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A Comparison of Technical Efficiencies for Climate Change Adaptation Strategies Used by Green Gram Farmers in Tharaka South Sub County, Tharaka Nithi County, Kenya

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Abstract: Kenya has experienced effects of climate change because most of the arable land is rain-fed yet the economy is dependent on agriculture. Climate change greatly affects crop production and has constrained legume yield globally. Green gram is an important and appropriate legume for Arid and Semiarid Lands (ASALs) as a source of livelihood yet climate change has been observed in these areas and has caused a fall in green gram yield. Adjusting to climate change at the farm level has resulted in rising income and yield as well as economic development. Farmers in Tharaka South Sub County have been vigorous in mitigating against climate variability but information on cost effective and efficient strategies is still inadequate to enable them make informed choices. This study aimed at comparing the technical efficiencies of various climate change adaptation strategies practiced by green gram farmers in in Tharaka South Sub County, Tharaka Nithi County, Kenya for the period 2017-2021. Primary data was sourced from 390 households obtained using stratified random sampling technique. Cobb-Douglas stochastic frontier method was used to determine technical efficiency of the various climate change adaptation strategies practiced by farmers. The findings of the study showed that most farmers (92.73%) had adjusted to climate change and further analysis showed that farmers who did not adapt to climate change recorded low yield. The model findings on technical efficiency levels of the climate adaptation strategies utilized by small holder green gram farmers showed that adaptation is an important factor explaining efficiency differentials among farmers. Use of minimum tillage was the most efficient adaptation strategy with a technical efficiency of 75.58% while use of irrigation was the least efficient strategy with a technical efficiency of 67.51%. The study concluded that though minimum tillage was the most technical efficient strategy to deal with climate change farmers should use a multiple of strategies to increase efficiency and enhance resilience in green gram production.

Keywords: Green Gram, Climate Change, Adaptation Strategies, Yield, Technical Efficiency

1. Introduction

Climate change is a global challenge affecting agriculture, livelihoods and overall economic growth. It has been acknowledged as a serious threat affecting agriculture sector and attributed to almost 60% of variance in global crop yield [1, 2]. Africa continent is affected more by climate change because of increased exposure and unavailability of adequate resources for adaptation. The continent is projected to warm more than other continents and to experience decline in rainfall mainly in Arid and Semiarid Lands (ASALs) [3]. Most of the arable land (over 95%) in Sub-Saharan Africa (SSA) is rain-fed yet the economies are dependent on agriculture which is the main source of livelihoods to 80% of the population [4]. Kenya climate has been rated variable, in 2019 the country's climate risk was rated extremely vulnerable and ranked at position 152 out of 182 countries [5]. Climatic variability greatly affects crop production and explains almost 60% of crop yield variability resulting to reduced household income [1]. Climate change also constraint legume yields globally affecting livelihoods and nutrition security [6]. Climate change has been observed in green gram growing areas and has caused changes that have altered areas suitable for optimum growth and production of green gram [7, 8]. The changes in climate has already caused a fall in green gram yield and the expected further change in climate is likely to exacerbate other related stress like increased emergence of pest and diseases further affecting quality of the crop yield [9, 10].

Farmers engage in several adaptation strategies that can be classified in to technological; change of behavior, change in management and policy options [11]. A study by Ahmed [12] recommended adaptation options such as use of climate-resilient varieties, a change in sowing dates, use of early maturing seeds, intercropping, and crop diversification as a way to combat climate change in legumes. Adjusting to climate change at the farm level could result in rising income and yield as well as economic development [13]. Technology adopters have been reported to have greater levels of technical efficiency [14]. Hakim [15] showed that use of mulch treatment as soil cover had a significant impact on the green gram growth, production, and yield components. A study by Ray [16] also reported increased green gram yield produced per hectare by 1.3 to 1.7 times due to mulch application. Minimum tillage increased soil organic matter, structure, microbial biomass, water retention, and crop yield [17]. According to Wang [18], increasing irrigation was a way to increase yield level in water-scarce areas while also making agricultural systems better able to withstand the effects of climate change while Ray [16] found that irrigation increased yield of pulses. A study by Degani [19] established that a mix of crop rotation and minimum tillage resulted to high efficiency of both input and output of the crops.

Farmers in Tharaka South Sub County have been vigorous in mitigating against climate variability but information on cost effective and efficient strategies is still inadequate to enable the green gram farmers make informed choices. Although there is increased research on climate change adaptation, there still exist a gap to compare the efficiency levels of the different adaptation strategies practiced by the farmers. The majority of research has concentrated on farm yield observed rather than evaluating the effectiveness of farming methods [20]. This study aimed at comparing the technical efficiencies of various climate change adaptation strategies practiced by green gram farmers in Tharaka South Sub County, Tharaka Nithi County, Kenya. Understanding the most efficient adaptation technique to lessen the effects of climate variability may assist in optimizing the scarce resources for sustainable green gram production.

2. Research Methodology

2.1. Study Area

The study location was in Tharaka Nithi County, Tharaka South Sub County in Eastern Kenya which is among the Kenya's Arid and Semiarid Lands (ASALs) Counties. It shares Mount Kenya with Kirinyiga and Nyeri to the west, and borders the counties of Embu to the south and south-west, Meru to the north and north-east, Kitui to the east and south-east. The County is located between longitudes 370 19' and 370 46' East and latitudes 000 07' and 000 26' South. The County covers 2,662.1 km^2 in total, including 360 km^2 of Mt. Kenya forest. Tharaka South Sub County covers 746.1 km^2 and has three administrative wards: Chiakariga, Marimanti, and Nkondi [21]. The population of the Sub County comprises of a total of 75,250 persons (36,190 males; 39,058 females and 2 intersex) in 18,603 households [22]. The Sub County experiences a bi-modal pattern of rainfall, with the long rains occurring from March to May and the short rains from October to December. About 500 mm of irregularly distributed rainfall and intermittently high temperatures of up to 40°C are experienced by the Sub County [21].

