Open Access

J. Glob. Innov. Agric. Sci., 2024, 12(3):803-813
ISSN (Online): 2788-4546; ISSN (Print):2788-4538
DOI: https://doi.org/10.22194/JGIAS/24.1383
http://www.jgiass.com

Society for Innovative Agiculture

Evaluating Effect of Climate Smart Agricultural Practices Adoption on Productivity of Drought-Tolerant Pulses: Insights from Dryland Areas of Makueni County, Kenya

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Increased productivity of drought-tolerant pulses could potentially reduce household food insecurity, particularly in developing countries. This paper examines the effect of socioeconomic and institutional factors and the adoption of climate smart agriculture (CSA) practices on productivity of green gram, pigeon pea and cowpea in Makueni County, Kenya**.** We consider six common CSA practices namely: benches, soil conservation practices, minimum tillage, agroforestry, irrigation practices, and crop diversification. Using data from 384 randomly selected farmers, we use Sseemingly Unrelated Regression (SUREG) model to estimate factors influencing productivity of drought-tolerant pulses. The results showed that soil conservation practices were the most adopted (72%), while irrigation practices were the least adopted (9.6%). Among the CSA practices, crop diversification and benches were key to significantly affect the productivity of the three pulses, while agroforestry did not affect productivity of any of the selected pulses. Farming experience, number of extension contacts, and years of schooling were key socioeconomic and institutional factors that significantly affected the productivity of drought-tolerant pulses considered. Results showed that the impact of CSA practices on productivity differed among the pulses, since the soil conservation practices affected the productivity of both green gram and pigeon pea, while other practices including minimum tillage soil and irrigation practices affected the productivity of cowpea and green gram, respectively. Consequently, policies should consider promoting the adoption CSA practices among smallholder famers in Sub-Saharan Africa to improve farm level crop productivity and ensure household food security. Furthermore, Sub-Saharan Africa governments and agricultural sector policy makers should promote sustainable financial incentives such as establishment of farmer-friendly credit financing schemes to enhance CSA adoption and in-turn boost smallholder farmers farm net returns.

Keywords: Climate smart agricultural practices, productivity, seemingly unrelated regression model, drought-tolerant pulses, smallholder farmers.

INTRODUCTION

Adverse weather and climatic conditions have been recognised as pressing global concerns (Bulkeley and Newell, 2023). It has adversely affected agricultural productivity, food security, and people's livelihoods worldwide, especially in less developed countries (Adhikari and Timsina, 2022). Among the many adverse climate change impacts, the risk to agriculture is considered the most significant (Ani *et al.*, 2022). The worldwide population is anticipated to hit 9.1 billion by 2050. With the accelerating effects of climate change, the agricultural sector is unlikely to generate adequate harvests to feed the growing population (Srinivasan and Yadav, 2023). World nations are considering implementing measures that reduce the adverse effects of climate change to ensure ecosystem protection and recovery as well as water conservation (Huang *et al.*, 2022). The United Nations Climate Change Conference, commonly called COP 27, held in Egypt, resolved to ensure climate finance, food systems, climate adaptation, and resilience, and usage of renewable energy are adopted as methods to mitigate the climate change adversative effects (Varyvoda and Taren, 2023).

Climate change is restraining efforts toward enhancing food commodities production among smallholder farmers in sub-Saharan Africa (SSA), increasing the percentage of food-insecure people (Njue *et al.*, 2023). The dependency on natural resources, rain-fed agriculture, and limited application of climate smart agricultural practices has increased the

Kioko, T.M., S. Ndirangu and W. Nyarindo. 2024. Evaluating effect of climate smart agricultural practices adoption on productivity of drought-tolerant pulses: Insights from dryland areas of Makueni County, Kenya. Journal of Global Innovations in Agricultural Sciences 12:803-813.
[Received 13 Apr 2024; Accepted 30 Jun 2024; Published 13 Aug 2024]

African continent's susceptibility to the impacts of climate change (Steenkamp and Thebuho, 2022). A study by Tekeste *et al.* (2023) shows that SSA governments should support farmers with climate change adaptive strategies and ensure they have access to extension services and affordable credit to boost crop productivity. With the adverse effects of climate change already being felt in crop production in SSA; increased pulse productivity and improved food security status can be achieved through increased adoption of climate smart agricultural practices such as crop residue management among smallholder farmers (Rama Rao *et al.*, 2022).

