Impact of Climate Variability and Change Adaptation Strategies on Technical Efficiency of Sorghum Production in Manyoni District, Tanzania

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Abstract

Climate variability and change adaptation strategies are increasingly becoming fundamental for improving efficiency in agricultural production in Tanzania and elsewhere in developing countries. However, empirical evidence on how adaptation strategies improve agricultural technical efficiency on drought resistant varieties like sorghum is inadequate in Tanzania. This study was conducted to address this knowledge lacuna in the literature. With cross-sectional research design, we used a household survey to collect data from 330 randomly selected household heads. A Cobb-Douglas stochastic frontier model was used to determine the impact of adaptation strategies on technical efficiency of sorghum production. Farmers adapted a number of strategies including drought tolerant crops, conservation agriculture, drainage system, early maturing crops, use of hired labour, resistant livestock breeds, membership in farmer organizations, access to extension services, and access to credit to cushion climate variability and change impact. Six strategies including use of drought tolerant crops, drainage systems, conservation agriculture, membership in farmer organizations, access to extension services and access to credit showed significant impact on technical efficiency of sorghum production at 5% level of significance. Such strategies were effective in improving technical efficiency of sorghum production. However, about half of the respondents were less efficient. Therefore, farmers' adaptation strategies were indisputably essential in semi-arid environments like Manyoni district. Nevertheless, a policy to heighten use of the effective farmers' adaptation strategies to cushion climate variability and change impact should be devised and effectively executed to strengthen farmers' efficiency.

Keywords: Adaptation strategies, climate variability, climate change, sorghum production, technical efficiency.

Introduction

This study determined the impact of Climate Variability and Change (CV & C) adaptation strategies on technical efficiency of sorghum production. It is undebatable that in this contemporary period, the world is witnessing CV & C. To that effect, the phenomena are increasingly becoming reality such that farmers should successfully learn how to live with them for their survival. The impact of the phenomena on agriculture production and other social-economic activities cannot be underestimated (Escarcha *et al.,* 2018). Scholars like Kihila (2017) argue that the CV & C manifest through a prolonged drought, floods, changes in surface temperature, and rainfall variability and unpredictability. This situation has attracted research attention in recent decades all over the world, not only because of its manifestation but also due to farmers' vulnerability accompanied by lack of adequate adaptation capacities among agricultural communities, more so in developing countries.

Small-scale farmers in developing countries like Tanzania are categorically vulnerable and so are negatively impacted by extreme weather episodes like drought and floods (Lyimo *et al.,* 2021). The impact has so far directly or indirectly affected farmers' livelihoods. Empirical studies also show that over 70% of the farmers living in sub-Saharan Africa have been affected by climate variability and change impact (FAO, 2016). Dependence on rain-fed agriculture exacerbate farmers' vulnerability to the impact of CV & C in the region, implying that the tragedy not only affects farming but also increases levels of poverty in the already vulnerable farming communities. Scholars like Adzawla and Alhassan (2021) argue that the widespread poverty in Africa is attributed to the poor performance of the agricultural sector aggravated by the impact of CV & C.

In Tanzania, climate variability explained by, among other things, changes in rainfall patterns is on the increase and varies enormously within the country, in a year and across years (Kabote *et al.,* 2013; 2017). This makes agriculture particularly in semi-arid environments, risky enterprise (Mkonda, 2017). Research shows that the agricultural sector performance has strong association with changes in rainfall patterns (Belay *et al.,* 2017). In addition, the future performance of this sector depends on the capacity of small-scale farmers to adapt to CV & C (Belay *et al.,* 2017). Therefore, investment in adaptation strategies to obtain a climate-smart food system is a necessary condition to enhance food security amid CV & C (Adzawla and Alhassan, 2021). According to the Intergovernmental Panel on Climate Change (IPCC) (2007), adaptation strategies are long-term and total adjustment of the entire agricultural system; they include: policies, structures, institutions, farming practices, behavior, and livelihood activities.