2.2. Research Design

The study employed a survey method which is a type of descriptive research design. It entails a brief interview or discussion with some selected persons about a specific topic and is preferred because it can be used to take opinion, thought and feelings [23].

2.3. Sample Size and Sample Procedure

2.3.1. Sample Size

The study used a 5% level of precision on a target population of 14,882 households and 390 households were selected. According to the formula a standard error (e) in the range of 2% to 5% is typically acceptable [24]. The formula is as shown in the following equation;

$$n = {}^{N}\!/_{1 + N(e)^2} \tag{1}$$

where;

n = Desired sample size

N = Population size

e = Acceptable error

$$n = \frac{14882}{1+14882(0.05)^2}$$

$$n = 390$$

2.3.2. Sampling Procedure

The sample size was drawn from the households that practice green gram farming in the three ward of Tharaka South Sub County. The distribution of individual interviews was carried out proportionately where the Wards (administrative units), served as the strata in the stratified random sampling approach. A sample size of 390 households was obtained and the majority (203) were drawn from Chiakariga Ward and the least number (78) from Nkodi Ward (Table 1).

Table 1. *Sample Size of Households by Ward.*

Ward (strata)	Number of villages	Total number of households	Households in green gram production	Sample size
Chiakariga	6	9703	7762	203
Marimanti	5	5181	4145	109
Nkodi	3	3719	2975	78
Total	14	18,603	14882	390

Source: Author's conceptualization 2022

2.4. Data Collection

The study used primary data that included information on farm-level adaptation strategies, inputs used in the production of green gram, yield, and other socioeconomic traits. Green gram production inputs considered comprised of labour, seed, manure, fungicide, insecticide, herbicide, foliar and chemical fertilizer used to grow the crop. The socioeconomic traits of farming households considered included; age, years of education, membership to a farmer group, access to title deed, extension services and credit.

2.5. Data Analysis

A stochastic production function technique suggested by Battese [25] was used to compare the technical effectiveness of various adaptation strategies used to reduce the effects of climate variability in the production of green gram. The level of a farmer's technical efficiency is indicated by a number between zero and one, if a farmer has a value of 1, they are fully technically efficient [25]. The methodology was used because it can discriminate between technical inefficiency and statistical noise as well as the impact of agricultural inputs on output. Taking the Cobb-Douglas form of stochastic production frontier the equation was as follows:

$$\ln Y = \beta_0 + \sum_{j=1}^{n} \beta_j \ln(X_{ij}) + (v_i - \mu_i) \quad \text{for } \varepsilon = v_i - \mu_i \qquad (2)$$

where:

Y = natural logarithm of green gram yield (kg/ha).

β_0= the constant

β_j = regression coefficient

Ln (X_{ij}) = natural logarithm of inputs i.e seeds, chemical, labour, fertilizer

ε = error term of two separate components v_i and u_i (variations due to random factors beyond the control of the farmer and technical inefficiency model, respectively)

3. Results and Discussion

3.1. Socio-Economic Characteristics of Green Gram Farmers

The findings of the study showed that majority of the respondents (28.57%), fell between the ages of 36 and 45. Another significant proportion (24.42%) of the farmers was in the age bracket of 46-55years while the farmers in 56-65 years' age bracket accounted for 13.25%. There was a significant number of farmers above 65 years (9.87%). In addition, the observed results revealed that the majority (43.64%) of the studied household heads had completed primary level. A sizeable percentage of farmers (32.21%) had completed secondary education, whereas only a small percentage (8.05%) had no formal education. It was also observed that few farmers had attained college and university education at 12.47% and 3.6%, respectively. Majority of the farmers who owned land (63.46%) did not have title deeds and only few farmers (36.36%) possessed tittle deeds. Most of the farmers had extension services access (88.31%) with majority of the farmers (89.87%) belonging to a farmer group and a large number of farmers accessed credit (Table 2).

Table 2. *Socio-economic characteristics of green gram farmers.*

Variable	Description	Frequency	Percent
Age range of respondents	18-35 years	92	23.90
	36-45 years	110	28.57
	46-55years	94	24.42
	56-65	51	13.25
	0ver 65 years	38	9.87
Education level of respondents	None	31	8.05
	Primary	168	43.64
	Secondary	124	32.21
	College	48	12.47
	University	14	3.64
Access to tittle deed	Yes	140	36.36
	No	245	63.64
Access to extension services	Yes	340	88.31
	No	45	11.69
Access to farmer group	Yes	346	89.87
	No	39	10.13
Access to credit	Yes	246	63.90
	No	139	36.10

3.2. Adaptation to Climate Variability by Green Gram Farmers

The study findings showed that most farmers (92.73%) had adjusted to climate change. The findings of this study are in line with those of Kalele [26] who established that increased extreme weather changes in Yatta region forced many farmers to adopt differing climate adaption strategies to improve their livelihoods.

3.2.1. Adoption of the Climate Adaptation Strategy by the Farmers

The study findings showed that farmers used a variety of adaptation strategies, majority of farmers (69.61%) used maximum soil cover. The findings of the study further observed that 47.01% used early maturing seeds, 40% practiced crop rotations while 38.7% used minimum tillage.

It was also observed that few farmers used irrigation (10.39%). A significant number of farmers (21.56%) used other adaptation mechanisms that included terracing, livelihood diversification, intercropping and mixed farming, use of weather-based advisories (Table 3).

Table 3. *Percentage Adoption of the Climate Adaptation Strategy by the Farmers.*

Adaptation strategy	Frequency	Percent
Use of early maturing seeds	181	47.01
Minimum tillage	149	38.70
Maximum soil cover	268	69.61
Crop rotation	154	40.00
Irrigation	40	10.39
Others	83	21.56

3.2.2. Green Gram Yield Distribution with and Without Climate Adaptation

The findings of this study observed that farmers who used climate adaptation strategies recorded higher yield than the farmers who did not adapt to climate change. The farmer who adapted to climate change achieved the highest yield in 2021 with an average of 334.33 kg/acre which is above the highest yield achieved by farmers not using climate adaptation strategies of an average of 241.93 in 2019. The lowest yield by farmers using climate adaptation strategies was 235.49 kg/acre while mean yield obtained by farmers not using climate adaptation strategies was 166.06 (Table 4).

