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Efficacy of Adaptation of Smallholder Maize Production to Climate Variability in Selected Countries of Kenya

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Abstract

Maize is a staple food for 96 percent of Kenyans. Smallholders supply up to 75 percent of maize produced in Kenya but are affected by unpredictable timing, duration, and distribution of rainfall, especially during the growing season. To enhance maize productivity adoption of robust adaptation measures is vital. The study aimed to evaluate the level of efficacy of adaptation of smallholder maize production to climate variability in Kitui and Laikipia counties. Data from 273 smallholder maize producers drawn from Kitui and Laikipia counties was analyzed. A questionnaire was administered to collect data on demographic, socio-economic characteristics, and adaptation choices. The level of efficacy of adaptation was derived based on the Multiple Criteria Evaluation. Results showed that the majority of smallholders in the study (47 percent) reported a low level of efficacy of adaptation most of whom were from Laikipia County (54 percent) as compared to Kitui County (44 percent). Overall, a very small proportion of smallholders reported a high level of efficacy of adaptation (7 percent). The study concluded that the level of efficacy of adaptation of smallholder maize production to climate variability in semi-arid areas was low. The County Governments through the department of agriculture and environment could establish guidelines for a robust combination of adaptation choices to ensure the suitability and enhancement of maize production.

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Keywords: Adaptation, Multiple Criteria Evaluation, Efficacy of adaptation, criteria weighted score, index

1. Introduction

World over, there is heightened concern about the need to increase food production to feed the growing population owing to the magnitude of challenges relating to hunger and famine. To sustain the resolve to combat hunger, much focus is on support to agricultural practices that lead to increased agricultural output, protection of ecosystems that support agriculture, strengthening the capacity to adapt agriculture to climate change, improvement of the quality of soils, increased access to inputs and knowledge to enhance agriculture production among other ways in line with the Sustainable Development Goals (United Nations, 2015).

Agriculture is one of the sectors adversely affected by climate variability despite the important role in food security. Climate variability affects agriculture through increasing temperatures, rainfall variability, recurrent droughts, recurrent famine, pests, and diseases among others (Olsson et al., 2019). This is detrimental to maize production in Kenya, especially where 80 percent of the land area already constitutes Arid and Semi-Arid Lands receiving only between 200 and 700 millimeters (Republic of Netherlands, 2018). It was further predicted that temperature in Kenya would rise by 1.7 Degree Celcius by 2050s (World Bank Group, 2021). This poses a huge risk for maize production systems.

In Kenya, maize consumption outstrips production. This has a direct negative impact on food security since the highest incidents of food insecurity are associated with maize shortage (Kabubo-Mariara and Kabara, 2015). Maize is the staple food for approximately 96 percent of Kenyans and about 75 percent of its production is by smallholders (Njagi et al., 2017). Furthermore, it accounts for about 40 percent of the crop area in Kenya (International Maize and Wheat Improvement Center, 2015). However, unpredictable timing, duration, and distribution of rainfall especially during the growing season affect maize production adversely. Adaptation is therefore vital for sustained production and improved household livelihoods. Ahmad et al. (2020) found out that adaptation of maize production systems to increasing temperature contributed to increased maize yield in current and future maize production systems. This implies that wrong selection or inappropriate application of adaptation choices could exacerbate low maize yields leading to financial losses.

Adapting smallholder maize production to climate variability entails water management, weed management, soil fertility management, planting appropriate crop variety, accurate timing during planting as well as proper land tillage among other interventions. Water management also involves growing

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crops that utilize water efficiently and use of farming technologies that encourage moisture retention (Muhamad *et al.*, 2021).

On the other hand, soil fertility management requires that soil analysis is undertaken to determine the missing nutrients from the soil. In addition, it also requires that the right nutrients are added to soil depending on the crop to be grown since different crops require different quantities of soil nutrients (Ketterings, Czymmek, Beegle and Lawrence, 2016). Soil fertility can be managed in several ways such as using organic or inorganic fertilizer, intercropping with legumes that fix nitrogen biologically such as beans and pigeon peas and crop rotation (Fung, Tai, Yong, Liu and Lam, 2019). Besides legumes, crops such as cassava improve soil properties through creation of biomass, enhancement of nitrogen and soil organic carbon which is beneficial to maize (Udom, Benwari and Osaro, 2015). In addition, depletion of nitrogen and phosphorus is low thus such crops could be intercropped or rotated with maize (Howeler, 2017).

Weeds management is also crucial as weeds compete for water, light, nutrients and carbon dioxide with crops (Iderawumi, 2018). Some management measures for weeds include: growing weed tolerant varieties; sowing seeds that are not contaminated with weeds; rotating cereals with trap crops that induce abortion in weed germination; application of organic and inorganic fertilizer to improve fertility and to suppress germination; use of herbicides; pulling out the weeds (Maqsood et al., 2020).