Literature on CV & C adaptation strategies is increasingly growing (Belay *et al.,* 2017; Mkonda, 2017; Shirima and Lubawa, 2017; Escarcha *et al.,* 2018; Fagariba *et al.,* 2018; Kurgat *et al.,* 2020; Rodenburg *et al.,* 2020; Atube *et al.,* 2021; Damnyag *et al.,* 2021). However, empirical studies modeling Technical Efficiency (TE) of adaptation strategies are limited and therefore causing meagre understanding about this relationship. In this study, TE is considered as an ability of the small-scale farmers to increase sorghum production with the use of available inputs and technology (Gaviglio *et al.,* 2021). Available studies including ones conducted by Roco *et al.* (2017) and Khanal *et al.* (2018) examined the impact of CV & C adaptation strategies on TE with an assumption that adaptation strategies only affect production frontier (output) excluding position of farmers on or beneath the frontier (factors influencing TE). Although such studies are important, they lack farmers' information on the significant factors influencing TE. Therefore, the purpose of this study was to determine the impact of CV & C adaptation strategies on the TE of sorghum production. Sorghum production has been extensively promoted among small-scale farmers owing to its ability to survive in semi-arid environments. It has also low inputs requirements, and it is pest and disease tolerant compared to most staple cereals (Chepng'etich *et al.,* 2015).

Theoretical Grounding: production theory

This study was guided by the production theory which shows a function association between inputs and output. Adaptation strategies were in this study considered inputs while sorghum production was considered an output. The production theory is part of the microeconomic theory and put its contract with the production of goods using a set of inputs (Shantha, 2019). Informed by Shantha (2019), the study adopted a simple production function for a sorghum producer as follows:

Y = f (L, F, S, and C)
where:
Y = sorghum production per season,
L = labour,
F = fertilizer,
S = land and
C = seeds.

This study argues that in a context of climate variability and change, a variable of adaptation strategies need to be factored in the equation to enable the farmer maximize profit either by increasing the output or by reducing the cost of producing the output, which is referred to as efficiency and therefore, the equation becomes Y = f (L, F, S, C and A), where A represent adaptation strategies.

The efficiency of a production unit can be measured in terms of technical efficiency, allocative efficiency, and economic efficiency

(Guth and Smedzik-Ambrozy, 2020). This study used TE, which allows measurements in both output model and inefficiency model (factors influencing TE). Additionally, there are two approaches to measuring TE: output-oriented and input-oriented. The output-oriented approach deals with the question "by how much output could be expanded from a given level of inputs?" In the output-oriented perspective, efficiency is measured by keeping inputs constant (Wassie, 2014). On the other hand, the input-oriented approach deals with the question "by how much can input of quantities be proportionally reduced without changing the output quantity produced?" (Wassie, 2014).

Although TE can be measured by using frontier methodologies that include econometric and non-parametric approaches (Bravo-Ureta and Pinheiro, 2016), the current study used stochastic frontier production (parametric method) to allow determination of both levels of TE that included output model (Production versus inputs) and inefficient model (factors that influence TE). Furthermore, Production theory can be applied in various forms including linear functional form, Cobb-Douglas functional form, polynomial form, Trans-log functional form, and transcendental functional form (Shantha, 2019). This study employed Cobb-Douglass functional form in order to handle multiple inputs, at the same time avoiding multicollinearity problems especially when one includes polynomial terms and interactions (Shantha, 2019).

Methodology

The Study Area

This study was conducted in the Manyoni District which is among the 6 districts in Singida Region. Data collection took place between May and December 2019. The district lies between 6˚7˚S and 34˚35˚E covering an area of 28 620 km², which is about 58% of the entire area of the Singida Region. The district was chosen because it lies within the semiarid areas of Tanzania where prolonged drought has become common (Benedict and Majule, 2015). Rain-fed agriculture dependence exceeds 95% in the district (NBS, 2019). In addition, the district forms part of the semi-arid central zone of Tanzania which experiences low rainfall that ranges from 500 mm to 700 mm per annum with high geographical, seasonal, and annual variations (Sawe *et al.,* 2018; Kabote *et al.,* 2013).