Smallholder farmers need sensitisation on the potential of drought-tolerant crops, for example, cowpea *(Vigna unguiculata* (L.) Walp.*)*, green gram *(Vigna radiata* (L.) R.Wilczek,), and pigeon pea *(Cajanus cajan* (L.) Millsp.*)*, in alleviating food-insecurity and poverty in Kenya (Orumo and Mwangi, 2023). Green gram, cowpea, and pigeon pea are drought-tolerant legumes. Green gram and cowpea take less than 90 days to mature (Muchomba *et al.*, 2023), and pigeon pea takes about 140 days (Soni and Savalia, 2023). Also, depending on the variety, they are pest and disease-resistant (Samal *et al.*, 2023). This means that more attention should be paid to increasing the productivity of pulses in Kenya's low yielding dryland areas. Pulses can also play an important role in human health, helping to control weight, cholesterol and blood pressure (Grdeń and Jakubczyk, 2023). Smallholder farmers are critical to achieving food security locally, nationally, and globally (Azadi *et al.*, 2023). Therefore, smallholder farmers should be empowered by SSA governments through the sensitisation on benefits of CSA adoption through training to increase the productivity of farm crops. A study conducted in Pakistan to assess pulses production status, constraints and opportunities underpinned that pulses contribute 33% of the global protein dietary requirements for the human population (Ullah *et al.*, 2020).

The production of green gram, cowpea, and pigeon pea in Kenya is below the consumption demand (Nyaga and Njeru, 2020). Kenya's Southeastern region primarily receives unreliable short rains ranging between 400-600 mm per season (Katumbi *et al.*, 2021), justifying the need for the adoption of climate smart agricultural (CSA) practices that fit the region. CSA practices include a pool of practices that are environmentally friendly, economically viable, and technically appropriate for farmers in specific regions (Forkuor *et al.*, 2022; Masoud *et al.*, 2022), such as benches, minimum tillage, and irrigation practices that help reduce soil erosion and improve agricultural yields (Fajeriana *et al.*, 2024; Bayissa *et al.*, 2023). The adoption of soil- and water-conservation practices such as conservation tillage, irrigation, and soil management intensifications are essential to increase the agricultural productivity of dryland farmers (Bhattacharyya *et al.*, 2023; Kaur *et al.*, 2023). CSA practices such as intercropping of maize and pigeon pea, and the application of organic manure, which are soil conservation practices were found to improve the productivity of these crops in Tanzania and Malawi respectively (Homann *et al.*, 2023). Adoption of CSA practices such as crop diversification, soil conservation, minimum tillage, and agroforestry significantly affected crop productivity and improved soil health (Rautaray *et al.*, 2024; Mohanty *et al.*, 2024; Ngaba *et al.*, 2024; Walder *et al.*, 2023).

While focusing on a clear adaptation strategy is critical to addressing a specific climate risk, more than one strategy is needed to address current and emerging climate change threats, which are highly diverse, dynamic and indeterminate (Bedeke, 2022). In a drought-prone setting, unreliable rainfall and dry spells can occur simultaneously, exposing farmers to productivity, consumption, and income losses in the same agricultural season (Shahzad *et al.*, 2021). Adoption rate of adaptive agricultural practices that lead to increased crop productivity is low. Therefore, the adoption of multiple CSA practices is vital to address the low agricultural productivity of the cultivated pulse crops (Paul *et al.*, 2023).

Previous studies in Kenya have also considered the impact of socioeconomic and institutional factors on productivity (Ashrit and Joshi, 2024). A study by Saubaber and Yollande (2023) found that agricultural land increase would ensure improvement in the region's food basket; and Muchomba *et al.* (2023) found that an institutional factor such as access to credit was a constraint to green gram productivity. The number of extension contacts that farmers receive and access to credit were found to positively and significantly affect crop productivity (Kehinde *et el.*, 2024; Nordjo *et al.*, 2024). Another study done in Nepal and data analysed using stochastic frontier production model found that education level, farm size, and membership to groups and cooperatives positively and significantly increased lentil technical efficiency (Ghimire, 2023). Other socio-economic factors such as farming experience and membership to farmer groups were found to significantly impact on pulses productivity (Singh *et al.*, 2020).

Recent studies by Kebede *et al.* (2022); Muchomba *et al.* (2022) have linked effect adoption CSA practices to the productivity of only one of these drought tolerant pulses. Therefore, to our knowledge, this is the first study that links the effect of CSA practices, socioeconomic, and institutional factors and on productivity of three drought-tolerant pulses in Southeastern Kenya. Furthermore, smallholders often plant more than one pulse in a season intercropped with cereals to complement production trade-offs (Jama *et el.*,, 2024; Dhaka *et el.*, 2023; Maitra *et el.*, 2020). Therefore, the main objective of this study was to access the socioeconomic and institutional determinants and effects of CSA practices on productivity of three drought-tolerant pulses. This information is vital for designing and promoting appropriate policies to encourage adoption of CSA practices that are adaptable to the local farmer needs.