The observed findings are in line with Lu [27] who found that farmers who were not using irrigation as a climate adaptation strategy recorded very low yield due to water stress of the crops. Generally, it is possible that lack of adaptive capacity may expose green gram farmers to higher risk of crop failure and reduced yield. There is a possibility that the lack of adequate adaptation measures may also contribute to a heightened risk of pest and disease outbreaks, which can further reduce yields and cause losses in income. Furthermore, the lack of appropriate resources to lessen the consequences of climate change may raise the danger of soil degradation, deforestation, and biodiversity loss, posing a further threat to crop production. Smallholder farmers were made more susceptible to the effects of climate unpredictability by their lack of access to resources like irrigation systems and loans [27].

Table 4. *Five Years' Green Gram Yield Obtained by Farmers Using/Not Using Climate Adaptation Strategies (kg/acre).*

Yield for 5 Years	Mean yield obtained by farmers adapting to climate change	Mean yield obtained by farmers not adapting to climate change
Yield in 2021	334.33	188.42
Yield in 2020	302.20	200.58
Yield in 2019	290.41	241.93
Yield in 2018	277.57	190.24
Yield in 2017	235.49	166.06

3.3. Comparing the Technical Efficiencies of Climate Variability Adaptation Strategies Used by Green Gram Farmers

The study employed a Cobb-Douglas stochastic frontier model to compare the technical efficiency levels of use of early maturing seeds, minimum tillage, maximum soil cover, crop rotation and irrigation aimed at identifying the most efficient adaptation technique in green gram production.

3.3.1. Use of Early Maturing Seeds Strategy in Green Gram Production

The stochastic frontier model's log likelihood was -281.781 with a *P*-value of 0.00, indicating a strong significant explanatory power for the model. According to the model's findings, when early maturing seeds to deal with climate change four out of the eight farm inputs had a substantial effect on green gram yield at 5% level of significance. The inputs included land, seed, foliar and chemical fertilizer whose *P*-value were less than 0.05 (Table 5).

Table 5. *Stochastic Frontier Model Parameter Estimates When Using Early Maturing Seeds.*

Variable	Coefficient	Std Error	Z	*P*-Value	95% Confidence interval	
Constant	3.565	0.201	17.73	0.00	3.171	3.96
Log land	0.285	0.057	4.99	0.00	0.173	0.397
Log seed	0.352	0.045	7.87	0.00	0.264	0.44
Log foliar fertilizer	-0.063	0.022	-2.93	0.003	-0.106	-0.021
Log chemical fertilizer	0.060	0.014	4.34	0.00	0.033	0.088
Log manure	0.017	0.012	1.43	0.152	-0.006	0.040
Log fungicide	0.045	0.014	0.32	0.75	-0.088	0.123
Log insecticide	0.040	0.013	0.91	0.361	-0.042	0.115
Log herbicide	0.047	0.036	1.31	0.189	-0.023	0.117
Log labour	0.153	0.045	3.43	0.001	0.066	0.241
Log Likelihood	-281.781					
Total Observations	385					
Prob>Chi2	0.000					

It was further observed that with the exception of foliar fertilizer, the coefficients for land, seed, chemical fertilizer, and labor were all positive. A unit increase in land for the farmers who had adopted the use of early maturing seeds increased the production of green gram by a factor of 0.285 (*P*-value=0.00<0.05). The model also showed that a unit increase in the use of planting seeds increased the production of green gram by a factor of 0.352 (*P*-value=0.00<0.05) for the farmers using early maturing seeds (Table 5). The is a possibility that certified and early maturing seeds are highly adaptable to climate variability and are able to withstand the adverse effects of weather changes. Increasing the area of land under certified seeds would assure the farmers high level of green gram yields since the likelihood of a possible crop loss was low (Table 5). The observed findings concur with those of Sundareswaran [28] who depicted that small scale farmers who allotted more land resource to high quality and certified seeds were more likely to get high crop yields.

Fertilizer was composed of both foliar fertilizer and chemical fertilizer. When using early maturing seeds, the model showed that foliar fertilizer had a negative and significant effect on production of green gram. Green gram output decreased by a factor of 0.063 for every unit increase in the usage of foliar fertilizer (*P*-value=0.003). This went against the notion that it would boost the production of green grams. The observed findings contradict those of Jena [29] who established that increased application of foliar spray accelerated the growth of the green gram and increased the yield obtained by the farmers. The findings also contradict those of Tursun [30] who established that increase in the application of foliar fertilization to the coriander increased the growth and the yield of the crops. Further, a unit increase in the use of chemical fertilizer increased green gram production by a factor of 0.060 (*P*-value=0.00<0.05) [Table 5]. The observed findings imply that farmers who had adopted the use of early maturing seeds and were using chemical fertilizer as opposed to foliar fertilizer were able to increase production of green gram. The stochastic production frontier when using early maturing seeds can be expressed as:

$$Y = 3.565 + 0.285X_1 + 0.352X_2 - 0.063X_3 + 0.060X_4 + 0.153X_5 \quad (3)$$

where:

Y = natural logarithm of green gram yield

X_1=natural logarithm of land size

X_2=natural logarithm of seed quantity

X_3= natural logarithm of foliar fertilizer quantity

X_4= natural logarithm of chemical fertilizer quantity

X_5=natural logarithm of labour quantity

The constant (3.565) which is the expected value of green gram production when farm inputs (land, seed, fertilizer and labour) value is zero.

