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# Sustainable Scaling of Climate-Smart Agricultural Technologies and Practices in Sub-Saharan Africa: The Case of Kenya, Malawi, and Nigeria

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**Abstract:** In the wake of climate change, climate-smart agriculture has been proposed as an option for mitigation and adaptation to the attendant harsh impacts among smallholder farmers in Africa. The approach has been promoted for nearly two decades in Kenya, Nigeria, and Malawi, but with low adoption among farmers. This study therefore sought to determine the pathways for sustainable scaling of climate-smart agricultural technologies and practices in the three countries. Secondary and primary data were obtained from desk review, field survey, key informant interviews, and focus group discussions. Data was analyzed using descriptive statistics and multivariate probit regression. The multivariate probit regression result showed eight negative correlated coefficients between the climate-smart agriculture technologies and practices adopted, thus implying that the practices are substitutes for each other. It was observed that gender had no significant influence on the adoption of a set of practices (refuse retention, minimum tillage, green manure, and mulching) but influenced significantly the adoption of early maturing varieties. Implicitly, therefore, apart from gender, the adoption of climate-smart agriculture technologies and practices might often be due to other factors.

**Keywords:** gender roles; smallholder farmers; agricultural practices; adoption

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## 1. Introduction

The adverse impacts of climate change are already manifesting in the form of increasing temperatures, weather variability, shifting agro-ecosystem boundaries, invasive crops, pests and diseases, and recurrent polarized weather events. Climate change has made agricultural production and productivity unstable. Globally, in regions with low agricultural productivity and with limited means for adapting to harsh climate realities, climate change will result in further reduction in agricultural productivity [1,2]. Shifting trends of key climate elements (temperature and rainfall) will most likely alter cropping seasons and patterns, accentuate incidences of pest and diseases, and alter the range of cultivable crops across landscapes, affect the pricing of agricultural produce, incomes, and livelihoods [3]. Climate change and agriculture are interlinked since agriculture not only is impacted by climate change but also has a profound effect on the climate. Worldwide, 19–29% of greenhouse gases (GHGs) are generated from agricultural activities, land management, and forestry, with the percentage of emissions rising to 74% in developing nations [4,5]. Notwithstanding, the agricultural sector has viable options for mitigation to meet long-term sustainability objectives [6], this being the basis of having mitigation among the three pillars of climate-smart agriculture (CSA). Climate-smart agriculture (CSA) has been defined as "agriculture that sustainably increases productivity, resilience (adaptation), reduces/removes GHGs (mitigation), and enhances achievement of national food security and development goals" [3]. The approach helps to guide actions aimed at transforming and reorienting agricultural systems to effectually and ecologically promote development and food security under the changing climate [3,7]. "Agriculture" in this case refers to crop and livestock production, and fisheries and forest management. Studies have shown that CSA technologies and practices can enhance agricultural productivity, livelihoods, ecological systems, and environmental sustainability under a changing climate in various locations. Examples include crop yield improvement through the adoption of stress-adapted crop varieties, conservation agriculture, agroforestry, and farming systems diversification, resulting in an increase in incomes through sales of surplus produce, and enhanced food and nutrition security for farming households [8,9]. Although CSA techniques have been implemented for nearly two decades in sub-Saharan countries like Kenya, Malawi, and Nigeria and show great potential for enhancing the welfare of smallholder farmers, adoption of the methods is still unsatisfactory [10], raising questions of the merit of CSA. It is therefore imperative to understand how institutional, societal, and economic factors affect the adoption of CSA in order to form basis for formulating remedial packages [11]. Understanding of these factors will not only facilitate adjustment of approaches for promoting CSA but will also help to manage available resources that will otherwise be lost without making the intended impact.

Basically, CSA links climate change and agriculture through a paradigm shift that focuses on enhancing food security among resource-constrained smallholder farmers and marginalized groups [12]. CSA is not a new production system; it is an approach of identifying and matching agricultural systems and supporting institutions that are well-matched to tackle location or site-specific impacts of climate change, and to sustain and improve the capability of agriculture to ecologically support food security in a sustainable way [3]. The purpose of the concept is to meet the following listed objectives: "sustainably increasing food security by increasing agricultural productivity and incomes; building resilience and adapting to climate change and developing opportunities for reducing greenhouse gas emissions compared to expected trends [13]." Some of the agricultural production technologies and practices falling under CSA are: "stress-adapted crop varieties, improved water management technologies (e.g., small-scale irrigation), agroforestry and conservation agriculture (CA), crop diversification, integrated soil fertility management (ISFM) practices (e.g., mulching and rotations)" among others [13]. The approach involves tools to identify climate-smart sustainable agricultural growth pathways for given locations and situations [3]. Estimates suggest that if CSA is adopted by farmers, about 69 million people would be less susceptible to hunger by 2050, while at the same time a significant contribution would be made towards the reduction of greenhouse gas emissions (GHGs) globally [13]. Therefore, CSA technologies and practices present opportunities for addressing climate change and improving food security and livelihoods of farming households. However, adoption of CSA technologies and practices among smallholder farmers seem to be influenced by an array of factors including gender [14]. This paper analyzes context-specific gender-responsive CSA technologies and practice, identified governance, socioeconomic, and cultural dynamics that impede adoption of CSA, and provides policy recommendations for the scaling of context-specific gender-responsive CSA technologies and practices in Kenya, Nigeria, and Malawi.

## 2. Materials and Methods

### *2.1. Description of Study Area*

The study was conducted in Kenya in Eastern Africa, Malawi in Southern Africa, and Nigeria in Western Africa (Figure 1). The selection of these countries was based on the contribution of agriculture to the respective national economies. The three countries have some similarity in terms of agro-ecological conditions with both wet and dry regions coupled with the fact that they have all been experiencing effects of climate change. Additionally, the three countries have national climate-smart programs that are being implemented, such as the Kenya Climate Smart Agricultural Project (KCSAP), Malawi–Mozambique Climate Smart Agricultural Project, and Climate Smart Nigeria Glow Initiative for Economic Growth, among others.

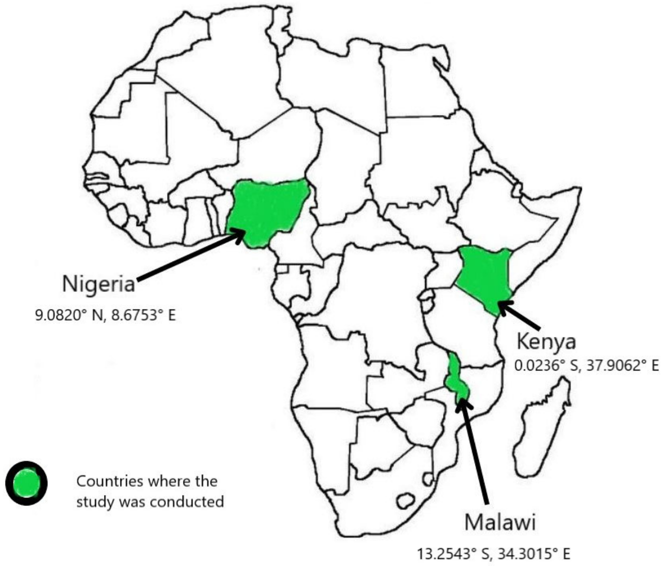


**Figure 1.** The three study countries: Kenya (East Africa), Malawi (Southern Africa), and Nigeria (West Africa).

Kenya has seven agro-ecological zones (AEZs): agro-alpine, high-potential, medium-potential, semi-arid, arid, very arid, and water bodies [15]. Malawi has four general AEZs: lower shire valley; lakeshore, middle and upper shire; mid-elevation upland; and highlands [16]. Nigeria has eight agro-ecological zones, namely, Lake Chad, Sahel savanna, Sudan savanna, Northern Guinea savanna, mid-altitude, Southern Guinea savanna, derived savanna, and humid forest [17]. Figure 1 shows the location of the three countries.

### 2.2. Research Design

This study utilized mixed methods for collecting and analyzing data. The rationale for mixed methods is that neither quantitative nor qualitative methods are sufficient by themselves to capture the trends and details of the situation. The design was chosen to allow quantitative and qualitative methods to complement each other and to provide a more complete understanding. In this study, qualitative data were obtained from the key informant interviews and focus group discussions while the quantitative data were obtained from a field survey using structured questionnaires.