The following sections are structured procedurally as stated below. We start by describing summary of the study area, research design and sampling, reliability and validity of the data, followed by conceptual framework and model specification then results in section 3. Discussion of main regression results comes in section 4 and finally conclusion and policy implication in section 5.

MATERIALS AND METHODS

***Study area*:** The research was conducted in dryland areas Kibwezi Sub-County (administrative unit) in Makueni County which lies within the dryland areas of Southeastern Kenya. The County lies in between Longitude 37°10' and 38°30' East and Latitude 1°35' and 2°59' South, with an area of 8,169.8 Km^2 and a population of 987,653 (KNBS, 2019). Makueni County is divided into 6 sub-counties namely; Mbooni, Kaiti, Kibwezi West, Kilome, Makueni, and Kibwezi East. It receives an average of 400 mm-600 mm per season of rainfall and is situated at. 950 m above sea level. Temperatures range between 17^0C and 26^0C. The major food crops grown in the area consist of green gram, maize *(Zea mays)*, cowpea, arrowroot (*Maranta arundinacea)*, pigeon pea, and bean *(Phaseolus vulgaris)* (Kathuri, 2022). Households in the area have experienced extensive crop failure leading to food insecurity and increased poverty levels due to climate change impacts (Syano *et al.*, 2022). As a result, considerable amounts of the foods consumed in the area are sourced from nearby counties such as Meru and Embu. These foods are expensive compared to locally produced pulses like green gram, cowpea, and pigeon pea.

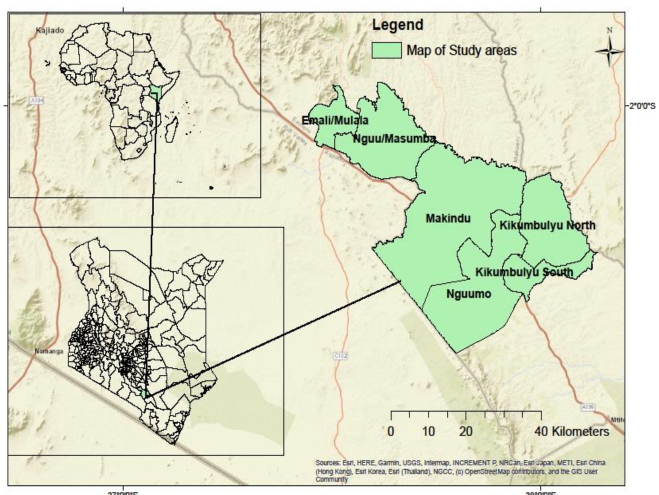

Figure 1. Map of the study area showing the five wards of Kibwezi Sub-County, (Emali/Mulala, Kikumbulyu North, Kikumbulyu South, Makindu, Nguu/Masumba and Nguumo) in Makueni County (Source Arcmap version 10.8).

***Research design, sample size and sampling technique*:** This study adopted a cross-sectional survey design, with a target population of 47,912 households (KNBS 2019) in the Sub-County. Based on the Cochran (1977) formula, the sample size was estimated to be 384 households. The multi-stage cluster sampling procedure was used to acquire sample size for data collection. Makueni County was chosen as a representative of Southeastern Kenya counties (Machakos, Makueni and Kitui). Out of the 6 sub-counties of Makueni, Kibwezi West Sub County was chosen since it is the most hit by adverse effects of climate change, Katumbi *et al.* (2021), and widely adopts production of the three drought-tolerant pulses and also due to the few studies on CSA practices done in the area. In step one, the (6) wards of Kibwezi West Sub-County (Kikumbulyu South and North, Makindu, Mulala, Nguumo, and Nguu) were selected. In step two, a sub-location was randomly chosen from each of the (6) wards making an overall of (6) sub-locations comprising of Kwakakulu, Kathyaka, Mbui Nzau, Makindu, Syumile and Kakili. Finally, 1 village was selected randomly from each of the (6) sub-locations leading to a total of 6 villages: Kwa Kotoe, Kathyaka, Kalembe, Kwa mumbe, Syumile, and Tabora. The probability proportional to size technique was used to obtain the number of households interviewed per village. A sample of 384 farming households from which primary data was collected through interview schedules was randomly selected.