Given the functional form used, the average technical efficiency level of green gram when using early maturing seeds as a climate adaptation strategy was estimated at 73.09% varying from 15.58% to 91.68%. The inefficiency part of the model was determined by the effects of socio-demographic and socioeconomic factors. The inefficiency part of the model showed that only the years of education had a significant effect on the level of technical efficiency when using early maturing seeds to produce green gram. Years of education in the model was negative, which showed that education had a beneficial impact on technical efficiency. When using early maturing seeds, it was found that an additional year of education increased the technical efficiency of green gram production by a factor of 0.199 (*P*-value=0.00) [Table 6]. The observed findings, may imply that farmers with more education have the knowledge and access to high yielding and suitable seeds that are adaptable to climatic variability. The observed findings are in line with Nikam [31] who established that access to information is crucial in decision making for viable and sustainable agricultural enterprise. The findings of Nikam [31] informs that farmers require crucial information about the type of certified seeds to use in the planting season so to ensure they are early maturing and are of high quality. Formal education may form part of prior knowledge that the farmers can rely upon as well as the farming experience.

Table 6. *Maximum Likelihood Estimates of the Inefficiency Model When Using Early Maturing Seeds.*

Variable	Coefficient	Std Error	Z	P-Value	95% Confidence interval	
Constant	1.647	0.956	1.72	0.085	-0.227	3.522
Age	0.003	0.013	0.24	0.807	-0.022	0.028
Years of education	-0.199	0.053	-3.76	0.00	-0.302	-0.095
Household size	-0.143	0.095	-1.52	0.13	-0.329	0.042
Access to title deed	-0.141	0.293	-0.48	0.632	-0.716	0.435
Access to extension services	-0.255	0.428	-0.59	0.552	-1.094	0.585
Farmer group	-0.591	0.499	-1.18	0.237	-1.569	0.388
Credit access	0.082	0.329	0.25	0.804	-0.564	0.728

Note: A parameter coefficient with a negative (-) sign indicates that as the independent variable rises, technical efficiency levels rise and the degree of technical inefficiency decreases

The important exploratory variable (years of education) can be used to express the inefficiency model as illustrated below:

$$Ui = -0.199W1 \quad (4)$$

where, W1= Years of education variable

3.3.2. Use of Minimum Tillage in Green Gram Production

The findings on the log likelihood was -278.182, and a p-value of 0.00 meant that the model was highly explanatory and had the best fit. The stochastic model showed that six of the eight farm inputs that had been taken into account in the study had a significant effect on green gram yield at the 5%

level of significance while utilizing minimum tillage to deal with climate variability. The six inputs were land, seed, insecticide, labor, chemical and foliar fertilizer whose *P*-values was less than 0.05 (Table 7). The findings of the study showed that the coefficients of land, seed, chemical fertilizer, insecticide, and labor factors was positive, with the exception of the foliar fertilizer variable. It was further observed that a unit increase in land area allotted for the production of green gram was associated with an increase in the level of yield of green gram by a factor of 0.241 (*P*-value=0.00<0.05) [Table 7]. The findings of this study found that in relation to the farmers using certified seeds, the factor increase in yield was less under minimum tillage alone but there would be a greater increase in the factor increase upon combining the two climate adaptation strategies. Farmers using minimum tillage may have had a reduction in labour inputs resulting to a significant cost savings that may be used to expand and intensify green gram production and hence increasing the yields. The finding of this study concur with those of Musafiri [32] who established that adopting minimum tillage under drought-tolerant crops like sorghum improved community wellbeing through increased crop productivity. Musafiri [32] depicted that as farmers increased the land area under minimum tillage more yield was obtained as a result of reduced soil disturbances.

Table 7. *Stochastic Frontier Model Parameter Estimates When Using Minimum Tillage.*

Variable	Coefficient	Std. Error	Z	P-Value	95% Confidence interval	
Constant	3.600	0.202	17.85	0.00	3.205	3.996
Log land	0.241	0.058	4.13	0.00	0.127	0.355
Log chemical fertilizer	0.036	0.014	2.54	0.011	0.008	0.064
Log seed	0.433	0.051	8.45	0.00	0.332	0.533
Log foliar fertilizer	-0.078	0.025	-3.13	0.002	-0.127	-0.029
Log manure	0.008	0.011	0.7	0.484	-0.014	0.031
Log fungicide	0.076	0.053	1.44	0.151	-0.028	0.179
Log insecticide	0.105	0.039	2.68	0.007	0.028	0.182
Log herbicide	0.033	0.023	0.68	0.496	-0.043	0.088
Log labour	0.085	0.039	2.17	0.03	0.008	0.162
Log Likelihood	-278.182					
Total observations	385					
Prob>Chi	0.000					

The findings of the model also showed that a unit increase in the use of chemical fertilizers by farmers relying on minimum tillage was associated with an increase in green gram yield by a factor of 0.036 (*P*-value=0.01<0.05). The findings of this study imply that a combination of the minimum tillage and the chemical fertilizers used was more beneficial to the green gram and it led to increased yields. The findings of this study concur with Morugán-Coronado [33] who established that the use of minimum tillage and fertilizer improved soil fertility and quality while preserving a ground cover that protected the soil, enhancing the growing environment and boosting crop production. The stochastic model also showed that farmers using minimum tillage to mitigate against climate change upon increasing the amount of seeds used in planting by a unit there was an increase in the level of green gram by a factor of 0.433 (*P*-value=0.00<0.05). The findings may imply that the farmers using minimum tillage were better off in provision of favorable environmental conditions that suits the germination and emergence of seeds because it reduces soil compaction, improves soil aeration, and increases the availability of water and nutrients. The findings are in line with Degani [19] and those of Lv [34] that revealed that minimum tillage would reduce soil compaction and conserve more soil moisture for the seedlings and therefore increase in the seeds used for planting would lead to higher yields.