In addition, proper crop husbandry requires appropriate timing of farming operations, selection of crop varieties that match available water and adjusting planting times to coincide with periods of adequate water. Some adaptation choices have multiple benefits. For instance, agroforestry enhances soil fertility, prevents soil erosion, provides shade for crops and provides off-farm incomes which can be ploughed back for maize production (Nyaga, Muthuri, Barrios, Oborn and Sinclair, 2019).

Smallholders are encouraged to practice Climate Smart Agriculture which involves enhancing agricultural productivity, incomes and the resilience of agriculture to climate change through adaptation and mitigation (Abegunde and Obi, 2022). However, resource and information limitations may affect the level or results of farm level adaptation despite awareness of the climatic changes (Schipper, 2020). It is therefore important to evaluate the efficacy of adaptation practiced by smallholders. Efficacy in the context of this study, is the perceived judgment of the capability of adaptation choices to successfully produce desired results with respect to effectiveness, high yield, affordability, farmer implementability, and additional benefits.

Studies on adapting agriculture to climate change (Hassan and Nhemachena, 2008; Kebede and Adane, 2011; Bryan et al., 2013; Mabe et al., 2014; Fadina and Barjolle, 2018; Ndamani and Watanabe, 2016; and Ahmed,

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2016) explored numerous adaptation choices employed by farmers and the determinants of adaptation. However, no studies in Kenya estimated the efficacy of adaptation, particularly in reference to smallholder maize production. In addition, most of the studies had challenges analyzing farmers' simultaneous application of multiple adaptation choices. Therefore, the main objective of this study was to evaluate the levels of efficacy of adaptation of smallholder maize production to climate variability in selected counties in Kenya to address the research gaps identified and add to existing knowledge.

2. Literature review

Hassan and Nhemachena (2008) investigated the determinants of farm-level adaptation strategies to climate change, the perception by farmers in Africa about climate change, and the actual adaptation strategies used. The study established that different adaptation alternatives were driven by seasonal climate changes. The findings of the study suggested that irrigation, multiple cropping, and mixed farming were the most popular adaptation strategies practiced by farmers. The study concluded that irrigation, multiple cropping, and mixed farming were the most preferred choices of adaptation while mono-cropping was the least preferred. The study's main limitation was that it did not consider specific adaptation measures but instead generalized them and grouped them into categories. Grouping adaptation alternatives may make it difficult to determine which alternatives led to increased yields.

Kebede and Adane (2011) carried out a study to assess and analyze farmers’ perceptions and adaptations to climate change in the Lake Tana Basin and agro-pastoralist areas of Oromiya and Amhara regional states in Ethiopia. The results of the study depicted that the most popular adaptation alternatives were changing planting dates, change in crop variety, and crop diversification. The study concluded that agricultural production had declined and therefore households had been adjusting their farming practices to reverse this trend. The main limitation of this study was that although it analyzed specific adaptation choices practiced by households, the methodology used in estimation did not allow for the analysis of multiple adaptation choices.

Bryan *et al.* (2013) analyzed adaptation measures and factors influencing farmers’ decision to adapt in Garissa, Mbeere, Njoro Mukurwe-ini, Othaya, Gem, and Siaya Districts in Kenya. The findings of the study showed that households were using multiple adaptation choices simultaneously. The adaptation choices identified were: planting trees (9 percent), change of planting dates (20 percent), change of crop type (33 percent), and soil water conservation (5 percent), while 19 percent of farmers did not adapt. The study concluded that although the majority of farmers had perceived changes in rainfall and temperature, they faced numerous challenges that inhibited their ability to adapt. One of the limitations of the study was that

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response categories by farmers were many and diverse making it difficult to group and analyze.

Mabe *et al.* (2014) investigated determinants of choice of climate change adaptation strategies in Northern Ghana. The farmers' adaptation choices identified in the study were: changing planting dates, changing crop varieties, destocking, fallowing, fertilization, mulching, increasing farm size, planting trees, and adaptation of a combination of at least five options. The results revealed that the choice of adaptation was mainly influenced by farmer characteristics and perception about the weather. The study combined crop and livestock sub-sectors during analysis yet the two sub-sectors had distinct adaptation choices that were not comparable.

Shongwe (2014) analyzed the factors influencing the choice of adaptation strategies by households in Mpolonjeni, Swaziland. Adaptation strategies were grouped into: no adaptation; drought-tolerant varieties, shifting planting dates and conservation agriculture; conservation agriculture and shifting planting dates; irrigation and any other adaptation strategies; and all strategies. Results indicated that 90.4 percent of land cultivated was dedicated for maize production and the rest was used to cultivate other crops. The results of the study showed that the most popular adaptation choices were: the use of drought-tolerant varieties, early and late planting, minimum tillage, crop rotation, intercropping, irrigation, and mulching. The main weakness of the study was that it combined some adaptation strategies making it difficult to determine how specific adaptation choices were influenced by the independent variables. It was also not clear whether the adaptation choices were suitable for all crops or the dominant crop.