***Data collection instruments, reliability and validity of the instruments*:** Interview schedule was used to collect primary data on adoption of CSA practices among the pulse smallholder farmers. Information collected was on the adoption of six CSA practices, in addition to socioeconomic and institutional profiles of the households. A pilot test was done with 30 interview schedules administered randomly to the sampled households to establish its reliability. The split-halve method was used to examine interview schedule consistency (Aithal *et al.*, 2020). A sample of 10 interview schedules for pilot study were used in assessing the accuracy (validity) of the instrument by enabling the researchers to determine the extent to which interview schedule scores measured the intended purpose. The questions in the interview schedule were cross-examined to ensure the collected the right information from the respondents. Additionally, triangulation method was employed by interviewing the smallholder farmers as well as observing their farms to ensure that the data obtained was concise for the researchers to draw meaningful findings and elaborate conclusions.

Conceptual framework and model specification

***Conceptual framework*:** The figure below shows interactions between the independent variables (X) and the dependent variable (Y).

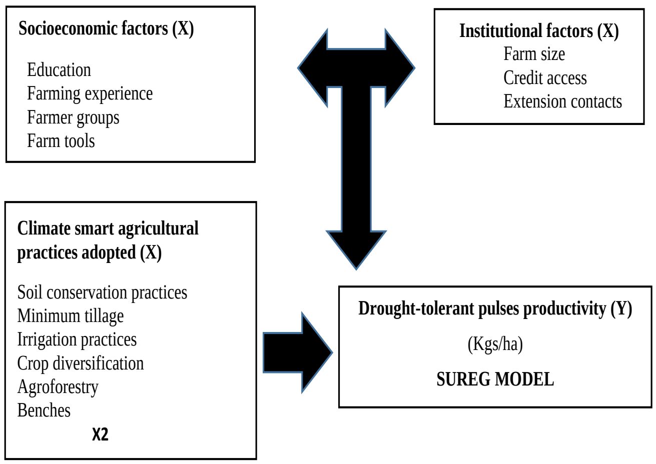

Figure 2. Conceptual framework.

The independent variables consist of the climate smart agricultural practices, socioeconomic and institutional factors and their effect on selected drought-tolerant pulses productivity.

***Model specification*:** We used Seemingly Unrelated Regression (SUREG) model developed by Arnold Zellner (1962) to analyse the impact of adoption of climate-smart technologies and socioeconomic and institutional factors on the productivity of green gram, cow pea, and pigeon pea. This model gives joint estimates of the productivity of the three selected pulses, and allows error terms to be correlated across the three equations thus produces more efficient estimates than ordinary least square estimates (Amare and Balana, 2023; West *et al.*, 2023). The model is more efficient in estimating the parameter than other regression models since each individual equation takes into account the information provided by other equations. It is a generalisation of the linear regression model that includes multiple equations, and is therefore appropriate for this study. Within the SUREG model, cross equation correlations were estimated and tested using the Breusch– Pagan test of independence (Rautenberg *et al.*, 2023). The regressions are correlated as the errors are linked to the dependent variable (productivity). The SUREG is a regression in which two or more unrelated outcome variables (output per ha of green gram, cowpea, and pigeon pea) are predicted by predictor variables (CSA practices, socioeconomic and institutional factors).

The SUREG model specification is below:

$$Y_i = \alpha_i + \beta_{1i}X_{1i} + \beta_{2i}X_{2i} + \beta_{3i}X_{3i} + \varepsilon_i \quad (1)$$

where Yi is the productivity of three crops (i = productivity of green gram/ pigeon pea/ and cowpea); α_i are are intercepts, β_{1i}, β_{2i} and β_{3i} are the coefficients of X_i, X_i is a vector of all other explanatory variables (Table 1) that are similar in both equations; ε_i are the error terms for the three joint equations.

$$Y_1 = \alpha_1 + \beta_{1i}X_{1i} + \varepsilon_{\text{i}} \quad (2)$$

$$Y_2 = \alpha_2 + +\beta_{2i}X_{2i} + \varepsilon_{\text{i}} \quad (3)$$

$$Y_3 = \alpha_3 + +\beta_{3i}X_{3i} + \varepsilon_3 \quad (4)$$

Equations 2-4 represent the productivities of green gram, cow pea, and pigeon pea respectively. While the above drought-tolerant pulses productivity equations are independent and can be estimated separately, estimating them simultaneously and testing them for error correlation gives reliable results.