The model showed that for farmers using minimum tillage an increase in the level of insecticides by a unit leads to an increase in the level of yields of green gram obtained by a factor increase of 0.105 (*P*-value=0.007<0.05) [Table 7]. The findings imply that farmers were using insecticides to control the pests and diseases in their farms as opposed to mechanical methods of controlling pests and diseases. The findings may also imply that the insecticides used were of the right quality and that they contributed in lowering the infestation of pests in the green gram farms which led to an increase in the level of green gram harvested by the farmers. The findings concur with those of Das [35] who established that a combination of minimum tillage practices including the use of insecticides to control pests is associated with decreased costs of production and an increase in the level of yields. The findings of the model also showed that for farmers using minimum tillage an increase in labour by unit lead to an increase in the level of green gram yields obtained by the farmers by a factor of 0.085 (*P*-value=0.03<0.05). The findings of this study imply that although minimum tillage involves reduction of soil disturbances employing more workforce to ensure adequate supply of all agro-chemicals to the green gram' farms would help improve the effectiveness of minimum tillage and thereby led to an increase in yield. However, the model findings found that an increase in the use of foliar fertilizers for farmers using minimum tillage was associated by a 0.078 (*P*-value=0.002<0.05) factor decline in the level green gram yield (Table 7). The findings of this study contradict the normal expectations of any farmer who anticipates that there may be increase in the level of yields upon the utilization of more foliar fertilizers. The observed findings also contradict the findings of Krishnaveni

[36] who established that increase in the use of foliar fertilizer on green gram yields lead to a 5-unit increase from 834 kg/ha to 835 kg/ha of the harvested green gram. The findings of this study also contradict those of Saleem [37] who established that an increase in foliar fertilizer on the crops was associated by an increase in the level of crop yield. The stochastic production frontier when using minimum tillage can be expressed as follows:

$$Y = 3.600 + 0.241X_1 + 0.433X_2 - 0.078X_3 + 0.036X_4 + 0.085X_5 + v_i - \mu_i \quad (5)$$

where:

Y = natural logarithm of green gram yield

X_1=natural logarithm of land size

X_2=natural logarithm of seed quantity

X_3= natural logarithm of foliar fertilizer quantity

X_4= natural logarithm of chemical fertilizer quantity

X_5=natural logarithm of labour quantity

v_i = variations due to random factors beyond the control of the farmer

u_i = technical inefficiency model

The constant=3.600 is the amount of green gram produced by the farmers using minimum tillage relying on no input use.

The average technical efficiency level of green gram when using minimum tillage as a climate adaptation strategy was 75.58% varying from 16.74% to 91.66%. The stochastic model showed that years of education had a significant impact on the level of technical efficiency of minimum tillage on the yields of greens gram produced, and that the effects of socio-demographic and socioeconomic factors determined the inefficiency portion of the stochastic model. The model findings revealed that an increase in years of schooling by one year led to increased technical efficiency of minimum tillage on green gram yields by a factor of 0.171 (*P*-value=0.002<0.05) [Table 8]. The findings imply that educated farmers may not only be aware of the practices but also may have been conversant with the ways, sequences and strategies of applying the practice appropriately. The findings concur with those of Ji [38] who established that farmers who had more educational knowledge, skills and experiences and using minimum tillage had the highest efficient farms. The findings also concur with those of Bakare [39] who revealed that the choice of climatic adaptation strategy by the farmers was largely dependent on the farmers' educational experience. However, the observed findings contradict those of Lejissa [40] who found that farmers who had no practicing skills of various practices in conservation agriculture such as minimum tillage were highly schooled as opposed to farmers who were used to practicing skills that were less schooled.

Table 8. *Maximum Likelihood Estimates of the Inefficiency Model When Using Minimum Tillage.*

Variable	Coefficient	Std. Error	Z	P-Value	95% Confidence interval	
Constant	0.904	0.027	0.88	0.379	-1.109	2.916
Gender	-0.266	0.327	-0.81	0.417	-0.907	0.376
Age	0.013	0.015	0.89	0.375	-0.016	0.041
Years of education	-0.171	0.055	-3.09	0.002	-0.279	-0.063
Household size	-0.073	0.104	-0.7	0.481	-0.277	0.131
Access to title deed	-0.620	0.377	-1.64	0.100	-1.360	0.120
Extension services	-0.099	0.071	-0.21	0.834	-1.022	0.825
Farmer group	-0.847	0.553	-1.53	0.125	-1.930	0.236
Credit access	-0.161	0.052	-0.46	0.648	-0.850	0.529

The inefficiency model can be expressed as follows:

$$Ui = -0.171W1 \quad (6)$$

where, W1= Years of education variable

3.3.3. Use of Maximum Soil Cover in Green Gram Production

The stochastic model revealed that when using maximum soil cover to deal with climate variability, at the 5% level of significance, four out of the eight farm inputs that were taken into account in the study had a substantial impact on green gram yield. The inputs include land, seed, chemical fertilizer and labour with p-values less than 0.05. The log likelihood statistics was 283.121 at *P*-value=0.00 implying a strong explanatory power of the stochastic frontier model. The findings of the model imply that for farmers using maximum soil cover a unit increase in land area portioned to green gram production had a significant increase in the level of green gram produced by a factor of 0.246 (*P*=0.00<0.05) [Table 9].

Table 9. *Stochastic Frontier Model Parameter Estimates When Using Maximum Soil Cover.*

Variables	Coefficient	Std. Error	Z	P-Value	95% Confidence level	
Constant	3.520	0.185	19.02	0.00	3.157	3.883
Log land	0.246	0.055	4.48	0.00	0.139	0.354
Log chemical fertilizer	0.058	0.014	4.16	0.00	0.030	0.085
Log seed	0.398	0.044	8.97	0.00	0.311	0.486
Log foliar fertilizer	-0.038	0.024	-1.57	0.116	-0.086	0.009
Log manure	-0.002	0.010	-0.15	0.884	-0.022	0.019
Log insecticide	0.065	0.037	1.76	0.079	-0.007	0.138
Log herbicide	0.036	0.015	0.46	0.644	-0.052	0.085

Variables	Coefficient	Std. Error	Z	P-Value	95% Confidence level	
Log labour	0.137	0.004	3.43	0.001	0.059	0.215
Log likelihood	283.121					
Observations	385					
Prob>Chi	0.00					

The observed findings imply that farmers relying on mulching and cover cropping were well equipped to address the negative consequences of climate change and were able to increase yield.