#### Sampling and Sample Size

The sample population was obtained through a multistage sampling technique across the three countries. At the first stage, three AEZs were randomly selected from each country to make a total of nine AEZs across the three countries. In Kenya, three AEZs were purposively selected: high-potential, medium-potential, and semi-arid zones, because they are the most significant in agricultural cultivation and crop–livestock systems. In Malawi, three AEZs—lower shire valley, lakeshore, middle and upper shire, and mid-elevation upland—were selected for the study since most of the agricultural production activities are carried out in these zones. Similarly, three AEZs—derived savanna, Northern Guinea savanna, and mid-altitude were randomly selected in Nigeria due to the high level of agricultural production. At the second stage, one farming community per AEZ was purposely selected based on the recognition that the area had been reported as the highest producer of the priority crop in the AEZ. At the third stage, 48 farmers categorized based on gender generational roles, i.e., young females (8), young males (8), adult males (8), adult female (8), elderly males (8), and elderly females (8) were selected. This gave a total of 144 farmers in each country and a total of 432 farmers from the three countries. Information was on the activities associated with CSA, existing CSA technologies and practices, climate-smart agricultural practices' adoption, preference by different gender in Kenya, and factors influencing climate-smart agriculture adoption. The data obtained were based on a gender generational category: youths aged 18–35 years (males and females), adults aged 36–55 years (males and females), and the elderly aged above 55 years (males and females) across the agro-ecological zones in each country.

### 2.3. Analytical Technique

Data were analyzed using a combination of descriptive and inferential statistical methods. Descriptive statistical tools were used to analyze data on farmers' awareness, perceptions, skill levels (knowledge gaps), and adoption rates of various CSA technonologies and practices. The descriptive statistics (means, proportions, standard errors, etc.) were computed and presented in tables and graphs. Key results were summarized and are presented in tables, diagrams, and charts.

#### Multivariate Probit Regression

Marginal rates of substitutions (MRS) based on coefficient estimates of the multivariate probit model of CSA T&P choices, following [18,19], were utilized to determine the factors that drive the adoption of CSA T&Ps and analyze the trade-offs that farmers make to address land degradation, enhance sustainability, and build resilience to climate change. A farmer was categorized as a CSA T&P adopter if she/he had used a CSA T&P for at least a planting season and was still using it at the time the interview was conducted.

Consider the *i*th farmer ($i$ = 1, . . . , n) facing a decision on whether or not to adopt a CSA practice on plot $p$. Let $U_0$ represent the benefits to the farmer from traditional management practices and let $U^*_k$ represent the benefit of adopting the *k*th CSA practice, where $k$ denotes choice of CSA practice. The farmer decides to adopt the *k*th CSA practice on plot $p$ if:

$$Y^*_{ipk} = U^*_k - U_0 > 0 \quad (1)$$

However, the net benefit ($Y^*_{ipk}$) that the farmer derives from the adoption of the *k*th CSA practice (A = CSAP1, B = CSAP2, C = CSAP3, D = CSAP4, E = CSAP5, F = CSAP6) is a latent variable determined by observed personal, household, plot and location characteristics ($X_i$), and the error term ($\varepsilon_i$):

$$Y^*_{ipk} = X_i\beta_k + \varepsilon_i \ (k = (A,B,C,D,E,F) \quad (2)$$

The unobserved preferences in Equation (2) translate into the observed binary outcome equation for each choice as follows:

$$Y^*_{ipk} = \{1 \text{ if } Y^*_{ipk} > 0/0 \ \textit{otherwise} \ (k = 1,2, \ldots \ k) \quad (3)$$

where $Y^*_{ipk}$ is the adoption of the *k*th CSA practice by the *i*th farmer on plot $p$.

Table 1 presents the description of both the dependent and independent variables. The dependent variables include sixCSA T&Ps: early maturing varieties, refuse retention, minimum tillage, green manure, crop rotation, and mulching. The independent variables include: gender (adult male, adult female, elderly female, male youth, female youth), age, educational level, household size, native, flood incidence, drought incidence, credit access, membership of cooperative society, farm size, distance from home to farm, land type, land ownership, extension contacts, off farm income ($), and household members that contributed to income (#).

**Table 1.** Description of both the dependent and independent variables.

| Variable | Description |
|---|---|
| Climate | Smart Agricultural Practices' Adoption |
| CSAP1 | If plot manager adopts CSAP1= 1, otherwise |
| CSAP2 | If plot manager adopts CSAP2 = 1, otherwise 0 |
| CSAP3 | If plot manager adopts CSAP3= 1, otherwise 0 |
| CSAP4 | If plot manager adopts CSAP4 = 1, otherwise 0 |
| CSAP5 | If plot manager adopts CSAP5 = 1, otherwise 0 |
| CSAP6 | If plot manager adopts CSAP6= 1, otherwise 0 |
| Socioeconomic characteristics | |
| Age | Age of the Plot manager |
| Sex | If plot manager is male = 1, otherwise = 0 |
| Marital Status | If the plot manager is married = 0; Otherwise = 1 |
| Years of Schooling | Years of formal education of the plot manager |
| Household size | Number of household members |
| Off-farm Income | Plot manager's total off-farm income in the last year (₦) |
| Asset ownership | 1 if the plot manager owns a major asset – (such as land, buildings, machinery) |
| Farmers' Group membership | If the plot manager is a member = 0; Otherwise = 1 |
| Institutional characteristics | |
| Extension Contact | 1 if an agricultural extension agent visited the plot manager or if the plot manager visited extension service office during last planting season, 0 otherwise |
| Access to credit | 1 if the plot manager received credit, 0 otherwise |
| Plot characteristics | |
| Farm Size (Ha) | Size of the plot cultivated by the plot manager in hectares |
| Lowland | If Plot is lowland = 1; Otherwise = 0 |
| Land ownership status | If plot manager owns the plot = 1; Otherwise = 0 |
| Plot Trekking distance from home | Number of minutes used in trekking to the plot |
| Land dispute | 1 if plot manager ever experienced dispute, 0 otherwise |
| Fertilizer Use | If plot manager used inorganic fertilizer on the Plot = 1; Otherwise = 0 |

## 3. Results

### *3.1. Practices Associated with Climate-Smart Agriculture Kenya, Malawi, and Nigeria*

Figure 2 reveals farmers' perceptions of practices associated with CSA in the three countries. Some of the common practices identified include: early planting, Kenya (12%), Malawi (17%), Nigeria (29%); mulching/maximum soil cover, Kenya (17%), Malawi (19%), Nigeria (5%); irrigation (gravity, treadle, or drip), Kenya (16%), Malawi (13%), Nigeria (36%); use of composite manure, Kenya (12%), Malawi (14%), Nigeria (5%); using adaptable crop varieties, Kenya (16%), Malawi (11%), Nigeria (4%); agroforestry, Kenya (10%), Malawi (9%); crop diversity, Kenya (5%), Malawi (10%), Nigeria (5%); pit/basin planting, Kenya (2%), Malawi (12%); home garden, Kenya (3%), Malawi (4%), Nigeria (3%); late planting Kenya (4%), Malawi (1%), Nigeria (9%). However, irrigation farming was not perceived by the farmers as being associated with CSA in Malawi. This potentially suggests low awareness among the farmers but also that perhaps irrigation farming is not well developed in the country [20].