***Variables description*:** Dependent variable was the productivity of the three drought-tolerant pulses while independent variables comprised of the 6 climate smart agricultural practices which are prevalent in the area and socioeconomic and institutional factors as shown in Table 1.

Table 1. Description of the dependent and independent variables considered in the study.

Variable	Description
Productivity	Kg/ha
Benches	1 if adopted and 0 if not
Soil conservation practices	1 if adopted and 0 if not
Minimum tillage	1 if adopted and 0 if not
Agroforestry	1 if adopted and 0 if not
Irrigation practices	1 if adopted and 0 if not
Crop diversification	1 if adopted and 0 if not
Education	Number of schooling years of household head
Farming experience	Number of years household head, involved in farming
Farmer groups	1 if member 0 if not a member
Farm size	Land under pulse farming in ha
Farm tools	Tools owned by smallholder farmers
Extension contacts	Frequency of extension services
Credit access	1 if household has access to credit facility, 0 otherwise

Source: Field data, 2023

RESULTS

Table 2 below illustrates the dependent variables considered in this study. The dependent variable comprised of three variables: the productivities of green gram, cow pea, and pigeon pea intercrops whereby productivity was measured in terms of each pulse output (kg ha^{-1}). Productivity of green gram, cow pea, and pigeon pea was 350, 340, and 310 kgs ha^{-1} respectively which is low compared to the standard output of 0.6 tonnes (600kgs) per ha. All the 384 farming households considered in this study grew these pulses. They are intercropped with other crops such as maize, bean, sorghum (*Sorghum bicolor L. Moench*) and cassava *(Manihot esculenta*).

Table 2. Descriptive statistics for dependent variables yield (Quantity/ha) for green gram, cow pea, and pigeon pea.

Dependent variable	Mean (kgs)	Std. Dev.
Quantity/ha of green gram	350	20.9
Quantity/ha of cow pea	340	19.4
Quantity/ha of pigeon pea	310	19.8

Source: Field data, 2023

Socioeconomic and institutional characteristics of the smallholder farmers**:** Descriptive statistics in Table 3 revealed that the average farming experience of the respondents was over 17 years. This implied that smallholder farmers in the study area have engaged in agricultural activities for a long time. The average number of household members in most households was eight, indicating that households had adequate family labor. On average, the sampled household head's number of years of schooling was 11, implying that a sizeable number had at least acquired secondary education whereby males were 263 and females 121. Education helps farmers broaden their thinking and expand knowledge horizons. Out of the 384 farming households, 54.6% of the respondents were members of farmer groups, which equipped them with the necessary information on climate smart agricultural practices.

The mean of the land size owned by respondents is about 2 ha while the mean of the farm size under pulse farming being more than 1.7 ha. The average number of extension contacts and visits farmers got was 1.348, suggesting that most of the farmers accessed extension services only once annually. Lastly, 71.5% of the respondents accessed affordable credit, which enabled them to finance their agricultural activities.

Table 3. Characteristics of the smallholder farmers.

Variable	Mean	Std. Dev
Continuous Variables		
Farming experience (years)	17.74	11.27
Number of schooling years	11.00	3.96
Household size	8.00	3.76
Total land size (ha)	2.24	4.93
Area under pulses (ha)	1.72	3.82
Number of annual extension contacts	1.35	1.12
Number of farm tools owned	3.10	1.68
Total livestock unit	2.00	0.90
Categorical variable	**Percentage**	
Gender		
Male	68.5	
Female	31.5	
Farm group membership		
Member	54.6	
Non-member	45.4	
Credit accessibility		
Yes	71.5	
No	28.5	

Source: Field data, 2023

Climate smart agricultural practices employed by smallholder farmers**:** Table 4 shows that over 50% of the smallholder farmers adopted soil conservation, agroforestry, and crop diversification. The main tree plants grown by farmers in the dryland area for agroforestry were neem plant (*Azadirachta indica)* and *Kigelia africana*. Benches, a water harvesting CSA practice, irrigation practices and minimum tillage were adopted by less than 50% of the respondents. Soil conservation practices were the most adopted CSA practice by smallholder farmers to advance soil fertility and lessen soil erosion while irrigation practices were the least adopted probably due to the high initial installation cost required.

Table 4. Climate smart agricultural practices adopted by smallholder farmers.