Thi and Chavanapoonphol (2014) evaluated levels of adaptation for highland robusta coffee production in Daklak province in Vietnam. The adaptation options considered in the study were: crop diversification, irrigation techniques, soil conservation; crop diversification and irrigation technique; crop diversification and soil conservation; soil conservation and irrigation; and a combination of the three techniques. The study adopted the Multiple Criteria Evaluation (MCE) to evaluate adaptation strategies. The following aspects were assessed: effectiveness, economic efficiency, flexibility, farmer implementability, and independent benefits. Results indicated that economic efficiency and effectiveness were assigned the highest weight by farmers. The majority of the farmers adopted one adaptation choice while the minority adopted all the options. Farmers were in favor of adaptation choices such as irrigation through sprinkling, crop diversification, or soil conservation. The study concluded that farmers were reactive rather than proactive in adapting to climate change.

Ndamani and Watanabe (2016) analyzed the determinants of farmers' adaptation to climate change in Ghana. The adaptation choices identified

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were: the use of improved crop varieties, crop diversification, farm diversification, change in planting date, income-generating activities, irrigation, and agroforestry. The results of the study showed that the most popular adaptation choice was the diversification of crops. Ahmed (2016) analyzed the most commonly used adaptation strategies that farm households applied and the determinants of these choices for maize production in the Central Rift Valley of Ethiopia. The dependent variable was the choice of adaptation strategies that included: use of improved crop varieties, adjusting planting dates, crop diversification, and soil conservation practices. Results of the study showed that the majority of farmers chose the use of improved crop varieties and adjusting planting dates. The study concluded that the choice of adaptation was influenced by social economic characteristics. The studies by Ndamani and Watanabe (2016) and Ahmed (2016) could not analyze multiple adaptation strategies.

Fadina and Barjolle (2018) examined farmers' adaptation strategies to climate change and their implications in the Zou Department of South Benin. The adaptation options were: no adaptation; crop-livestock diversification (mixed cropping, crop rotation, mulching, organic fertilizer); use of improved varieties, chemical fertilizers, and pesticides; agroforestry and perennial plantation; diversification of income-generating activities and multiple coping strategies. Results of the study indicated that although 90.8 percent of farmers had observed changes in climate, only 85 percent of them acted. Most of the farmers preferred crop-livestock diversification, use of improved varieties and agroforestry, and perennial plantation while 14.2 percent did not adapt at all. The study concluded that crop-livestock diversification; use of improved varieties; agroforestry and perennial plantation; diversification of income-generating activities were the most preferred adaptation strategies. However, the study's main weakness was that adaptation strategies with different outcomes were grouped under crop-livestock diversification.

3. Methods

3.1. Area of study

Smallholders were the respondents who cultivated 5 acres of land and below. Two counties in the semi-arid areas were considered in the study: Kitui located in lowland areas and Laikipia County located in highland areas. The counties have also been reported to suffer from food insecurity.

In Kitui County, the absolute poverty level was estimated as 47.5 percent compared to the national average of 36.1 percent while the food poverty rate was estimated as 39.4 percent as compared to the national average of 32 percent (Republic of Kenya, 2018a). The annual rainfall varies between 500 millimeters and 1050 millimeters with 40 percent reliability while minimum temperature ranges from 22 to 28 Degree Celsius and maximum temperature ranges from 28 to 32 Degree Celsius (Khisa, 2017). Although a large area (77,551 Ha) was dedicated to maize production, the annual production was lower (10,858 metric tonnes) as compared to sorghum (11,989 metric tonnes) with a lower land area (68,307) (Republic of Kenya, 2018a).

In Laikipia County, the absolute poverty level was estimated as 46 percent compared to the national average of 36.1 percent while the food poverty rate was estimated as 24.2 percent as compared to the national average of 32 percent (Council of Governors and Kenya Institute of Policy, Research and Analysis, 2020). Agriculture supported over 60 percent of the population. The annual rainfall varies between 400 millimeters and 750 millimeters while the mean annual temperature ranges between 16 degrees Celsius and 26 Degree Celsius (Republic of Kenya, 2018b). The main crop cultivated is maize which comprises 51 percent of the total crop area.

3.2. Sampling and data collection

A cross-sectional research design was used where data with respect to the long rain growing season of 2017 (March to August) was collected from smallholders to facilitate the assessment of the level of efficacy of adaptation of smallholder maize production to climate variability. A questionnaire was used to collect data on adaptation practiced and socioeconomic variables. Both open-ended and closed-ended questions were used. The enumerators administered questionnaires to selected respondents in the farms. Data was collected on: smallholders' awareness of climate change; the nature of changes observed; access and accuracy of climate information received; type of landholding; farming experience; access to extension services; number of social groups and the challenges faced in maize production due to climate-related changes. Furthermore, the study analyzed adaptation strategies smallholders used to overcome the climate-related challenges in maize production. Thereafter, smallholders evaluated the adaptation strategies employed based on their perception. The adaptation strategies selected were the most commonly applied in maize production based on the literature reviewed.