The observed findings concur with those of Muchomba [41], who established that soil cover had contributed to maximum use of land leading to increased yield. The findings of the model also showed that a unit increase in the use of chemical fertilizers by farmers using maximum soil cover was associated by an increase in green gram yields by a factor of 0.058 (*P*-value=0.00<0.05). The stochastic frontier model exhibited that a unit increase in the planting seeds by farmers using maximum soil cover was accompanied by an increase in green gram yield by a factor of 0.398 (*P*-value=0.00<0.05) [Table 9]. The findings of the study may also imply that maximum soil cover was essential for optimal seed germination by reducing water loss and keeping the seed warmer during cold weather. Mulching may help to prevent water runoff, reduce the amount of water lost through evaporation allowing more water to be absorbed into the soil and increasing water availability for the plants thereby reducing the risk of drought. According to Ray [16] mulching helped in water retention thus maintaining the presence of soil moisture in green gram seeds leading to increased yields.

The observed findings further showed that a unit increase in labour by farmers using mulching was linked with an increase in green gram by a factor of 0.137 (*P*-value=0.001<0.05) [Table 9]. The findings of this study imply that mulching may help reduce weeds, control soil erosion and help to conserve soil moisture, reducing the labour required for these operations. According to Gautam [42] maximum soil cover played an important role in increasing cropping intensity, reducing weeds and soil erosion. The stochastic model when farmers rely on maximum soil cover would be given as follows:

$$Y = 3.520 + 0.246X_1 + 0.398X_2 + 0.058X_3 + 0.137X_4 + v_i - \mu_i \quad (7)$$

where:

Y = natural logarithm of green gram yield

X_1=natural logarithm of land size

X_2=natural logarithm of seed quantity

X_3= natural logarithm of chemical fertilizer quantity

X_4=natural logarithm of labour quantity

v_i = variations due to random factors beyond the control of the farmer

u_i = technical inefficiency model

The constant (3.520) is the amount of green gram produced by the farmers using maximum soil cover and not involved in any input use.

The model findings on technical efficiency of green gram production when using maximum soil cover as a climate adaptation strategy was 74.86% varying from 16.92% to 91.88%. The inefficiency part of the stochastic model revealed that years of education had a significant effect on the level of technical efficiency of maximum soil cover on the yields of greens gram produced. The model findings revealed that an increase in years of education by one year led to increased technical efficiency of maximum soil cover on green gram yields by a factor of 0.203 (*P*-value=0.00<0.05) [Table 10]. The observed findings imply that years of education of the farmer has a major influence on their understanding and implementation of mulching. The results of this study are consistent with those of Kitheka [43], who found that more educated farmers had a stronger preference for employing mulching to manage pests.

Table 101. *Maximum Likelihood Estimates of the Inefficiency Model When Using Maximum Soil Cover.*

Variables	Coefficient	Std. Error	Z	P-Value	95% Confidence level	
Constant	1.800	0.998	1.8	0.071	-0.156	3.756
Gender	-0.298	0.311	-0.96	0.338	-0.907	0.311
Age	0.004	0.014	0.3	0.765	-0.022	0.031
Years of education	-0.203	0.055	-3.67	0.00	-0.312	-0.095
Household size	-0.16	0.01	-1.6	0.11	-0.356	0.036
Title deed access	-0.314	0.312	-1.01	0.315	-0.926	0.298
Extension service	-0.117	0.452	-0.26	0.795	-1.002	0.768
Farmer group	-0.783	0.524	-1.5	0.135	-1.809	0.243
Credit access	0.113	0.346	0.33	0.743	-0.563	0.79

The inefficiency model can be given as follows:

$$Ui = 1.80 - 0.203W1 \quad (8)$$

where, W1= Years of education variable

3.3.4. Use of Crop Rotation in Green Gram Production

The stochastic model revealed that when using crop rotation to deal with climate variability, five out of the eight farm inputs considered in the study had a significant effect on green gram production at 5% level of significance. The inputs include land (*P*-value=0.00), seed (*P*-value=0.00) chemical fertilizer (*P*-value=0.009), foliar fertilizer (*P*-value=0.016) and insecticides (*P*-value=0.002) and had their *P*-values less than 0.05. The log likelihood ratio test gave a value of -278.898 at *P*-value =0.00 which was an indication that the model had a high explanatory power. The findings of the model showed that for the farmers who used crop rotation, an increase in land area resulted in a factor increase in green gram yield of 0.217 (*P*-value=0.00) [Table 11].

Table 11. *Stochastic Frontier Model Parameter Estimates When Using Crop Rotation.*

Variable	Coefficient	Std. Error	Z	*P*-Value	95% Confidence Interval	
Constant	3.534	0.204	17.32	0.00	3.134	3.934
Log land	0.217	0.058	3.72	0.00	0.103	0.331
Log chemical fertilizer	0.037	0.014	2.59	0.009	0.009	0.065
Log seed	0.457	0.052	8.78	0.00	0.355	0.556
Log foliar fertilizer	-0.058	0.024	-2.42	0.016	-0.105	-0.011
Log manure	0.006	0.012	0.53	0.596	-0.017	0.029
Log fungicides	0.041	0.052	0.8	0.427	-0.060	0.143
Log insecticides	0.111	0.037	3.04	0.002	0.039	0.182
Log labour	0.085	0.045	1.89	0.059	-0.003	0.173
Log likelihood	-278.894					
Total Observations	385					
Prob>Chi2	0.00					