CSA practices*	Percentage (n=384)
Soil conservation practices	72.8
Crop diversification	67.4
Agroforestry	61.1
Benches	49.4
Minimum tillage	42.9
Irrigation practices	9.6

Source: Field data, 2023 * Multiple responses

Effect of adoption of climate smart agricultural practices, socioeconomic, and institutional factors on green gram, cowpea, and pigeon pea productivities using a seemingly unrelated regression model**:** The seemingly unrelated regression model results (Table 5) explained 80%, 78%, and 79% of green gram, cowpea, and pigeon pea productivities respectively which shows that the model was fit for analysis since R^2 is above 50%. Post-estimation test using the Breusch-Pagan test of independence for cross equation correlation was statistically significant at 1% level of significance, (chi2 (11) = 46.73; p = 0.002) suggesting that the null hypothesis of residuals being independent was untrue, and thus it was rejected. This implied that errors were not independent suggesting that SUREG model results were reliable; further supporting the goodness of fit of the model. The chi-square results for error correlation indicated that the error terms of the three drought-tolerant pulses productivity were contemporaneously correlated, signaling the appropriateness of simultaneous modelling.

For the CSA practices considered, five out of six were found to significantly affect the productivity of the three pulses. Adoption of benches and crop diversification positively influenced the productivity of green gram, cowpea, and pigeon pea at 1% and 5% levels of significance. Soil conservation practices had a significant effect on green gram and pigeon pea productivity. This means that soil conservation practices such as mulching help in moisture retention in the soil thus providing green gram and pigeon pea with the requisite moisture for their growth. Minimum tillage and irrigation practices significantly and positively influenced the productivity of green gram and cowpea at a 5% level of significance respectively.

For the socioeconomic and institutional factors, the number of extension contacts led to increased productivity of green gram and cowpea by 27 and 12 units and number of years of schooling positively affected Green Gram and Cowpea productivity by 39 and 33 units respectively. Farm size had positive effect on green gram and cow pea productivity while group membership and access to affordable credit affected only Green Gram productivity. In addition, pigeon pea productivity seems not to be induced by most factors except farming experience. Include briefly the results for all the variables highlighted.

Table 5. Seemingly Unrelated Regression Model results on the effect of adoption of smart agricultural practices and other explanatory variables on productivities of green gram, cowpea, and pigeon pea.

Variables	Green gram productivity Coefficient	Cowpea productivity Coefficient	Pigeon pea productivity Coefficient
CSA practices			
Soil conservation techniques	39.157***	-10.645	16.650**
	(9.189)	(9.454)	(8.611)
Minimum tillage	6.449**	-5.240	-3.602
	(4.082)	(4.200)	(3.825)
Crop diversification	20.889***	8.638**	8.768***
	(3.417)	(3.515)	(3.202)
Irrigation practices	14.482*	9.185**	9.783
	(7.757)	(7.980)	(7.269)
Benches	7.295**	10.162***	10.769***
	(3.354)	(3.450)	(3.143)
Agroforestry	-2.720	-8.269	-3.096
	(5.934)	(6.105)	(5.561)
Socioeconomic and institutional factors			
Farming experience	0.733**	0.690	0.487**
	(0.320)	(0.330)	(0.300)
Farm size	0.362**	0.149**	0.216
	(0.288)	(0.296)	(0.270)
Farmer group membership	7.965***	4.461	3.032
	(2.919)	(3.003)	(2.735)
Number of extension contacts	0.277**	0.122**	-0.176
	(0.999)	(1.028)	(0.937)
Access to affordable credit	0.000**	-0.000	-0.000
	(0.000)	(0.000)	(0.000)
Farm tools	-18.617***	-4.777	-5.803
	(4.629)	(4.762)	(4.338)
Number of years of schooling	39.760***	33.611***	0.593
	(6.280)	(6.461)	(5.885)
Observations	384	384	384
R-squared	0.806	0.788	0.795

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1
Source: Field data, 2023 (***, **, *, show statistical significance at 1% and 5%respectively).

DISCUSSION

With the adverse effects climate change experienced by the smallholder farmers in southeastern Kenya, adoption of CSA practices is essential. Descriptive statistics revealed that out of the six CSA practices, soil conservation practices were the most used by pulse farmers (72%). The study collaborates with (Montenegro *et al.*, 2020) findings that cover cropping and mulching soil conservation practices decrease soil erosion and improve soil fertility. Additionally, majority of the respondents were male and had acquired secondary education. A study in Machakos County established that the majority of the green gram and cow pea producers were male and the productivity of these crops was higher because the majority of the smallholder farmers had college education (Wambua *et al.*, 2019).