The sample of smallholder maize producers was drawn from four sub-counties of Kitui County (Kitui Central, Kitui South, Kitui Rural, and Mwingi Central) and two sub-counties in Laikipia County (Laikipia North and Laikipia East). The targeted maize producers were those who had land sizes of five acres and below. The sampling frame for the smallholder maize producers was obtained from the County Directors of Agriculture of the respective counties. The sample size was obtained following Cochran (1977) as follows:

$$n = \frac{Z^2 P(1-P)}{e^2} \text{...} 1$$

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Where Z is the selected critical value of the desired confidence level (Israel, 2003). For the present study, 95 percent confidence level translating to 1.96 from the standard normal cumulative distribution table was preferred. P is the estimated proportion of the population of smallholder maize producers approximated as 0.5 while e is the desired level of precision estimated at ±5 percent (Israel, 2003). On the other hand, e represents the margin of allowable error between the sample and the population (Israel, 2003). This estimate represents maximum variability applied where there is a large population whose variability is not known (Israel, 2003). Therefore, the sample size was estimated as follows:

$$n = \frac{1.96^2 \times 0.5 \times 0.5}{0.05^2} = 384.16 \qquad (2)$$

The sample size of 384 was distributed based on a ratio of 2 sub-counties in Laikipia County to 4 sub-counties in Kitui County leading to a total of 128 respondents for Laikipia County and 256 for Kitui County. Over and above the sample size of 384 respondents, 27 more respondents representing 7 percent of the sample size were included to compensate for targeted respondents who could not be reached, nonresponse or inadmissible questionnaires due to errors (Israel, 2003). Therefore, a total of four hundred and eleven (411) smallholder maize producers were sampled. Upon data cleaning, data from 397 smallholder maize producers was found fit for analysis. A total of 273 out of 397 smallholders adapted maize production to climate variability while 124 did not adapt. The level of efficacy was evaluated based on 273 smallholders.

Respondents were selected using multistage sampling. Respondents from each of the selected six sub-counties were clustered according to Wards and then selected using simple random sampling. All the Wards of the sub-counties were included except for Sosian and Mukogodo West Wards from Laikipia County which were mainly on the range lands and Nanyuki Ward in Laikipia County and Kitui Township Ward in Kitui County located in the urban areas. The sample was therefore drawn from the following Wards: Mutomo, Athi, Ikanga, Ikutha and Kanziko from Kitui South Sub-County; Kisasi, Yatta Kwa Vonza, Kanyangi and Mbitini from Kitui Rural; Kyagwitha East, Kyagwitha West, Miambani and Mulango from Kitui Central; Mwingi Central, Waita, Kivou, Mui, Nguni and Nuu from Mwingi Central; Mukogodo East and Segera from Laikipia North; Thingithu, Tigithi, Umande and Ngobit from Laikipia East.

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3.3. Measurement of the levels of efficacy of adaptation of smallholder maize production to climate variability

The multiple criteria evaluation method was used in deriving levels of efficacy. The approach of evaluating adaptation choices based on various criteria was established by the Intergovernmental Panel on Climate Change (Carter et al., 1994). Some of the criteria used in evaluating adaptation by earlier studies include effectiveness, efficiency, flexibility, farmer implementability, and independent benefits (Thi and Chaovanapoonphol, 2014). The evaluation of efficacy in the present study was based on five criteria: effectiveness, high yield, farmer implementability, affordability, and additional benefits. In the context of this study, effectiveness measures the ability of the adaptation choice to reduce losses in smallholder maize production. According to Smith (1996), effectiveness was used to measure the ability of adaptation to reduce vulnerability to climate change (Thi and Chaovanapoonphol, 2014). High yield in the present study was used to measure the ability of adaptation choice to increase yield despite climate variability. Titus (1990) measured the ability of adaptation choice to perform well under different climate change settings with the criteria of flexibility (Thi and Chaovanapoonphol, 2014). Affordability was used to measure smallholders' ability to meet the cost of adapting. According to Dolan et al. (2001), economic efficiency could be used to assess whether the additional cost of farming occasioned by adaptation exceeded the economic benefits of adaptation.

Farmer implementability was used to measure the extent to which smallholders could implement selected adaptation choices considering their level of knowledge and skills. Thi and Chaovanapoonphol (2014) measured farmer implementability as the degree to which an adaptation choice was understandable, observable, and compatible with farm operations. Additional benefits criterion was used to measure the extent to which an adaptation choice had additional benefits such as improving soil fertility, improving organic matter among other benefits. Smith and Lenhart (1996) suggested that the benefits of adaptation irrespective of the adverse impacts of climate change could be evaluated based on independent benefits criteria (Dolan et al., 2001).

Smallholders selected their preferred adaptation choices from the following options: manure, fertilizer, agroforestry, changing planting dates, increasing land size, decreasing land size, irrigation, mulching, mixed cropping, and conservation agriculture. Thereafter, they evaluated the adaptation choices by assigning scores to the adaptation applied using a five-point scale (1- lowest score and 5 highest-score) with respect to effectiveness, high yield, affordability, farmer implementability, and additional benefit criteria.