According to the Singida's Socio-economic profile, the number of livestock kept in the eastern part of the Manyoni district is higher than the human population (URT, 2017). The zone has low rainfall averaging between 500 mm to 650 mm per annum (URT, 2017), and it grows maize, sorghum, millet, paddy, groundnuts, cassava, and beans. Furthermore, the Western part experiences low rainfall of 500 mm to 700 mm per year, and it grows maize, millet, sorghum, cassava, sweet potatoes, and groundnuts. Therefore, small-scale farmers have, over the years, adapted several CV & C adaptation strategies such as selling livestock, off-farm employment, supplementing livestock feeds, decreasing quantity, frequency, and diversity of meals, stock movement, wetland farming, petty business (charcoal and firewood selling) and receiving remittances from relatives (Shirima *et al.,* 2017).

Research design, sampling, and data collection methods

The study adopted cross-sectional research design that allowed data collection at a single point in time (Creswell, 2003). The design has a greater degree of accuracy and precision in social science studies as compared to other research designs (Casley and Kumar, 1998). As reported by Kesmodel (2018), cross-sectional studies allow examination of multiple variables and multiple outcomes in a one single study. The study population constituted small-scale farmers producing sorghum. The data collection method was a household survey using a structured questionnaire with closed and open-ended questions. Eight CV & C adaptation strategies were identified during pre-testing of the research tool. They include drought tolerant crops (Sorghum), early maturing crops (Maize), resistant livestock breeds (Local breeds), conservation agriculture (CA), proper food storage, drainage systems, irrigation practices and rainwater harvesting.

We used purposive sampling techniques to select wards that receive low rainfall, hence