This study's SUREG model results revealed that, adoption of crop diversification and digging of benches among farmers are crucial since they boost the productivity of the three drought-tolerant intercrop pulses. Benches facilitate water harnessing on the smallholder farmers' farms, thus providing the required moisture for green gram and cowpea crops to grow without moisture stress. It implies that the pulses grown in terraced farms will do better than those planted on bare land with water run-off. Legumes fix nitrogen, which improves the productivity of other crops. Crop diversification may lead to increased legume productivity when farmers grow trap crops such as sorghum and maize which will attract pests and insects away from the target crops (pulses), allowing them to thrive and yield more per ha.

We explain that crop diversification provides resilience to highly variable weather conditions resulting from climate change effects and ensures that smallholder farmers have a steady flow of income. If one crop fails, other crops that thrive during such weather conditions may cushion the farmer. This study agrees with Kagata, (2021), where bench construction as a land-use intervention practice was found to have a significant influence on crop production. Also, 23.4% of smallholder farmers in Machakos County, Kenya, were found to have employed benches in their farms, and they helped boost the productivity of green gram and cowpea (Orumo and Mwangi, 2023). Crop diversification was a smart agriculture practice for improving agriculture production systems in India (Birthal and Hazrana, 2019). This suggests with a wider population of smallholder farmers who practice legume farming in Southeastern Kenya diversifying their crops would enhance their productivity and in turn improve food security.

Agroforestry was the only CSA practice that did not affect any of the selected intercrop pulses' productivity. Probable reason could be that agroforestry reduces efficiency in planting these pulses due to increased spacing and farmer faces problems in weeding crops intercropped with trees. Also, trees reduce light intensity required by crops, reducing rate of photosynthesis (Baligar *et al.* 2020).

Practices such as soil conservation retain soil moisture and has the ability to fix nutrients in the soil, which are vital to drought-tolerant intercrop pulses' growth and yields. Soil conservation practices such as mulching and leaving plant materials in the farm to decompose provides crops grown in the field with nutrients required for growth and yield improvement. Additionally, among the CSA practices, minimum tillage reduces soil erosion, boosts soil health, and increases crop yields. It also improves water penetration into the soil since the land is less disturbed with cultivation activities thus less likelihood of formation of hard soil pans which deter water penetration. The study agrees with Moran-Rodas *et al.* (2022) findings done in Bangalore, India where cover cropping and mulching had a positive and increasing correlation with pigeon pea and cowpea productivity. Minimum tillage positively and significantly impacted green gram productivity among green gram farmers in Tharaka Nithi Sub County, Kenya (Orumo and Mwangi, 2023). Furthermore, adoption of irrigation practices by farmers is key to improving their farm level productivity, with reference to this study. Crop irrigation provides the required moisture and nutrients when the irrigation water is mixed with fertilizers, boosting crop growth and yields that the smallholder farmers achieve per acre of land. It implies that farmers who employ irrigation practices get higher yields compared to those who do not irrigate their farms. Correspondingly, Yeleliere *et al.* (2023); Kaur *et al.* (2022) findings, irrigation farming as a CSA practice that contributes to food and nutritional security significantly affected farm grown crops productivity. Irrigation practices are viable in the dryland areas, thus both private individuals and organizations as well as SSA governments should build water harvesting and water conservation infrastructure by construction of dams and digging of boreholes in the rural settings and promote drip-irrigation-based agriculture due to the drought conditions which will improve legume productivity and food security.

The coefficients of the socio-economic and institutional variables influencing the three pulse productivities were generated jointly using the SUREG model. Experienced and literate farmers understood the best-fitting CSA practices which are complementary to use in their farms, leading to increased farm yields. Therefore, new smallholder farmers should benchmark from experienced and educated farmers to ensure the exchange of knowledge and gaining of practical skills on the CSA practices fit for different farm topographies. Older and experienced farmers were found to have high pigeon pea yields in Uganda (Namuyiga *et al.*, 2022). Likewise, knowledgeable semi-arid Kenyan farmers employed mulching and conservation tillage, which boosted green gram productivity (Hakim *et al.*, 2022). Farm size significantly affected the productivity of green gram and cowpea. This could be because an increase in farm size under green gram and cowpea leads to their increased yields. southeastern Kenya farmers need to intensively practice legume production on their farm sizes to improve total yield per ha and households' total income. Also, extension contact frequency between farmers and extension officers helps farmers' access information on CSA practices from the government and Non-Governmental Organisations. This enables farmers to make comparative decisions among the various practices and choose the one that suits their farm. Extension services beef up farmers with practical skills on how to use CSA practices and heighten their productivity. Extension services in Kenya range from technical to advisory services to farmers on how they can produce more using fewer resources to maximize profit. This study collaborates with Régina *et al.* (2022), were advisory services to farmers' were found to have a positive and significant effect on cowpea and maize productivity in North Benin.