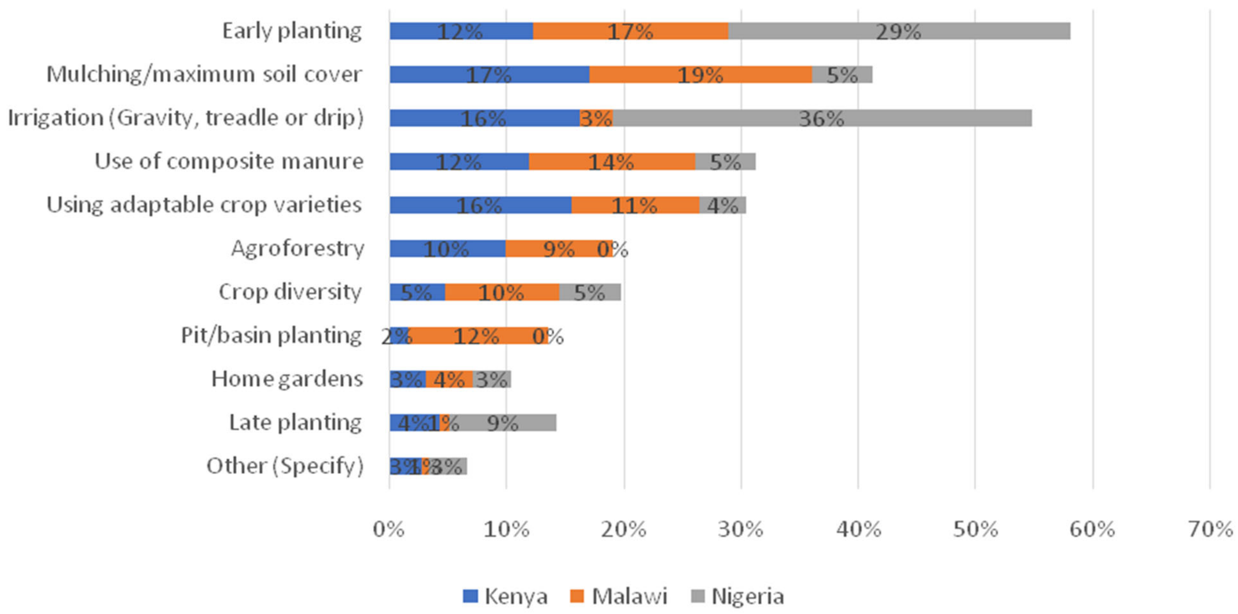


**Figure 2.** Farmer perceptions of activities associated with CSA in Kenya, Malawi, and Nigeria.

### *3.2. Existing Climate-Smart Agricultural Technologies in Kenya, Malawi, and Nigeria*

Figures 3–5 show the CSA technologies that are currently/frequently used in Kenya, Malawi, and Nigeria. The results reveal that most farmers opt for the use of the cultivation of early maturing and drought-tolerant varieties. The high number of farmers opting to use the technology as the first option may suggest an accelerated effort in breeding of the varieties, dissemination, and adoption by the farming community [21] and potentially this could be as a result of the increase in temperature and rainfall variability. Furthermore, the proportion of farmers opting to use other mentioned technologies was low across the countries. The trend may potentially suggest the following: low availability and/or awareness of improved varieties, and therefore this may require improvement in technology dissemination [22]; lack of materials for production of manure, poor quality of the available materials in terms of nutrient content, large quantities required per unit area, labor requirements for production and transportation to the farm and associated costs, among others [23]. For rotations, the trend potentially reflects the complexity of the technology in terms of the knowledge required for implementation, but also constraints in land since rotations require a large land area that may not be available [24]. On the other hand, adoption of minimized tillage operations could be impeded by lack of equipment, labor, and the cost of managing weeds using herbicides [25].

On the other hand, the deliberate cultivation and plowing in of cover crops and intercropping cover crops with main crops are among the least adopted practices, so the trend of choices may depict lack of adequate knowledge and technical knowhow of implementation of the technology [26]. Further, the availability and viability of seeds of appropriate cover crops in some cases are a constraint to the implementation of the technology, as well as the environmental and seed pretreatment requirements of some known cover crops such as kudzu (*Pueraria phaseoloides*), and this may also contribute to the impediment [27].

Furthermore, for mulching to conserve soil water, much as the practice is largely common, the lack of adequate materials and where available the attendant labor requirements stand in the way of implementation. There is the challenge of competing use of crop residue/organic mulching material, particularly in crop–livestock systems, since they are also used as livestock feed. Such is the dilemma for resource-poor smallholder farmers who may not be able to afford costly mulching alternatives, with availability and cost of inorganic mulches constraining their use [28].