It is possible that green gram is grown in rotation with other crops, such as maize, sorghum and other non-legumes crops, the nitrogen-fixing properties of the green gram help to increase soil fertility. The soil may also retain more water through reduced run-off increasing green gram yield. The results of this study support those of Naik [44], who found that crop rotation increased green gram yield due to increased soil fertility. According to the model's results, a unit increase in chemical fertilizers caused a factor of 0.037 (*P*-value=0.009) increase in farmers' green gram yields when crop rotation was used (Table 11). The observed findings may imply that crop rotation is an important part of sustainable agriculture, and it can have a significant impact on the use of chemical fertilizers in green gram production. The findings of the model observed that for farmers depending on crop rotation, a unit increase in planting seeds led to factor increase in green gram yield by a factor of 0.457 (*P*-value=0.00<0.05). The findings imply that use of crop rotation leads to increased soil fertility which in turn enables seeds to germinate fast and strong. The findings also imply that crop rotation helped to reduce pests and diseases that attacks seed on the ground before germination. The observed findings correspond to those of Adzawla [20] who established that climate adaptation, particularly, crop rotation, remained essential adaptation strategies for sustainable green gram production.

The model showed that for farmers relying on crop rotation, a unit increase in insecticides led to unit increase in green gram yields by a factor of 0.111 (*P*-value=0.002) [Table 11]. The findings imply that crop rotation can reduce the need for pesticides by creating an environment in which natural predators and pests can thrive. This concur with the findings of Chaudhary [45] that showed that repeated use of herbicide resulted to development of chemical resistance. The findings of the model showed that for farmers associated with crop rotation, a unit increase in foliar fertilizers caused the yield of green grams to rise by 0.058 (*P*-value = 0.016) units (Table 11). It is possible that crop rotation may help to improve soil fertility by allowing for a more balanced nutrient in the soil. The findings concur with those of Rawat [46] which established that use of foliar fertilizers in green gram production led to increased yields. The stochastic model when farmers rely on maximum soil cover would be given as follows:

$$Y = 3.534 + 0.217X_1 + 0.457X_2 - 0.058X_3 + 0.037X_4 + 0.111X_5 + v_i - \mu_i \quad (9)$$

where:

Y = natural logarithm of green gram yield

X_1=natural logarithm of land size

X_2=natural logarithm of seed quantity

X_3= natural logarithm of foliar fertilizer quantity

X_4= natural logarithm of chemical fertilizer quantity

X_5=natural logarithm of insecticides quantity

v_i = variations due to random factors beyond the control of the farmer

u_i = technical inefficiency model

The constant (3.534) is the amount of green gram produced by the farmers that have adapted to crop rotation and not using any input.

The level of technical efficiency of green gram production when using crop rotation is 75.55% varying from 16.38% to 91.60%. The stochastic model's inefficiency component found that education level had a substantial impact on crop rotation's technical efficiency as measured by the yields of generated green gram. The model's results showed that a one-year increase in years of schooling resulted in a factor of 0.169 increase in the technical efficiency of crop rotation on green gram yields (*P*-value=0.003) [Table 12]. The findings imply that farmers who had more years of school had more educational experience and were well informed of the various crop rotation practices. Education level may have led farmers to be conversant with the ways, sequences and strategies of applying crop rotation appropriately. The findings concur with those of Tanti [47] who established that farmers with more years of schooling were more likely to apply crop rotation practices which led to increased green gram yields.

Table 12. *Maximum Likelihood Estimates of the Inefficiency Model When Using Crop Rotation.*

Variables	Coefficient	Std. Error	Z	P-Value	95% Confidence level	
Constant	0.964	1.033	0.93	0.35	-1.07	2.988
Gender	-0.215	0.324	-0.67	0.506	-0.849	0.419
Age	0.014	0.015	0.97	0.334	-0.015	0.043
Years of education	-0.169	0.053	-3	0.003	-0.262	-0.055
Household size	-0.127	0.104	-1.21	0.225	-0.331	0.078
Title deed access	-0.570	0.375	-1.52	0.128	-1.304	0.164
Extension services	-0.122	0.464	-0.26	0.792	-1.031	0.787
Farmer group	-0.894	0.538	-1.66	0.096	-1.948	0.16
Credit access	-0.085	0.355	-0.24	0.812	-0.78	0.611

The inefficiency model can be given as follows:

$$Ui = 0.964 - 0.169W1 \quad (10)$$

where, W1= Years of education variable

3.3.5. Use of Irrigation in Green Gram Production

The stochastic model revealed that when using irrigation to deal with climate variability, at the 5% level of significance, four out of the eight farm inputs that were taken into account in the study had a substantial impact on green gram yield. The inputs include land, seed, foliar fertilizer and labour with p-values less than 0.05. The log likelihood statistics was 264.131 at *P*-value=0.00 implying a strong explanatory power of the stochastic frontier model (Table 13).

Table 13. *Stochastic Frontier Model Parameter Estimates when using Irrigation.*

Variables	Coefficient	Std. Error	Z	P-Value	95% Confidence level	
Constant	2.890	0.155	18.03	0.00	2.187	2.990
Log land	0.120	0.025	3.45	0.04	0.129	0.230
Log chemical fertilizer	0.153	0.024	3.23	0.00	0.019	0.067
Log seed	0.067	0.034	6.79	0.00	0.043	0.097
Log foliar fertilizer	0.063	0.033	1.06	0.00	-0.06	0.010
Log manure	-0.004	0.002	-0.23	0.771	-0.032	0.012
Log insecticide	0.043	0.027	1.45	0.065	-0.003	0.139
Log herbicide	0.032	0.016	0.32	0.543	-0.053	0.089
Log labour	0.125	0.023	2.98	0.002	0.059	0.216
Log likelihood	264.131					
Observations	385					
Prob>Chi	0.00					

The findings of the stochastic model showed that for farmers using irrigation a unit increase of irrigated land under green grams was associated by a significant increase in the level of green gram yield produced by a factor of 0.120 (p=0.04<0.05) [Table 13]. The findings of this study imply that farmers who had irrigated their lands were able to harvest higher yields. The findings complied with those of Wang [18] study who established that irrigation reduced the impacts of drought and led increased crop production. The study findings also showed that for farmers using irrigation upon increasing the seeds for planting by a unit there was a significant increase in the level of green grams yield by a factor of 0.067 (*P*=0.00<0.05). The findings complied with those of Lu [27] who established that irrigated crops are free from water stress and therefore most of the seeds germinates and produces leading to high yields averting a possible crop loss.