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Furthermore, extension officers evaluated the criteria for assessing the efficacy of adaptation by assigning scores to each criterion on a scale of 1 to 5 based on how best they perceived the criterion contributed to a reduction of the adverse impacts of climate variability (Dolan et al., 2001). The average criteria score corresponding to each criterion was divided by the total criteria score and weighted by 10 to derive the criteria weighted score (Cw) for each criterion as follows:

$$\mathrm{Cw} = \frac{\sum_{i}^{n} \mathrm{ACs_i}}{\mathrm{TCs_i}} \times 10 \quad \ldots\ldots 1$$

Where $\mathrm{ACs_i}$ is the average criteria score while $\mathrm{TCs_i}$ is the total criteria score.

Thereafter, the scores assigned by smallholders for the respective adaptation under each criterion was multiplied by the criteria weighted score to derive the weighted sum ($\mathrm{Wsum_{ij}}$) as follows:

$$\mathrm{Wsum_{ij}} = \sum_{i=1}^{n} \mathrm{S_j} \times \mathrm{Cw} \quad \ldots\ldots 2$$

Where $\mathrm{S_j}$ is the score assigned by smallholder i for adaptation j, Cw is the criteria-weighted score (Thi and Chaovanapoonphol, 2014). A proportion of smallholders applied multiple adaptation alternatives at the same time. Therefore, the weighted sum with respect to all the adaptation choices employed by a smallholder was added up to create an index for efficacy. The index for efficacy of adaptation ($\mathrm{Z_i}$) was expressed as follows:

$$\mathrm{Z_i} = \mathrm{MWsum_i} + \mathrm{FWsum_i} + \mathrm{AGWsum_i} + \mathrm{PWsum_i} + \mathrm{INWsum_i} + \mathrm{DWsum_i} + \mathrm{IRWsum_i} + \mathrm{MUWsum_i} + \mathrm{MXWsum_i} + \mathrm{CAWsum_i} \quad \ldots\ldots 3$$

Where $\mathrm{MWsum_i}$ is the weighted sum for manure, $\mathrm{FWsum_i}$ is the weighted sum for fertilizer, $\mathrm{AGWsum_i}$ is the weighted sum for agroforestry, $\mathrm{PWsum_i}$ is the weighted sum for changing planting dates, $\mathrm{INWsum_i}$ is the weighted sum for increasing land size, $\mathrm{DWsum_i}$ is the weighted sum for decreasing land size, $\mathrm{IRWsum_i}$ is the weighted sum for irrigation, $\mathrm{MUWsum_i}$ is the weighted sum for mulching, $\mathrm{MXWsum_i}$ is the weighted sum for mixed cropping and $\mathrm{CAWsum_i}$ is the weighted sum for conservation agriculture.

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The equal interval scale was used in classifying the index for efficacy into three levels (low, moderate, and high) as shown below (Thi and Chaovanapoonphol, 2014):

$$\text{Interval} = \frac{\text{Highest Value} - \text{Lowest Value}}{3} \quad \ldots\ldots4$$

4. Results and Discussion

4.1. Weighted scores for evaluation criteria and adaptation choices

Seven government agricultural extension officers evaluated the following criteria and thereafter the criteria were weighted as per equation 3: effectiveness, high yield, affordability, farmer implementability, and additional benefits. The criteria weighted score is shown in table 1:

Table 1. Criteria weight

Criterion	Weight (Cw)
Effectiveness	3.2
High yield	2.3
Affordability	1.8
Farmer implementability	1.5
Additional benefit	1.2

Source: survey data

Table 1 shows the average score assigned by the seven extension officers for each criterion. It also shows the weighted score for each criterion. In addition, smallholders evaluated each of the following adaptation choices and assigned scores: manure, fertilizer, agroforestry, changing planting dates, increasing land size, decreasing land size, mulching, mixed cropping, and conservation agriculture. The scores assigned by smallholders with respect to each adaptation applied were multiplied by the criteria weighted score to obtain the weighted sum for each adaptation choice under each evaluation category. The summary results are presented in table 2.

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Table 2. Weighted scores for the adaptation choices

Adaptation choices	Effective ness	High yield	Affordability	Farmer implement ability	Additional benefit	Weighted sum	Ranking
Manure	10.9	9.55	7.51	4.73	4.74	37.42	4
Fertilizer	11.94	9.65	6.23	3.81	4.77	36.4	7
Agroforestry	10.2	8.76	6.83	4.13	4.55	34.47	9
Changing planting dates	11.59	9.42	7.58	4.14	4.76	37.49	3
Increasing land size	9.51	9.44	6.35	5.51	4.13	34.94	8
Decreasing land size	7.42	6.17	7.2	4.98	4.04	29.8	10
Irrigation	12.38	10.21	7.13	4.67	4.8	39.2	1
Mulching	10.63	8.84	7.26	5.03	4.8	36.56	6
Mixed cropping	11.2	9.05	7.48	4.49	4.72	36.94	5
Conservation Agriculture	12.04	9.8	7.66	3.78	4.85	38.12	2