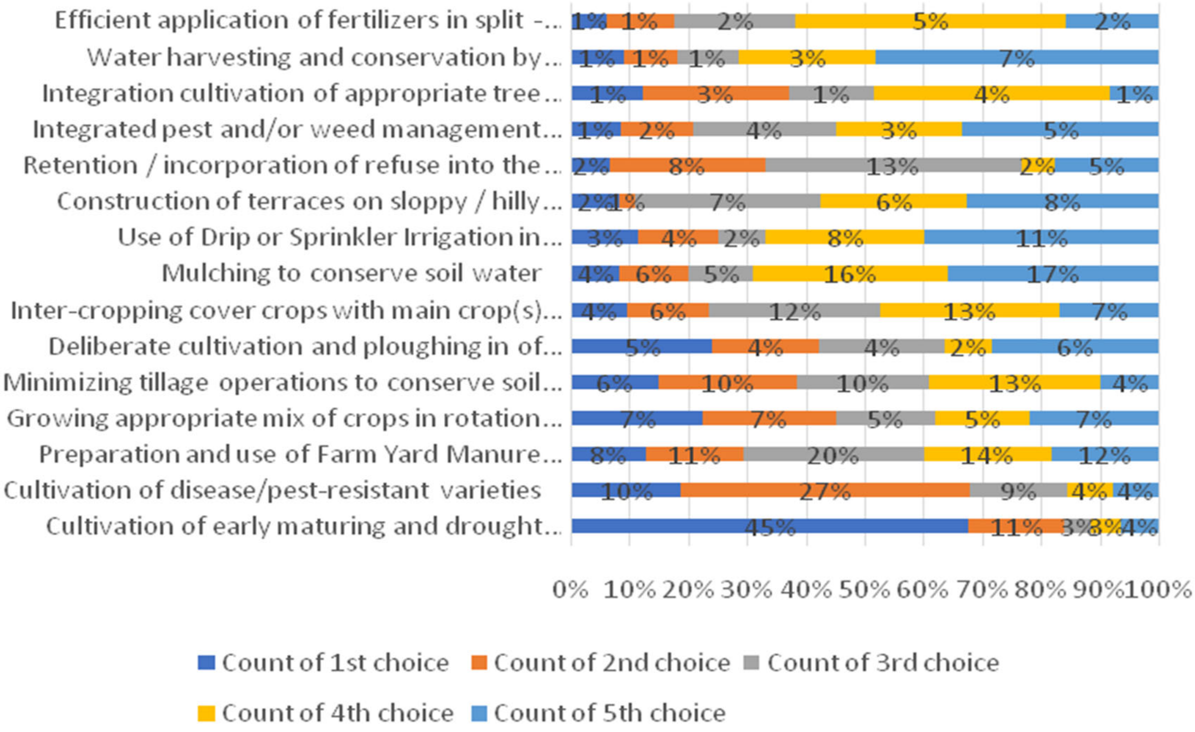


**Figure 3.** Currently/frequently used CSA technologies in Kenya.

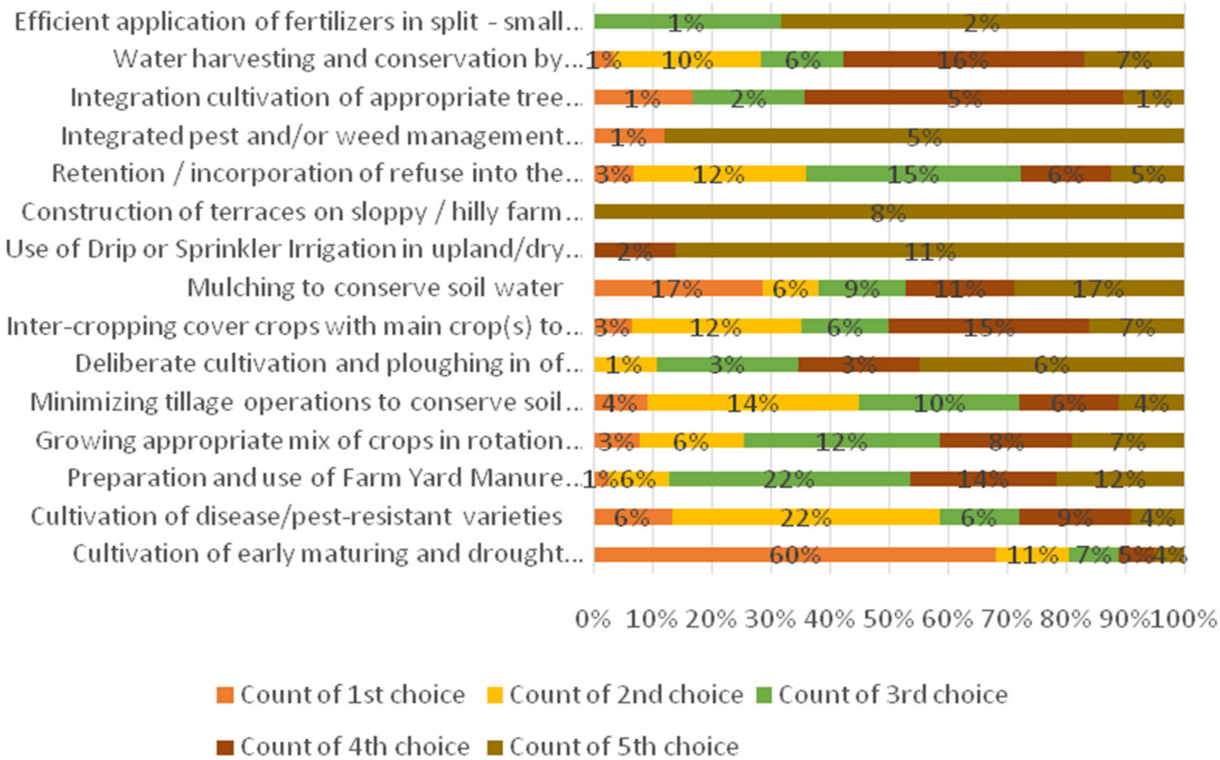


**Figure 4.** Currently/frequently used CSA technologies in Malawi.

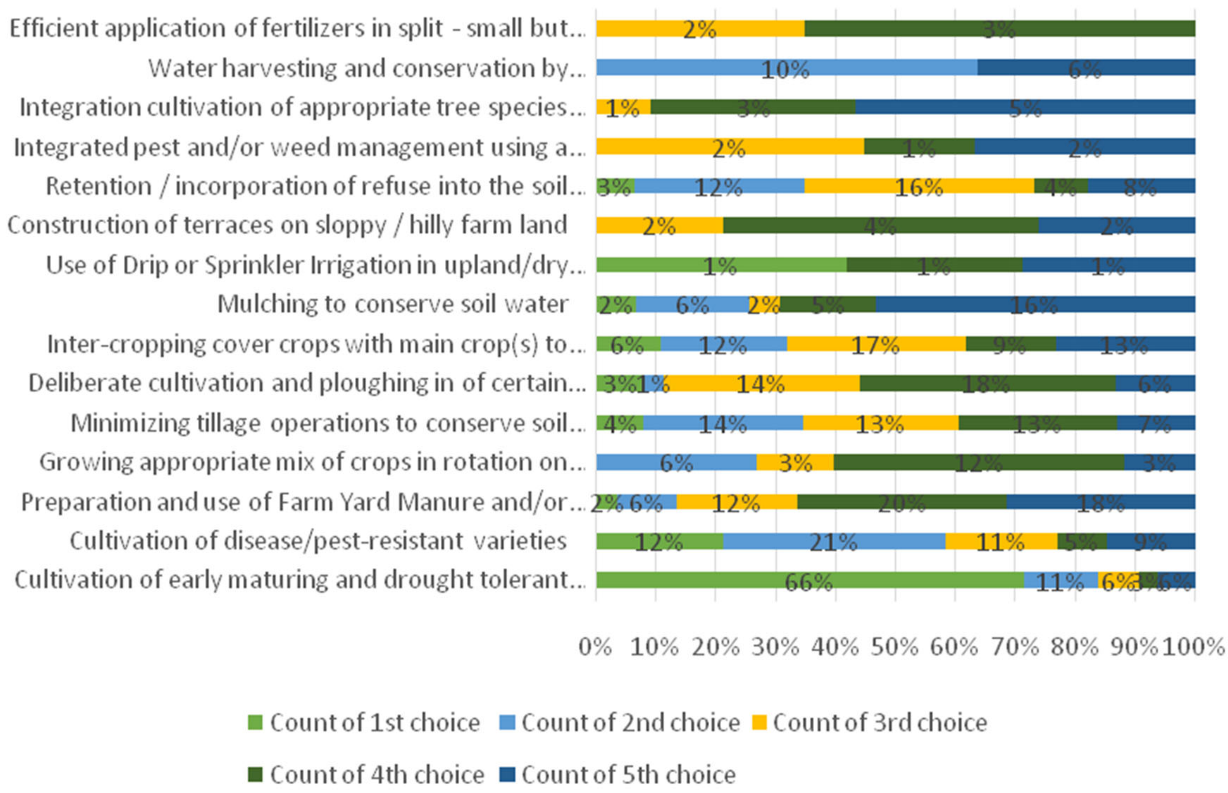


**Figure 5.** Currently/frequently used CSA technologies in Nigeria.

The trends on the use of drip, treadle, or sprinkler irrigation potentially may suggest low development status of irrigation farming in the countries and hence its limited use; but also the cost associated with irrigation in terms of purchase of the equipment, installation, operation, and management, which further limit the use of the technology [29,30].

In Kenya, 2% of the farmers mentioned the construction of terraces on sloppy/hilly terrain as first choice, 1% as second choice, 7% as third choice, 6% as fourth choice, and 8% as fifth choice (Figure 3). In Malawi, 8% of the farmers mentioned the construction of terraces on sloppy/hilly terrain as fifth choice (Figure 4). In Nigeria, 2% of the farmers mentioned the construction of terraces on sloppy/hilly terrain as third choice, 4% as fourth choice, and 2% as fifth choice (Figure 5). This pattern suggests, among other things, lack of technical knowhow, high-labor requirements, and farmers not being willing to pay the costs associated with construction and maintenance of terraces [31].

On the retention/incorporation of residues to the soil, the status resonates with documented reasons in the literature for the limited use of the practice. For instance, poor cultural practices such as burning of crop residues after harvest are common in Malawi. Recalcitrant crop residues that take time to decompose when incorporated in some cases attract termites that end up dislodging the main crop in the cropping season, there is a high labor requirement, and competing use in crop–livestock systems since they are utilized as livestock feed [32].

The pattern on the choice of the use of integrated pest and/weed management and the cultivation of appropriate trees (agroforestry) may likely suggest the intensity of the knowledge accompanying the technology and therefore resultantly the deficiency of proficiency in implementation among farmers [33]. Specifically, agroforestry is a practice that requires ample land, capital, and labor; it takes a long time for benefits to emerge and is knowledge-intensive [34]. The associated challenges implicitly exclude farmers who lack one or more of the attendant requirements. Therefore, there is need to simplify and contextualize technology information for easy understanding and use by the farmers.

Relative to other technologies and practices, water harvesting and conservation is a "new" concept that is gradually being established, and therefore this may explain the trend in the choices [35,36]. Notwithstanding, it is labor- and knowledge-intensive, and as such there is need for sustained effort to train farmers and equip them for implementation. On the choice of efficient fertilizer application, the trend reflects the limited availability or the lack of mineral fertilizer to use on fields since the commodity is expensive and with the conflict in eastern Europe, the prices are increasing further [37].

### *3.3. Climate-Smart Agricultural Practices' Adoption and Preference by Gender in Kenya*

The study found that farmers of different age and gender groups expressed differences in preference of CSA practices. Generally, females of different age groups preferred different climate-smart agricultural technologies (CSA). The female youth preferred cultivation of disease/pest-resistant varieties; preparation of farmyard manure/compost, and use of sprinkler or drip irrigation in the dry areas. Adult females preferred cultivation of early maturing and drought-tolerant crop varieties, incorporation of residue, and efficient use of fertilizer. Elderly females preferred construction of terraces, crop rotation, and cultivation of disease-resistant crops. Additionally, males of different age groups preferred different CSA technologies. Male youths preferred integrated pest and weed management methods, intercropping cover crops with the main crops, and efficient application of fertilizers. Adult males preferred minimum tillage operations to conserve soil moisture, efficient application of fertilizers, and construction of terraces in sloppy farms. Elderly males preferred deliberate plowing of certain leguminous crops to enhance soil nutrients, agroforestry that involves integration of trees and crops, and water harvesting and conservation by construction of bands (Figure 6).