The findings of the model also demonstrated that an increase of one unit in the use of foliar fertilizers by farmers who depend on irrigation was related with a factor of 0.063 increase in green gram yields (*P*-value=0.00). The observed findings concur with those of Halder [48] who found that green grams are very responsive to irrigation and foliar application leading to increased crop performance. The observed findings also demonstrated that a unit increase in labor for the irrigated field under green grams is connected with a rise in level of yield by a factor of 0.125 (*P*-value=0.002). The findings imply that for farmers using irrigation to carry out farming upon increasing labour use there was proper water management in the farm implying crops were well fed with water leading to increased green gram yield. The findings concur with those of He [49] who established that labour is key in ensuring sustainable water management in the farm since continuous flooding of water would cause a decrease in the level of yields.

The stochastic model when farmers rely on irrigation would be given as follows:

$$Y = 2.890 + 0.120X_1 + 0.067X_2 + 0.063X_3 + 0.125X_4 + v_i - \mu_i \quad (11)$$

where:

Y = natural logarithm of green gram yield

X_1=natural logarithm of land size

X_2=natural logarithm of seed quantity

X_3= natural logarithm of foliar fertilizer quantity

X_4=natural logarithm of labour quantity

v_i = variations due to random factors beyond the control of the farmer

u_i = technical inefficiency model

The constant =2.890 is the amount of green gram produced by the farmers using irrigation and not involved in any input use.

The level of technical efficiency of green gram production when using irrigation as a climate adaptation strategy is 67.51% varying from 12.52% to 88.58%. Years of education had a substantial impact on the level of technical efficiency of irrigation on the yields of green gram that were produced, according to the stochastic model's inefficiency component. The model's results showed that a one-year increase in schooling years resulted in a factor of 0.184 improvement in the technical efficiency of irrigation on green gram yields *(P-*value=0.00) [Table 14]. The findings imply that farmers who had more educational experience were well informed of the various methods of irrigation that could be useful in ensuring sufficient water supply to the farms. In addition, the farmers were also aware of the methods of ensuring efficient water management in the farms. The findings concur with those of He [49] that established that knowledge is key on the methods of ensuring that water supply through irrigation in the farms is sufficient and efficient.

Table 14. *Maximum Likelihood Estimates of the Inefficiency Model When Using Irrigation.*

Variables	Coefficient	Std. Error	Z	P-Value	95% Confidence level	
Constant	1.700	0.988	1.7	0.061	-0.146	2.954
Gender	-0.338	0.212	-0.34	0.228	-0.208	0.297
Age	0.007	0.002	0.2	0.785	-0.012	0.034
Years of education	-0.184	0.090	-2.97	0.00	-0.347	-0.097
Household size	-0.123	0.134	-1.8	0.13	-0.396	0.436
Title deed access	-0.234	0.113	-0.41	0.329	-0.826	0.998
Extension service	-0.237	0.352	-0.26	0.795	-3.003	0.748
Farmer group	-0.343	0.234	-1.6	0.435	0.409	0.743
Credit access	0.213	0.246	0.343	0.673	-0.563	0.89

$$Ui = 1.70 - 0.184W1 \quad (12)$$

where, W1= Years of education variable

3.3.6. Determining the Most Efficient Climate Adaptation Strategy Used in Green Gram Production

The assessment of the technical efficiency levels of the climate adaptation strategies utilized by small holder green gram farmers showed that minimum tillage was the most efficient with 75.58%., followed by crop rotation (75.55%), mulching (74.86%) and early maturing seeds with 73.09%. The least efficient adaptation Strategy was use of irrigation at 67.51% (Table 15). Farmers therefore who relied on minimum tillage in order to lessen the harmful effects of climate change were much more efficient than farmers who relied on other strategies.

Table 15. *Technical Efficiency Levels for the Climate Adaptation Strategies.*

Climate adaptation strategy	Mean technical efficiency (%)	SD	Minimum technical efficiency level (%)	Maximum technical efficiency level (%)
Early maturing seeds	73.09	14.13	15.58	91.68
Minimum tillage	75.58	13.56	16.74	91.66
Maximum soil cover	74.86	13.99	16.92	91.88
Crop rotation	75.55	13.18	16.38	91.60
Irrigation	67.51	11.99	12.52	88.58

It is possible that green gram farmers who were doing minimum tillage were able to increase the soil microbial activity of their farms and lead to more soil fertility thereby increasing yields than when using other climate adaptation strategies. The findings concur with those of Auci [50] who established that farmers who had adopted the climate adaptation strategy had higher technical efficiency than farmers who had adapted the strategy. However, the findings of the current study contradict those of Adzawla [20] who established that crop rotation was the most technical efficient strategy in adapting to climate variability for the maize farmers in Ghana. The observed findings also contradict those of Tilahun [51] who found that the most desired adaptation approach among smallholder crop producers in Ethiopia, using a cost-benefit analysis was crop rotation.

4. Conclusion

The study concluded that most farmers (92.73%) had adjusted to climate change and recorded higher yield. Use of minimum tillage was the most efficient adaptation strategy with a technical efficiency of 75.58% while use of irrigation was the least efficient strategy with a technical efficiency of 67.51%. The study recommended that farmers should intensify use of minimum tillage as an efficient strategy to deal with climate change. Farmers should also embrace use of multiple adaptation strategies to increase efficiency and enhance resilience in green gram production.

Conflict of Interest

The authors declared no competing interest.

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