Ghana are not fully efficient in maize production, they

**Table 6** Technical efficiency levels of the farmers

Efficiency level	Model 3		
	Freq.	%	Cumulative %
11–20	1	0.2	0.2
21–30	0	0.0	0.2
41–50	7	1.1	2.3
51–60	8	1.3	2.6
61–70	17	2.8	5.4
71–80	27	4.3	9.7
81–90	51	8.2	17.9
91–100	508	82.1	100.0
Mean	0.938		
Min	0.181		
Max	1.00		

are able to use production inputs with relatively less wastage than farmers in previous years and/or different locations.

### Conclusions and policy implications

Climate change impacts on crop production have become a major concern for players in the agricultural sector. The global drive under the Sustainable Development Goal 2 to achieve zero hunger by 2030 is threatened by climate impacts. The role of climate adaptation among farmers have become a necessary step to ensuring that crop yields are not overly affected by climate change. Within the background that there is the need to ensure that efficiency is not compromised by the adoption of climate adaptation strategies, this study analyzed the effect of climate adaptation on technical efficiency of maize production. Evidently, the study concluded that climate adaptation has a positive significant role in improving maize output in northern Ghana. Overall, the efficiency levels of the farmers are high, and this has to be maintained and improved. However, only two of six significant climate adaptation strategies led to an improvement in the efficiency of maize production. Since farmers generally seek to maximize output and reading into the negative impacts of climate change on crop yield, it is vital that farmers engaged in the adoption of more on-farm climate adaptation strategies, particularly crop rotation and row planting. Non-governmental organizations such as International Institute of Tropical Agriculture (IITA) that works closely with farmers should engage in promoting these climate adaptation strategies. These organizations should also reassess their education on climate adaptation strategies to ensure that the adoption of climate adaptation strategies improves efficiency as well as output of the farmers.

Similarly, in order to raise maize output and not compromise technical efficiency of production, maize farmers are encouraged to adopt eight or eleven climate adaptation strategies. Unfortunately, this study is unable to determine the combination of these eight and eleven strategies, and this is a subject for future studies to analyze which adaptation strategies farmers have to combine in order to effectively adapt to climate change. Perhaps, this must involve an experimental research. Generally, the study recommended the adoption of more on-farm climate adaptation strategies in order to enhance maize output in the region. Also, farmers are encouraged to invest more lands into maize production and increase the seed density of their farms in subsequent years. There is the need for maize input dealers in



collaboration with the Ministry of Food and Agriculture (MoFA) to ensure that quality and efficient chemicals are provided to the farmers while the farmers are also advised on the usage of such chemicals appropriately.

The study admitted a likely endogeneity in the inclusion of climate adaptation in both the output and inefficiency components of the SFA. This may have some implications on the estimated coefficients. However, addressing this endogeneity in the models would be complicated, especially in the inefficiency model where as many as fourteen adaptation variables were considered. Nonetheless, a future study is being considered to address this limitation. Although the findings, conclusions, and recommendations are well fitted into the maize production environment of the northern regions of Ghana, policy makers are advised to use the findings of this study within this caveat.

## Appendix

**Table 7** SFA estimates of Models 1 and 2

Variable	Model 1			Model 2		
	Coef.	Std. Err.	P>z	Coef.	Std. Err.	P>z
<b>Output model</b>						
Farm size	0.650***	0.062	0.000	0.665***	0.063	0.000
Hired labor	- 0.109***	0.026	0.000	- 0.099***	0.026	0.000
Family labor	0.095**	0.045	0.035	0.106**	0.045	0.019
Seed	0.443***	0.055	0.000	0.451***	0.055	0.000
Chemical	0.189***	0.036	0.000	0.180***	0.035	0.000
Fertilizer	- 0.004	0.032	0.901	0.006	0.031	0.837
Adaptation				0.195***	0.057	0.001
Constant	3.841***	0.111	0.000	3.705***	0.115	0.000
<b>Inefficiency model</b>						
Planting date	26.722	1094.03	0.981	26.694	1023.44	0.979
Early maturing variety	0.578	0.596	0.332	0.281	0.73	0.7
Drought resistant variety	0.657	0.565	0.245	0.793	0.83	0.34
Crop rotation	- 1.514**	0.705	0.032	- 4.781**	2.458	0.052
Land rotation	0.457	0.56	0.414	0.244	0.813	0.764
Mixed farming	0.459	0.618	0.458	0.5	0.753	0.507
Intercropping	1.305**	0.572	0.023	1.015	0.692	0.142
Refilling	- 1.213**	0.562	0.031	- 1.913***	0.759	0.012
CA	1.298**	0.576	0.024	0.687	0.77	0.372
ISFM	1.366**	0.65	0.036	1.192	0.911	0.191
Mulching	1.195**	0.614	0.052	1.641	0.792	0.038
Row planting	- 1.489**	0.633	0.019	- 3.037***	0.977	0.002
IPM	- 0.426	0.642	0.507	- 1.798*	1.099	0.102
Contour farming	0.12	0.664	0.856	- 0.433	0.804	0.59
Constant	- 30.56	1094.04	0.978	- 28.92	1023.45	0.977
sigma_v	0.592	0.018		0.593	0.018	
RTS	1.263			1.503		

\*, \*\* and \*\*\* indicates significance at 1%, 5% and 10%, respectively

**Table 8** Technical efficiency estimates of Models 1 and 2

Efficiency level	Model 1		Model 2	
	Freq.	%	Freq.	%
11–20	0	0.0	1	0.2
21–30	1	0.2	1	0.2
41–50	9	1.5	1	0.2
51–60	13	2.1	6	1.0
61–70	27	4.4	20	3.2
71–80	87	14.1	63	10.2
81–90	201	32.5	123	19.9
91–100	281	45.4	404	65.3
Mean	0.873		0.913	
Min	0.229		0.183	
Max	1.00		1.00	

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**Authors' contributions**

WA wrote the background and managed the data analysis. HA discussed the results and conclusions. The authors read and approved the final manuscript.

**Availability of data and materials**

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

**Competing interest**

The authors declare no competing interest.

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