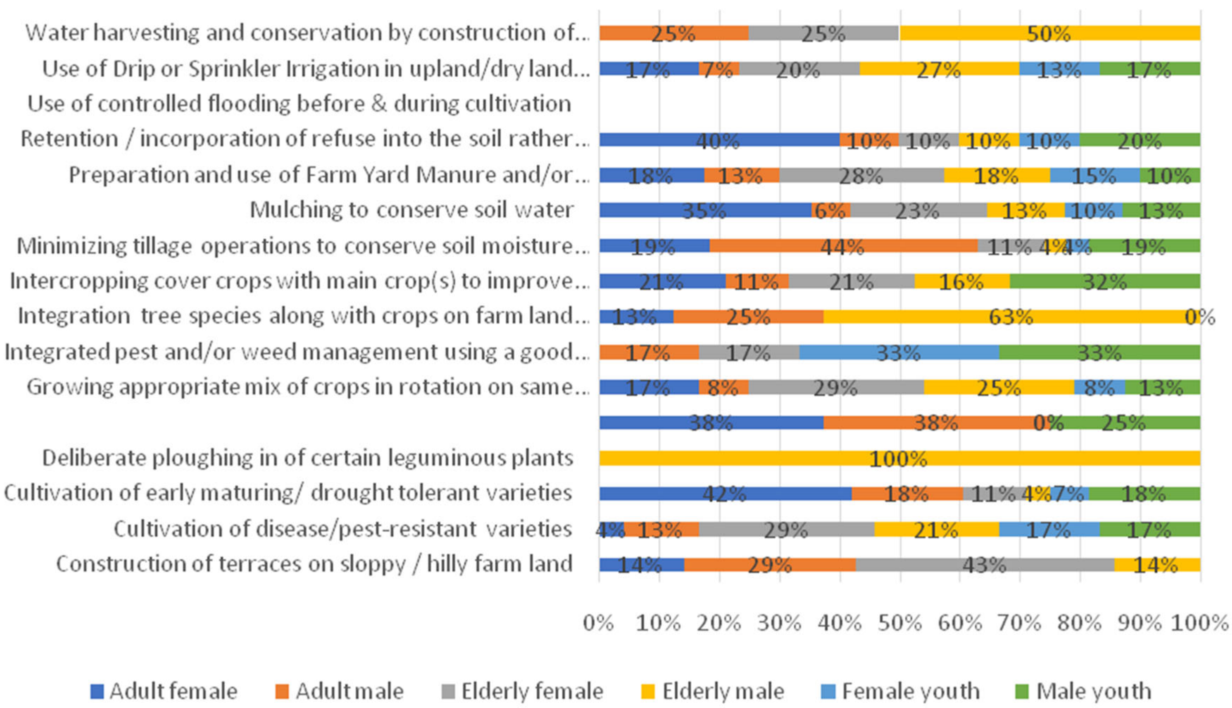


**Figure 6.** Preference of CSA practices adopted by gender in Kenya.

In Kenya from the FGDs, it was learnt that CSA T&Ps adopted in the semi-arid and medium-potential areas were almost similar, but gender and age group determined the preference for particular CSA technology adoption. Youth and adult males and females were energetic and able to invest in irrigation for high-value crops. Managing the irrigation system was normally done at night and elderly farmers may not endure the chilly conditions. Youths were also aggressive, and able to diversify into greenhouse farming for quick returns and able to take risks. Adult women were responsible for food security at the household level and therefore keen on the varieties planted with bias to early maturing varieties. Women were also keen in managing kitchen gardens using available wastewater from the kitchen to provide nutritional quality at the household level. Adult men were responsible for making long-term development decisions on the farm and were responsible for agroforestry practices, and soil and water conservation. While men preferred trees that can provide timber in future, the youths preferred fruit trees that can provide quick money. Adult men also designed terraces and dug them. Elderly men and women had little energy for digging but were comfortable with shallow weeders for conservation agriculture. Different categories adopted different technologies. For example, women did not choose soil conservation structures due to excavation of the ground but they were adopted by adults between 35 and 60 years old because they are strong. People above 60 years hardly engaged in heavy menial labor because of the strength and energy required.

The key informants noted that youths did not participate in farm activities because of the land tenure system (land ownership). Land was owned by the parents who hardly accepted long-term changes such as excavation of the soil for construction of structures for soil and water conservation. Planting of high-yielding varieties was adopted by women and supported by men as they were the ones who gave the money to buy the certified seeds which are high-yielding. Farms have continued to become smaller, therefore men supported the women so that they could be food-secure. It was observed that the youth that engaged in agriculture did not support activities that did not bring high returns. Hence, they preferred high-value horticultural crops such as onions, carrots, tomatoes, and cabbages.

### *3.4. Climate-Smart Agricultural Practices' Adoption and Preference by Gender in Malawi*

The results of the current study indicate that different gender and age groups prefer different CSA technologies in Malawi. Adult females preferred controlled flooding before and during cultivation, preparation and use of farmyard manure, and intercropping cover crops with main crops. Adult males preferred construction of terraces on sloping farmland, deliberate plowing of certain crops, and retention or incorporation of refuse into the soil to enhance the soil nutrients. Elderly females preferred mixed cropping and crop rotation, intercropping of cover crops with the main crops, and deliberate plowing of crops into the soil. Elderly males preferred construction of terraces on sloping farmland, retention of refuse into the soil, and cultivation of early maturing crops. Female youth preferred to minimize tillage operations to conserve soil moisture, cultivation of disease- and pest-resistant crop varieties, and mulching of the crops. The male youth preferred use of drip or sprinkler irrigation in drylands, use of controlled flooding before and during cultivation, and integrated pest and disease management (Figure 7).

On the other hand, the FGDs revealed that preference of technologies differed from location to location. For instance, in one location, men preferred the use of early maturing varieties, use of crop residues for mulching (reduces farming costs), and adopted one maize plant per planting station, 25 cm apart. Women preferred box ridges, water harvesting, mulching, and one maize plant per planting station, 25 cm apart. Preference was affected by weather conditions, labor availability, and geophysical condition of the piece of land (topography, closeness to dam and/or water source. Older women's preferences were influenced by cultural background and what was practiced by ancestors, for instance, tilling to reach different soil profiles, use of cultural/biological weed control (*Ricinus communis* L. (castor oil plant)) for removal of *Striga asiatica* (witchweed), early planting, and adopting one maize plant per planting station, 25 cm apart. Furthermore, slopes in this area affected selection of CSA practice. Extension agents were promoting practices that were adopted by men, women, youths, and the elderly who may still be involved in new practices, and all household members were involved in CSA practices.