Source: survey data

4.1.1. Effectiveness

Table 2 shows the two most effective adaptation choices in reducing maize production losses were irrigation and conservation agriculture. Conservation agriculture improves water holding capacity and reduces evaporation hence facilitating the minimization of the adverse impacts of climate variability (Su et al. (2021)). Verma (2021) also notes that conservation agriculture contributes to the reduction of warming of the atmosphere by sequestering carbon dioxide thereby reducing the vulnerability to the impacts of global warming. Liu and Basso (2020) simulated long-term maize yields using a crop model and confirmed that conservation agriculture reduced yield loss considerably as compared to conventional tillage. On the other hand, irrigation was found to moderate canopy temperature thus enhancing adaptation from heat stress thus suggesting that irrigation was effective in reducing loss in maize production (Moradi et al., 2013). The results suggest that dedicating more land to maize production to the conservation of agriculture and irrigation could be key to minimizing maize losses caused by climate variability.

The least effective adaptation choices were decreasing land size and increasing land size. The results suggest that adjustment of farm size may not be effective in reducing losses in maize production. Increasing maize farm size is associated with the loss of land area covered with trees which leads to an increase in maize yield in the short run and a decrease in the long run (Epule and Bryant, 2015). This is because deforested areas escalate the adverse

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impact of climate change on maize production when such areas become vulnerable to soil erosion and compromise nutrient storage (Khodadadi et al., 2021).

4.1.2. High yield

From table 2, irrigation was also found to contribute the most to high yield followed by conservation agriculture. This finding is consistent with previous studies on irrigation. Moradi et al. (2013) established that irrigation contributed to increased maize yields as compared to baseline values. Olajire et al. (2020) also classified irrigation among adaptation choices that were efficient in improving yields. On the other hand, findings that conservation agriculture contributed to high yields are supported by Su et al. (2021) who established that conservation agriculture enhanced yields and attributed this to the presence of crop residues which facilitated enhanced soil organic matter, water retention capacity and reduction in soil water evaporation and surface runoff. Furthermore, Mutuku et al. (2021) found that conservation agriculture increased yields in low-fertility land. The results suggest that enhancement of irrigation and conservation agriculture could contribute to increased maize production thereby improving food security.

Decreasing land size and agroforestry were found to contribute the least to high yield. The result is supported by Abdulaleem et al. (2019) who established a positive relationship between farm size and maize yield. However, increased yield due to a reduction in farm size could occur if the land used was of high quality (Gollin, 2018). This implies that if low-quality land was reduced, yields would decline. Noack and Larsen (2019) also found that in Uganda yield decreased with an increase in farm size. The finding on agroforestry was not as expected. However, although agroforestry is instrumental in improving microclimate, carbon sequestration, soil fertility, and soil moisture, it may contribute to low maize yields since smaller crops may compete for light, water, and nutrients with the trees (Nyaga et al., 2019). In addition, agroforestry may inhibit the use of machinery during farming due to hindrances by the roots of the trees (Ibrahim et al., 2019). The findings on agroforestry suggest that the provision of technical guidance on agroforestry to smallholders could enhance its adoption and its ability to promote increased yields. For instance, identification of the right tree species to combine with maize production and the right tree species for the respective agroecological zones since results could be site-specific (Raskin and Osborn, 2019). The findings further suggest the need for proper farm planning to enhance positive results.

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4.1.3. Affordability

Table 2 shows that conservation agriculture and changing planting dates had the highest weighted score on affordability. Conservation agriculture was found to significantly reduce the cost of farming since ploughing is not required and it preserves crop cover permanently (Verma, 2021). On the other hand, smallholders' practice of changing planting dates mostly depends on indigenous knowledge (Nyakaisiki et al., 2019). Therefore, it does not require any financial outlay. Waongo et al. (2015) observed that changing planting dates was a low-cost climate change adaptation strategy. Although affordable, smallholders may be challenged in determining when to commence planting. Mugiyo et al. (2021) found that there was no consistency in the dates reported by farmers as the early planting date. The findings suggest that accurate identification of appropriate planting time could facilitate the practice of changing planting dates. Mugiyo et al. (2021) therefore recommended the establishment of a crop calendar to facilitate the selection of planting time with respect to specific crop varieties.

The least affordable adaptation choices were fertilizer and increasing land size. Fagariba et al. (2018) found that fertilizer was less affordable to the majority of farmers even though they acknowledged that it boosted yields. It was therefore ranked low among other adaptation choices such as changing planting dates, agroforestry, manure, irrigation, and growing drought-resistant crops. Other studies (Wushuai et al., 2021; Elise et al., 2020) found that fertilizer costs could be prohibitive leading to low application, especially with an increase in land size. Ndamani and Wanatabe (2016) also established that adaptation to climate change was higher in small farm sizes than in large farms due to cost. In China, the increase in subsidies made fertilizer affordable leading to increased agricultural productivity (Ren et al., 2019). The results suggest that reduction of the cost of farm inputs such as fertilizer could render an increase in land size more affordable to smallholders.