Smallholder farmers in the study area who were members of the farmer groups, which are organized farmer cohorts which agitate for the interests of farmers and also act as platforms from were farmer trainings can be easily done by extension officers increased their farm crop productivity. A plausible explanation is that farmers who are members of input groups are well positioned to get certified green gram seeds and knowledge on the CSA practices thus boosting green grams yields per ha. This concurs with Wamuyu *et al.* (2022) findings, where farmers' group membership was found to have a significant effect on green gram productivity among smallholder farmers in Kenya. Access to credit was a crucial factor in improving green gram productivity. Probable reason is that access to affordable credit enables farmers to purchase the required inputs, such as certified green gram seeds and fertilizers, and adequately prepare the land before rains set in as measures to ensure bumper harvest per hectare. Also, affordable credit access offers financial support to farmers to help bridge the gap between their income levels and field expenditures. This study agrees with Wambua *et al.* (2021) findings, that access to credit had a significant positive effect on the commercialisation of green gram and pigeon pea production. Unexpectedly, farmers who owned farm tools used them so limitedly in pulses production thus little impact on pulses productivity. Farm tools boost productivity, but in this study their impact on green gram productivity was insignificant. This study differs from Abeyratne and Takeshima (2020), where agricultural mechanisation in Sri Lanka was found to have a positive correlation with green gram productivity as the adoption levels of these agricultural technologies in the country are much better and crop-specific as compared to sub-Saharan Africa, which should promote usage of climate smart agricultural practices.

***Conclusion*:** Despite continued efforts by government and other research projects such as Kenya Climate Smart Agricultural Practices (KCSAP) project to increase adoption of CSA practices to boost crop productivity, productivity is still low. This study evaluated the effect of adoption of CSA practices and other socioeconomic and institutional factors on the productivity of green gram, cow pea, and pigeon pea. Seemingly unrelated regression results revealed adoption of crop diversification, benches, minimum tillage, soil conservation, and irrigation CSA practices positively influenced the pulses productivity. For the socio-economic and institutional factors: number of years of schooling, access to affordable credit, number of extension contacts, farming experience, and farm size positively affected the selected pulses productivity while ownership of farm tools negatively impacted pulses productivity. Notably, agroforestry was the only CSA practice that did not influence the productivity of the three drought-tolerant pulses an indication that other sustainable agriculture practices such as crop rotation should be promoted in the area. The CSA practices considered in this study not only affected selected pulses productivity, but also overall farm productivity which composed of other crops such as maize, beans, and sorghum. Results imply CSA practices impact on productivity differs across the pulses. Thus, policies should consider promoting the adoption of adaptable CSA practices depending on particular crop types and climatic conditions of the region. The study recommended that further in-depth research should be conducted in dryland areas to provide insights to the barriers to adoption of CSA practices among smallholder farmers and the potential trade-offs.

Based on the study findings, it is therefore recommended that government should progressively recruit more extension officers for they are crucial in equipping farmers with the necessary skills and knowledge through trainings on new CSA practices, fit for their areas to facilitate increased farm output and farm returns. Moreover, the government should work towards establishing farmer-friendly credit financing schemes and institutions to ensure easy access to affordable credit funds by farmers, which will facilitate the adoption of the CSA practices, which is capital-driven. With SSA and other world regions having being negatively affected by climate change impacts, governments and agricultural sector policy makers should advocate and implement adoption of irrigation systems to reduce over-reliance on rain-fed agriculture to ensure higher farm productivity. Therefore, this study strongly recommended advances in policies that promote increased adoption of CSA practices to enhance farm productivity and to improve food security.

***Author's contribution statement*:** Timothy Meti Kioko: Conceptualization, Methodology, Formal analysis, Writing-original draft manuscript.

Samuel Ndirangu: Writing-editing and revision, Formal analysis and Supervision.

Wilckyster Nyarindo: Data revision, Writing-editing and revision, Formal analysis and Supervision.

***Conflict of interest*:** The authors declare no conflict of interest.

***Acknowledgments*:** The authors are greatly thankful to the smallholder green grams, cowpeas, and pigeon peas farmers for their acceptance to be part of this research.

***Funding*:** This research work was not funded.

***Ethical statement*:** There is no animal study included in the present work.

***Availability of data and materials*:** Data will be available on request.

***Consent to participate*:** All author's participated in this research study.

***SDG's Addressed*:** Zero Hunger, Climate Action, Life on Land.

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