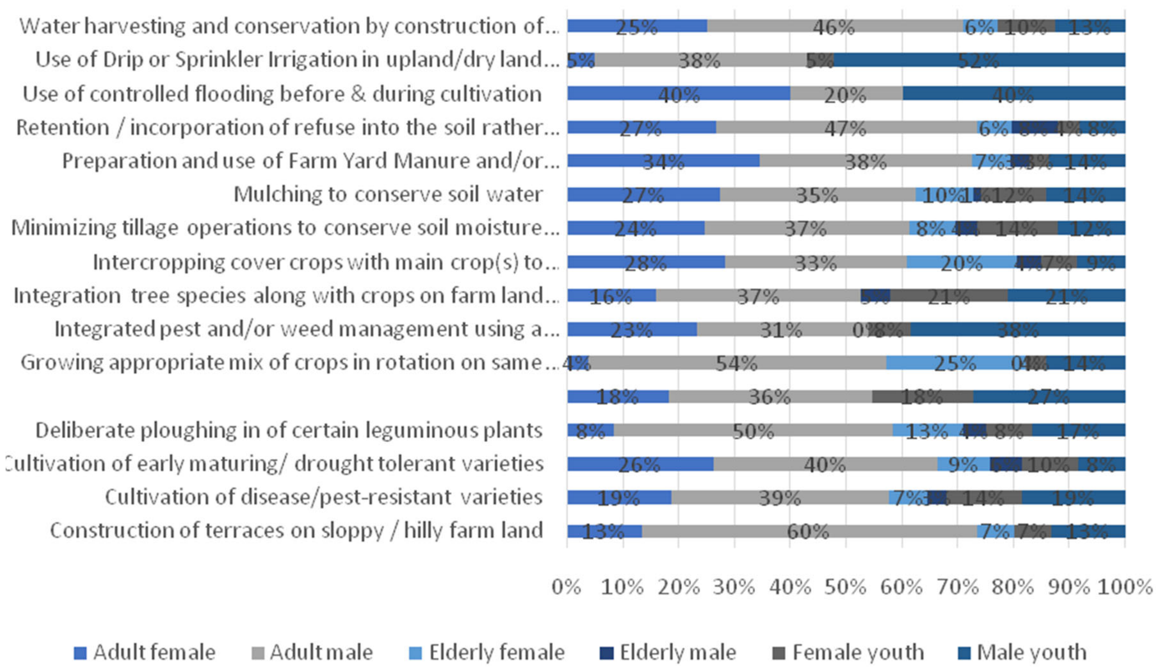


**Figure 7.** Preference of CSA practices adopted by gender in Malawi.

In contrast, in another location, men preferred mulching and pitting (30 cm). They felt they had the energy to do this and the practice was beneficial for crop growth; they also prepared and used manure. On the other hand, women preferred mulching, composting manure, and adopted one maize plant per planting station, 25 cm apart. They also preferred making ridges, saying that ridges helped crops to grow faster, and zero tillage delayed crop growth. The elderly women preferred ridge refilling, simple pitting of not more 10 cm (requires less energy than full pitting), use of manure in pits, zero tillage. The young men and women preferred pitting, weed management, and water conservation practices. Within a household, younger men were tasked with making pits, the elderly were tasked with manure application, and boys and girls tasked with collecting crop leftovers for mulching. The elderly were usually in charge of farm operations, and directing how box ridging was carried out.

### *3.5. Climate-Smart Agricultural Practices' Adoption and Preference by Gender Categories in Nigeria*

Our current study indicates that different age groups and genders have different preferences for different CSAPs in Nigeria. The adult females preferred retention or incorporation of refuse into the soil (25%), preparation and use of farmyard manure (18%), and cultivation of disease- or pest-resistant varieties (17%). The adult males preferred minimum tillage operations to conserve soil moisture (57%), mulching to conserve soil moisture (33%), and intercropping of cover crops and main crops (31%). Elderly females preferred growing an appropriate mixture of crops in rotation on the same land (33%), cultivation of early maturing and drought-tolerant crops (14%), and cultivation of disease- or pest-resistant varieties (14%). Elderly males preferred use of drip or sprinkler irrigation in drylands (67%,) growing an appropriate mix of crops in rotation in the same land (67%), retention or incorporation of leftovers in the soil (50%), and deliberate plowing in of certain leguminous crops (50%). The female youths preferred cultivation of early maturing or drought-tolerant varieties (16%), construction of terraces on sloping land (14%), and intercropping cover crops with main crops (12%). The male youths preferred mulching to conserve soil moisture (67%), deliberate plowing in of certain leguminous crops (50%), and use of drip or sprinkler irrigation in dry areas (33%) (Figure 8). Some of the reasons given for technology preference through FGDs included inter-cropping practices, which were widely preferred because they harvested two different crops from the same piece of land. Additionally, if one crop was affected by environmental stress, e.g., pest or drought, the farmer would receive something from the farm instead of losing all, and use of organic manure because it costs almost nothing (financially) and maintains soil fertility for a longer time.

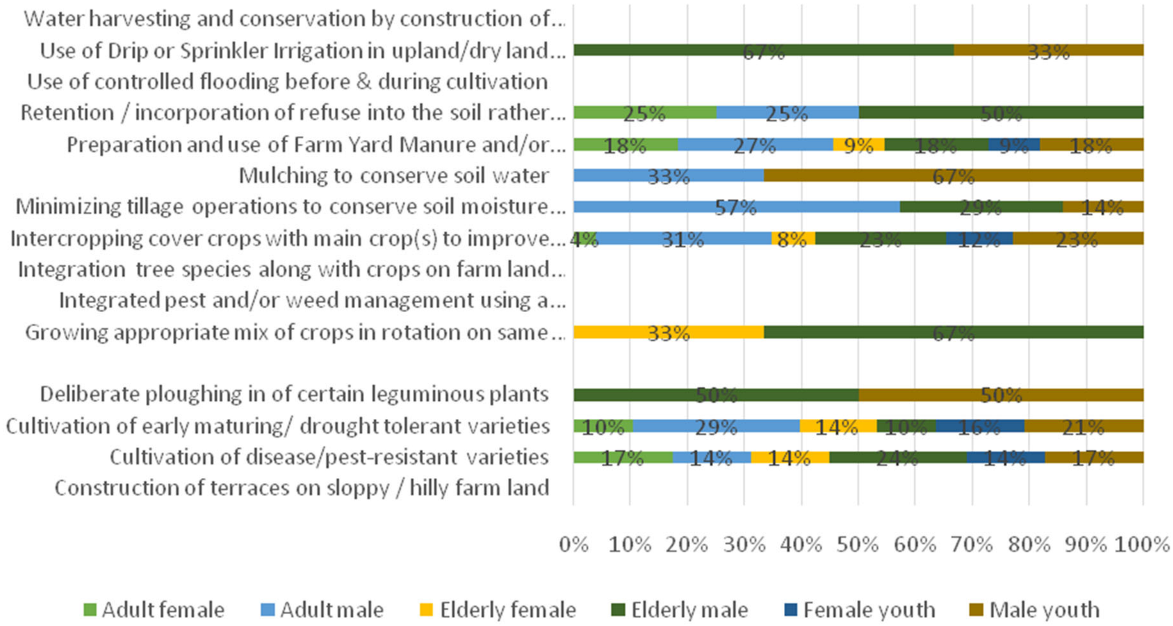


**Figure 8.** Preference of CSA practices adopted by gender in Nigeria.

### *3.6. Climate-Smart Agricultural Practices' Preference by Gender Categories in Kenya, Malawi, and Nigeria*

Due to the different agro-ecological zones across the three countries, different gender and age groups preferred different CSAPs across the three countries. The most common CSAPs among the elderly females were the cultivation of disease- or pest-resistant varieties and growing an appropriate mix of crops in rotation in the same farm. Across the three countries, adult females preferred preparation and use of farmyard manure, and retention or incorporation of refuse into the soil. The female youths had only one preferred CSAT&Ps, i.e., cultivation of disease- or pest-resistant varieties across the three countries. Elderly males preferred retention or incorporation of refuse into the soil, deliberate plowing in of certain leguminous crops, and agroforestry. The adult males preferred minimum tillage operations to conserve soil moisture, and construction of terraces on sloped land. The young males preferred use of a drip or sprinkler in dry areas, and integrated pest and disease management (Figure 9). One thing to note is that cultivation of disease/pest-resistant crop varieties was common among elderly and young females.

### *3.7. Multivariate Probit (MVP) Estimates of Factors Influencing Climate-Smart Agriculture Adoption*

In determining the factors influencing the adoption of CSA T&P across the three countries under study, the choice of the explanatory variables used in the empirical model were based on an empirical literature review of studies on the adoption of sustainable agricultural practices [38–40]. The choice to adopt any of these six (early maturing varieties, refuse retention, minimum tillage, green manure, crop rotation and mulching) CSA T&Ps was based on those that were most adopted among the farmers. The MVP model results are presented in Table 2. The Wald chi-square test statistics ($\chi^2(120) = 705.26$) show that the hypothesis that all regression coefficients in each equation are jointly equal to zero is rejected at 1% (prob. > $\chi^2 = 0.00$). This shows that the model fits, and the chosen explanatory variables are relevant in explaining the model.