4.1.4. Farmer implementability

Table 2 also shows that increasing land size and mulching had the highest weighted scores for farmer implementability. The results are plausible because the most commonly used mulches are largely available locally from the farms. Some of the materials used include crop residues such as ground nut cover, wheat and paddy straws, dry leaves, grass, bark, sawdust, and compost (Telkar et al., 2017). Mulch is applied artificially or naturally on the surface of the land and therefore is not knowledge-intensive (Ranjan et al., 2017).

Conservation agriculture and fertilizer had the lowest farmer implementability. According to Tadesse (2016), few farmers adopt conservation agriculture due to technical constraints. Conservation agriculture

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also requires specialized equipment, particularly for seeding and planting hence farmers may require training to use them appropriately (Verma, 2021). There could be uncertainties relating to the management of pests, especially for farmers accustomed to conventional tillage (Fanadzo et al., 2018). Smallholders may also need knowledge of sustainable weed management strategies (Lee and Thierfelder, 2017). The findings suggest that although conservation agriculture was found affordable, effective, and contributing to high yield, its adoption is hampered by technological challenges. On the other hand, knowledge of the right time, type, and quantity of fertilizer and the condition of the soil are necessary. Cairns et al. (2021) noted low adoption of fertilizer use among women. In addition, Mideksa et al. (2021) found that the majority of the farmers applied fertilizer below the recommended quantities. However, education was found to improve the intensity of fertilizer usage attributed to the ability of farmers to understand and interpret information (Mideksa et al., 2021). The results suggest that education and capacity building of farmers could enhance proper adoption of conservation agriculture and fertilizer.

4.1.5. Additional benefits

From table 2, conservation agriculture had the most additional benefits followed by irrigation and mulching. Conservation agriculture saves time, reduces production and environmental costs, increases yield, and improves soil quality (Jat et al., 2021). Irrigation also promotes an increase in farm income besides lessening the adverse impacts of climate change (Osewe et al., 2020; Da Cunha et al., 2015). Mulching on the other hand helps to moderate soil temperature, conserves soil moisture, and suppresses diseases and pests (Ranjan et al., 2017). Decreasing the land size and increasing land size were found to have the least additional benefits. Adjustment of land size could be affected by other factors such as the inability of farmers to apply adequate input to boost production in the case of increasing land size (Zhang et al., 2021). The results suggest that a combination of adjustment of land size and other adaptation choices could contribute to the realization of additional benefits.

Overall, conservation agriculture emerged as the most robust adaptation alternative based on the outlined criteria. This result suggests that enhancing smallholders' capacity to adopt conservation agriculture could boost maize production.

4.2. Distribution of smallholders based on the levels of efficacy of adaptation

Results showed that the lowest index of efficacy was 12.4 while the highest was 260.4. The difference between the highest and lowest index of

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efficacy was divided by three to establish the interval scale as 82.6. The interval scale was established in line with Thi and Chaovanapoonphol (2014). Based on the interval scale, the levels of efficacy were defined as follows: low level of efficacy of adaptation (12.4 to 95); moderate level of efficacy of adaptation (95.1 to 177.7), and high level of efficacy of adaptation (177.8 to 260.4). Table 3 shows the levels of efficacy of adaptation for Kitui and Laikipia counties.

Table 3. Distribution of smallholders as per the levels of efficacy of adaptation

Levels of efficacy	Laikipia County		Kitui County		Combined	
	Frequency	%	Frequency	%	Frequency	%
Low	45	54	84	44	129	47
Moderate	32	39	93	49	125	46
High	6	7	13	7	19	7

Source: survey data

Table 3 shows that most of the smallholders reported a low level of efficacy of adaptation (47 percent) while very few (7 percent) reported a high level of efficacy of adaptation. The majority of the smallholders who reported a low level of efficacy of adaptation were from Laikipia County (54 percent) while most of those who reported a moderate level of efficacy of adaptation were from Kitui County (49 percent). However, an equal proportion of smallholders (7 percent) reported a high level of efficacy of adaptation in both counties.

The findings indicate that although Laikipia County is located in the highlands and perceived to have agroecological zones with better potential for maize production than Kitui County, the level of efficacy of adaptation was low for most of the smallholders than in Kitui County. This suggests that there is a possibility that smallholders in areas perceived to have a better potential for maize production might not be practicing intensive adaptation despite the knowledge that climate was changing (Adeagbo et al., 2021). The results are also supported by Mutunga et al. (2017) who found that smallholders in drier areas adopted more than those who resided in wetter areas. This further brings to question the optimality of adaptation, especially where multiple adaptation choices are practiced. For instance, a combination of organic and inorganic fertilizers was found to enhance soil fertility and consequently maize productivity (Roba, 2018). However, the proportion to be applied when they are used in combination to achieve optimal results may not be obvious to smallholders. These results suggest that capacity building on multiple applications of adaptation choices could facilitate the enhancement of the level of efficacy of adaptation to smallholder maize production (Bedeke et al., 2019).