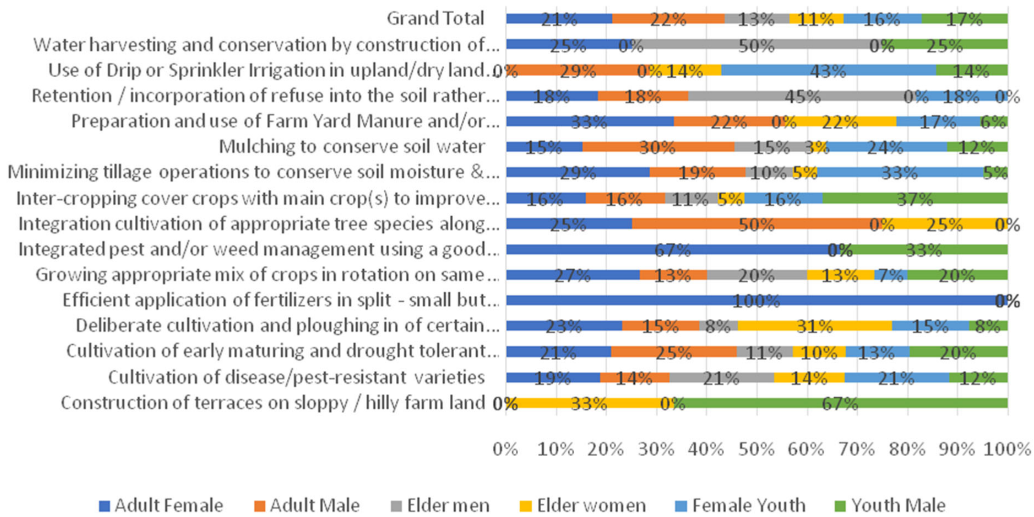


**Figure 9.** First choice of CSA by gender in Kenya, Malawi, and Nigeria.

The likelihood ratio test ($\chi^2(15) = 59.925$), which tests the hypothesis that correlation exists between the error terms of the equations that were all zero, was rejected at 1% (prob. > $\chi^2 = 0.00$), thereby implying that some level of interdependence exists between some of the CSA practices considered. These results support the choice of the MVP model as compared to estimating six different logit or probit models; this is evident from the correlated error terms.

The error term correlation results are presented in Appendix A, Table A1. Of the fifteen pair cases in the estimated correlation coefficients, eight are statistically significant, thus implying that the choices to adopt CSA practices are mutually determined. The correlation results show that negative correlation exists between the practices, thus implying that the practices are substitutes for the farmers. Negative correlation exists between crop rotation and the cultivation of early maturing varieties, green manure and the cultivation of early maturing varieties, minimum tillage and refuse retention, crop rotation and refuse retention, mulching and refuse retention, crop rotation and minimum tillage, mulching and green manure, and mulching and crop rotation.

The MVP result has revealed that the factors affecting different practices are not uniform. Based on our gender categorization, male elderly was dropped in the analysis due to multicollinearity. It is interesting to note that being an adult male, an elderly female, or a male youth positively influenced the adoption of early maturing varieties among farmers as compared to being an elderly male. In contrast, being an adult male negatively influenced the adoption of crop rotation. Gender had no significant influence on the adoption of the remaining four practices (refuse retention, minimum tillage, green manure and mulching). The implication of this is that despite the existence of gender disparities, the adoption of CSA T&Ps was often because of other factors.

The age of the farmers had a negative influence on the adoption of minimum tillage. This may not be surprising given that theoretically older farmers find it very difficult to change their farming habits as compared to younger farmers, although there are diverse opinions on the effect of age on CSA adoption in the literature [39,41]. The educational level of the farmers also significantly influenced the adoption of green manure. The more educated a farmer, the higher the ability to process information and the higher the likelihood of adopting technologies that would be beneficial to their productivity as compared to less educated farmers. This corroborates the finding of [42]. However, the assumption that households with large household size will increase the adoption of technologies was negated as the number of persons in the household reduced the likelihood of a farmer adopting mulching. This contradicts the results of [43,44], which found that increase in the household size increased the likelihood of adopting sustainable practices.

**Table 2.** Factors affecting the adoption of climate-smart agriculture practices and technologies.

| Variables | Early Maturing Var. | | Refuse Retention | | Minimum Tillage | | Green Manure | | Crop Rotation | | Mulching | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Coeff. | Z | Coeff. | Z | Coeff. | Z | Coeff. | Z | Coeff. | Z | Coeff. | Z |
| Gender (adult male) | 0.910 ** (0.374) | 2.44 | −0.130 (0.312) | −0.42 | 0.275 (0.330) | 0.83 | 0.076 (0.336) | 0.23 | −0.599 * (0.334) | −1.79 | −0.195 (0.316) | −0.62 |
| Gender (adult female) | 0.575 (0.355) | 1.62 | 0.258 (0.328) | 0.78 | 0.419 (0.342) | 1.23 | 0.254 (0.356) | 0.71 | −0.348 (0.335) | −1.04 | −0.209 (0.330) | −0.63 |
| Gender (elderly female) | 0.510 * (0.261) | 1.95 | −0.083 (0.254) | −0.33 | 0.271 (0.262) | 1.03 | 0.399 (0.276) | 1.44 | −0.353 (0.258) | −1.37 | −0.092 (0.258) | −0.36 |
| Gender (male youth) | 1.022 * (0.525) | 1.95 | 0.302 (0.475) | 0.63 | −0.294 (0.498) | −0.59 | 0.587 (0.530) | 1.11 | −0.332 (0.487 | −0.68 | −0.670 (0.485) | −1.38 |
| Gender (female youth) | 0.865 (0.528) | 1.64 | 0.421 (0.469) | 0.90 | 0.346 (0.488) | 0.71 | 0.154 (0.545) | 0.28 | −0.111 (0.491) | −0.23 | −0.679 (0.481) | −1.41 |
| Age | 0.010 (0.013) | 0.77 | −0.004 (0.012) | −0.34 | −0.020 * (0.012) | −1.69 | 0.004 (0.013) | 0.29 | −0.005 (0.012) | −0.39 | −0.013 (0.012) | −1.16 |
| Educational level | −0.031 (0.019) | −1.60 | 0.012 (0.016) | 0.77 | −0.025 (0.016) | −1.57 | 0.037 ** (0.018) | 2.02 | −0.010 (0.016) | −0.63 | 0.016 (0.017) | 0.93 |
| Household size | 0.034 (0.032) | 1.06 | 0.004 (0.024) | 0.16 | −0.016 (0.024) | −0.66 | 0.036 (0.029) | 1.24 | 0.003 (0.025) | 0.13 | −0.124 *** (0.031) | −4.00 |
| Native | 0.000 (0.006) | 0.02 | 0.015 *** (0.006) | 2.61 | −0.002 (0.006) | −0.28 | −0.002 (0.005) | −0.38 | 0.001 (0.005) | 0.14 | 0.001 (0.005) | 0.11 |
| Flood incidence | 0.299 * (0.178) | 1.68 | 0.421 *** (0.172) | 2.45 | 0.640 *** (0.177) | 3.62 | −0.074 (0.179) | −0.41 | −0.125 (0.168) | −0.75 | 0.508 ** (0.176) | 2.88 |
| Drought incidence | 0.182 (0.169) | 1.08 | 0.104 (0.147) | 0.7 | 0.128 0.160 | 0.80 | 0.291 * (0.163) | 1.79 | −0.042 (0.161) | −0.26 | −0.108 (0.153) | −0.7 |
| Credit access | 0.117 (0.170) | 0.69 | −0.231 (0.153) | −1.51 | 0.365 ** (0.155) | 2.36 | 0.383 ** (0.171) | 2.24 | −0.242 (0.155) | −1.56 | −0.313 ** (0.151) | −2.07 |
| Membership of cooperative society | −0.170 (0.175) | −0.97 | −0.027 (0.162) | −0.16 | −0.324 ** (0.162) | −2.00 | 0.055 (0.182) | 0.3 | 0.159 (0.171) | 0.93 | −0.547 *** (0.172) | −3.19 |
| Farm size | 0.048 (0.031) | 1.55 | −0.017 (0.030) | −0.56 | 0.117 *** (0.025) | 4.68 | 0.009 (0.029) | 0.31 | −0.051 (0.033) | −1.57 | 0.026 (0.028) | 0.94 |
| Distance from home to farm | −0.006 * (0.003) | −1.76 | 0.000 (0.003) | −0.08 | 0.000 (0.003) | −0.04 | 0.004 * (0.002) | 1.80 | 0.002 (0.003) | 0.58 | 0.006 * (0.003) | 1.87 |
| Land type | −0.497 ** (0.196) | −2.53 | 0.151 (0.175) | 0.86 | 0.124 (0.181) | 0.68 | 0.466 ** (0.206) | 2.26 | 0.984 *** (0.203) | 4.86 | −0.393 ** (0.176) | −2.23 |
| Land ownership | −0.004 (0.181) | −0.02 | 0.000 (0.166) | 0.00 | −0.168 (0.167) | −1.01 | −0.485 *** (0.170) | −2.85 | −0.061 (0.174) | −0.35 | −0.138 (0.169) | −0.82 |
| Extension contacts | 0.702 *** (0.202) | 3.47 | 0.153 (0.197) | 0.78 | −0.218 (0.197) | −1.11 | 0.640 *** (0.225) | 2.85 | −0.077 (0.206) | −0.37 | 0.311 (0.194) | 1.60 |
| Off farm income ($) | 0.001 (0.001) | 1.11 | 0.000 (0.001) | −0.17 | 0.001 * (0.001) | 1.69 | 0.002 *** (0.001) | 2.82 | 0.001 (0.001) | 1.41 | −0.002 *** (0.001) | −2.79 |
| Household members that contributed to income (#) | −0.026 (0.059) | −0.45 | 0.000 (0.000) | 1.19 | −0.001 *** (0.000) | −4.13 | 0.000 (0.000) | 1.16 | 0.000 (0.000) | 0.06 | −0.001 *** (0.000) | −4.40 |
| Constant | −1.421 (0.985) | −1.44 | −1.632 (0.899) | −1.81 | −1.170 (0.919) | −1.27 | −3.300 (0.982) | −3.36 | 0.038 (0.961) | 0.04 | 1.170 (0.911) | 1.28 |

Wald chi$^2$(120) = 705.26, log pseudolikelihood = −1308.0561 prob. > chi$^2$ = 0.000; likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho61 = rho32 = rho42 = rho52 = rho62 = rho43 = rho53 = rho63 = rho54 = rho64 = rho65 = 0: chi$^2$(15) = 59.925 prob. > chi2 = 0.000; robust standard error in parenthesis. ***, **, and * denote significance at 1%, 5%, and 10%.

Similarly, farmers who are natives of the rural communities in which they stay are more likely to adopt the retention of refuse, which is a very simple practice as compared to long-term practices such as agroforestry, if they do not have secure land tenure. Furthermore, the incidence of flood affecting farmers had a significant and positive influence on the adoption of early maturing varieties, refuse retention, minimum tillage, and mulching. This is not surprising as all these practices are targeted at reducing erosion, conserving soil moisture, and reducing the period between planting and harvest.

The findings have further shown that the occurrence of drought influences the adoption of green manure among farmers. The conscious incorporation of leguminous crops into the soil by farmers was influenced by the occurrence of drought. Access to credit or the participation in the decision to borrow had a significant influence on the willingness to adopt CSA T&P. The findings revealed that access to credit increased the adoption of minimum tillage and green manure while it reduced the likelihood of the adoption of mulching. Farmers are better able to make positive decisions in their production when they have access to funds for input purchase or for scaling up production. This is in line with the findings of [45].

The results have shown that social capital (membership of a farmer association) positively influences the likelihood of adopting green manure and negatively influences the adoption of minimum tillage and mulching. This finding may be of importance in the selection of appropriate green manure species [46]. Membership of a farmer group is particularly important, with benefits such as serving as an avenue to learn new practices, accessing both formal and informal credits, and obtaining informal trainings [47].

An increase in the farm size of farmers positively influenced the adoption of minimum tillage among farmers. This is consistent with the findings of [48], who reported that an increase in farm size would positively increase the likelihood of adopting CSA. Furthermore, the likelihood of using green manure and mulching increased with walking distance to the cultivated plots. This contradicts the finding of [44]. They reported a contrary finding in Kenya: that distance can be a significant barrier to the adoption of some labor-intensive technologies.

Similarly, farmers that cultivated crops in the lowlands had a higher likelihood of adopting green manure and crop rotation. Lowland use is an adaptation strategy that farmers adopt by cultivating different crops on the same plot during different planting seasons to increase fertility. Land ownership negatively influenced the adoption of green manure. This is contrary to a priori expectation, as secure land is expected to serve as an incentive for farmers to consider investing in the adoption of long-term practices. This is in consonant with [49] the argument of Marshallian inefficiency with farmers making use of fewer inputs or lower investments on rented owned plots compared to owned plots. The importance of agricultural extension in diffusion and continued use of technologies among farmers was observed. The results showed that frequency of contact with extension agents positively influenced planting of early maturing varieties and mulching adoption. This is consistent with earlier findings in the literature [49,50].

Additionally, farmers who engaged in off-farm activities had a higher likelihood of adopting minimum tillage and green manure. This is not surprising, since green manuring requires a considerable financial commitment from adopters. For instance, the adopters of green manuring must be willing to allow an economically unproductive fallow period. Therefore, farmers engaged in other income-generating activities have a higher likelihood of adopting these practices, given that they have other income sources to supplement household consumption [51].

## 4. Conclusions

Climate-smart agriculture (CSA) has been identified as playing a crucial role in tackling the adverse effects of climate change. It focuses on sustainably increasing agricultural productivity, resilience, and enhancing food security. Climate-smart agriculture presents an opportunity to advance agriculture in Kenya, Nigeria, and Malawi. CSA technologies and practices are adopted across the different agro-ecological zones in eastern, western, and southern Africa. However, for farmers to fully benefit from CSA, the practices have to align with local conditions to allow adaptability, innovation, and social–cultural issues to be incorporated. This study has consolidated the literature and information from Kenya, Malawi, and Nigeria that presents a new case about the scarcity of information on adoption of integrated climate-smart technologies across multiple African countries. The study has shown that CSA adoption varies across agro-ecological zones for different crops cultivated. Some CSA technologies and practices are commonly adopted across the three countries. These include crop rotation, minimum/zero tillage, improved seed varieties, conservation agriculture, use of farmyard manure, and agroforestry. The study has outlined some of the most important drivers affecting the uptake of CSA practices. Some of the drivers of CSA technologies and practices drivers identified across the three countries include access to extension services, the age of the farmers (with the younger farmers being more willing to adopt CSA T&Ps as compared to older farmers), land tenure and property rights, gender, educational level of farmers, and social capital among others. It is recommended that policies and strategies incorporate these factors in addition to addressing programmatic issues that affect adoption. Though adoption and continuation of specific CSA practices is less studied, this is probably due to their recent introduction. Hence, there is a need to establish and maintain a data and information management system, build capacities on data collection and information management, and promote data generation and dissemination during planning, implementation, monitoring, and evaluation at both national and local levels in individual countries. Integrating data from specific and different countries will help in developing reliable country/regional inventory system on CSA practices as well as enhance reporting and verification of these technologies. This study notes the importance of increasing the awareness of common CSA practices in the three countries by gender groups. Additionally, the study identifies the need for consolidated information database for CSA that can be implemented in eastern, southern, and western Africa. Consolidating information databases for CSA across the region will assist policymakers and various stakeholders to design well-informed programs that are relevant and timely to meeting the identified needs of various farmers across Africa.

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**Data Availability Statement:** Data of the study can be found at: https://ee.kobotoolbox.org/x/0SsIkJoJ (accessed on 21 March 2022).

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## Appendix A

**Table A1.** Coefficients of climate-smart practice correlation results.

| | Coefficient | Std. Err. | Z |
|---|---|---|---|
| rho21 | 0.096 | 0.086 | 1.11 |
| rho31 | −0.077 | 0.089 | −0.87 |
| rho41 | −0.237 ** | 0.095 | −2.49 |
| rho51 | −0.190 ** | 0.092 | −2.06 |
| rho61 | −0.076 | 0.087 | −0.87 |
| rho32 | −0.170 ** | 0.082 | −2.06 |
| rho42 | 0.106 | 0.091 | 1.16 |
| rho52 | −0.164 ** | 0.079 | −2.07 |
| rho62 | −0.178 ** | 0.087 | −2.06 |
| rho43 | 0.134 | 0.094 | 1.42 |
| rho53 | −0.217 ** | 0.081 | −2.68 |
| rho63 | −0.003 | 0.081 | −0.04 |
| rho54 | 0.042 | 0.088 | 0.47 |
| rho64 | −0.285 *** | 0.089 | −3.19 |
| rho65 | −0.300 *** | 0.081 | −3.7 |

Note: early maturing var. = 1, refuse retention = 2, minimum tillage = 3, green manure = 4, crop rotation = 5, mulching = 6. ** and *** denote significance at 5%, and 10%.

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