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Conclusion

In Kenya, maize is the staple food for approximately 96 percent of Kenyans hence its adequate production is synonymous with food security. Smallholders supply up to 75 percent of maize produced in Kenya but are affected by unpredictable timing, duration, and distribution of rainfall, especially during the growing season. Further, they experience increasing temperatures, increasing weeds infestation increasing incidents of pests and diseases among other issues. Smallholders recognize that the climate is changing and the majority of them are adapting to climate variability based on imitation, knowledge, and resources at their disposal. However, the outcome is not always as expected. Although the majority of smallholders could be practicing single or multiple adaptations, inappropriate application or wrong selection of adaptation choices coupled with limited knowledge by smallholders could further contribute to low maize yields and consequently financial losses. Thus, the need to evaluate the levels of efficacy of adaptation.

This study takes a departure from previous empirical studies as it undertakes a comparison of two semi-arid areas; one in the highlands and the other in the lowlands. In addition, this study focused on smallholder maize producers and not maize farmers in general, and examined the levels of efficacy of adaptation noting that previous studies in Kenya had mostly assessed adaptation and determinants of adaptation.

The objective of the study was to evaluate the level of efficacy of adaptation of smallholder maize production to climate variability. Primary data on demographic, and socio-economic characteristics was collected directly from smallholder maize producers. A total of 273 smallholder maize producers were sampled through multistage sampling. The respondents were drawn from the Ward level from Kitui South, Rural, Central, and Mwingi Central sub-counties of Kitui County and Laikipia North and East sub-counties of Laikipia County.

The level of efficacy of adaptation of smallholder maize production to climate variability was evaluated based on Multiple Criteria Evaluation. The results showed that on aggregate most of the smallholders reported a low level of efficacy of adaptation while very few reported a high level of efficacy of adaptation. This implies that although the majority of smallholders in the overall sample adapted maize production to climate variability, they did not achieve desired results. Majority of the smallholders who reported a low level of efficacy of adaptation were from Laikipia County while the majority of those who reported a moderate level of efficacy of adaptation was from Kitui County. Evaluation of individual adaptation choices showed that the two most effective adaptation choices in reducing maize production losses and also contributing to high yields were: irrigation and conservation agriculture while the least effective adaptation choices were decreasing land size and increasing

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land size. Decreasing land size was also found to contribute the least to high yield followed by agroforestry. The results also showed that the most affordable adaptation choices were conservation agriculture and changing planting dates while the least affordable adaptation choices were fertilizer and increasing land size. However, increasing land size had the highest farmer implementability followed by mulching while conservation agriculture and fertilizer had the lowest farmer implementability. The adaptation choices perceived to have the most additional benefits were conservation agriculture, irrigation, and mulching while decreasing land size and increasing land size were found to have the least additional benefits.

The study concludes that the level of efficacy of adaptation for smallholder maize production in semi-arid areas was low. The study also concludes that most of the smallholders in areas perceived to have better potential in maize production such as Laikipia County have low levels of efficacy of adaptation in comparison to smallholders in areas with lower maize production potential such as Kitui County.

This study provides evidence that smallholder maize production in semi-arid areas yields a low level of efficacy of adaptation, especially in areas that are considered less vulnerable. Increasing the levels of efficacy of adaptation calls for appropriate selection of the type and combination of adaptation practices by smallholders. The County Governments through the department of agriculture and environment could establish guidelines for a robust combination of adaptation choices. Smallholders may therefore require support from the department in charge of crop production through capacity-building programmes such as; field practical training on effective ways to implement conservation agriculture and irrigation to enhance adoption. The capacity building should also be backed up by policies and incentives such as affordable pricing for the requisite tools and equipment to encourage adaptation choices providing high levels of efficacy. The County Government in areas with a better potential for maize production should sensitize smallholders on the need to augment adaptation even in areas perceived to have fertile soil.

The present study addressed the research gap and contributed to knowledge by evaluating the efficacy of adaptation. Evaluation of adaptation practises could shed more light on why there was insufficient maize production despite adaptation by the majority of the smallholders. The study also explored an alternative approach that could be used in analyzing multiple adaptations to address the challenges faced by most empirical studies assessing adaptation. In addition, the study provided a methodology that can be used in ranking adaptation practises to facilitate policy decisions.

The scope of the present study was to assess smallholder maize production and the results of the analysis may not be generalized for large-

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scale maize production. In addition, the areas of study were mainly semi-arid and results may not be generalized for high-potential areas. Further research could be undertaken on determinants of levels of efficacy of adaptation. In addition, a study on maladaptation in smallholder maize production could explain low levels of efficacy despite adaptation by smallholder maize producers. Furthermore, the study covered the adaptation choices employed by smallholder maize producers and efficacy of the adaptation based on perception. Future studies could explore quantitative evaluation of the adaptation choices.

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