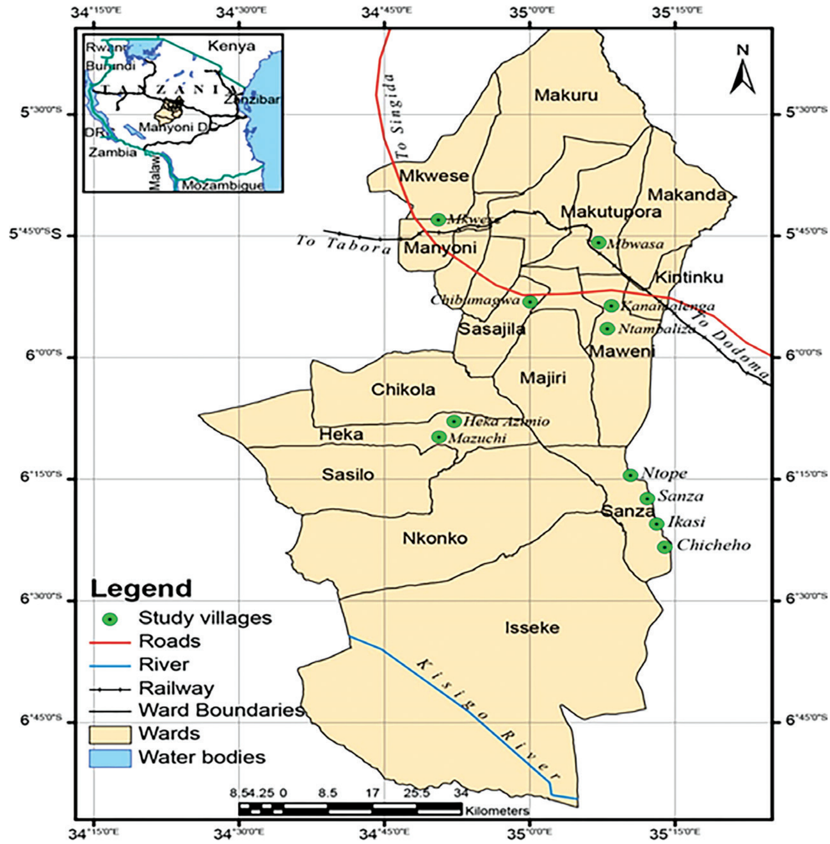

Figure 1 shows sites involved in the study

facing prolonged drought throughout a year. A simple random sampling technique was adopted to select villages and respondents. In 11 villages, a sub-sample of 30 households from each village was randomly selected making a total sample size of 330 for the survey. A minimum sub-sample of 30 in each village was considered adequate because the study population was homogeneous in terms of producing sorghum. For the homogenous population, a minimum sub-sample of 30 selected randomly is a true representative of the population and it is adequate for statistical data analysis (Martinez-Abrain, 2014). Combining the homogeneousness of the population, and the fact that the study used a random sampling technique, which is a rigorous sampling method, the sub-sample of 30 irrespective of the village population size was important to avoid wastage of resources that could occur if proportionate sampling techniques were adopted (Mgoba and Kabote, 2020).

Data processing and analysis

Data analysis was done using both descriptive and econometric methods. The study used measures of central tendency and dispersion such as percentages distribution, mean and standard deviation. In addition, the stochastic frontier model was used to determine the impact of CV & C adaptation strategies on TE of sorghum production. This model was estimated using STATA software version 16. Unlike non-parametric statistical models like data envelopment analytical model, the stochastic frontier model treats deviations from best practice as comprising both random error (white "noise") and inefficiency. The data envelopment analytical model does not explicitly accommodate the effect of data noise, attributing all the deviations to inefficiencies. Furthermore, the data envelopment analytical model does not offer statistical framework for modeling the performance of farms outside the sample, whereas, the stochastic frontier model considers random errors and permits for hypothesis testing on the production structure. To derive the intended analysis, the stochastic production frontier model tested the following hypothesis:

i) H0: Independent variables (adaptation strategies, age, sex, household size, marital status, education, experience, farmers' organization, distance from home to farm, extension services, and credit access) have no impact on the technical efficiency of sorghum production.
ii) Ha: Independent variables (adaptation strategies, age, sex, household size, marital status, education, experience, farmers' organization, distance from home to farm, extension services, and credit access) have an impact on technical efficiency of sorghum production.

According to Aigner *et al.* (1977) and Meeusen and van der Broek (1977), the stochastic frontier model is given as:

$Yi = \beta 0 + \beta Xi + \varepsilon i$ ....(1)

Where *Yi* is the log of output and *Xi* is a 1 x Z vector of input quantities, β is a Z x 1 vector of parameters that are to be estimated, and εi =-*Ui* + *Vi*. *Vi* is assumed to be independently and identically distributed N(0, σ2v) and independent of the *Ui* while *Ui* is a non-negative random variable, assumed to be independently and identically distributed as half-normal; *Ui* ˜ *iid N+ (0,σ2u)*. Equation 1 can be redefined as:

$Yi=f(Xi;\beta)exp(Vi-Ui)$ ....(2)

Where *f(.)* can assume different production functional forms, mostly Cobb-Douglas or Trans-log functional forms. In this study, the Cobb-Douglass functional form is assumed that allow the estimation of input elasticities at constant levels. From equation 2, the TE of the farmer is defined as:

$$TE_i = \frac{Y_i}{Y_{i*}} = \frac{f(X_i;\beta)\exp\,(V_i - U_i)}{f(X_i;\beta)\exp\,V_i} \quad ....(3)$$

Where the numerator is the frontier output and the denominator is the observed output of the farmer. Therefore:

TEi = Exp(-Ui) ....(4)

Further analysis is to regress a set of factors on –*Ui*. Thus,

$$u_{i=}\delta_0 + \sum_{n=1}^{k} \delta_i\, Z_i + e_i \quad ....(5)$$

Where *Zi* is a vector of factors that influence TE and in this study includes climate Adaptation strategies and δi is the parameter estimates of *Zi.* The method of maximum likelihood estimation (MLE) is used to obtain the estimates of the stochastic frontier and the inefficiency model in one step (Battese and Coelli, 1995). Empirically, the output model and the inefficiency model are respectively given as:

Sorghum output = β0+β1 Farmsize+β2 Family labor+β3 Hired labor +β4 Seed+β5 Fertilizer+Vi ....(6)

In the output model, the positive estimated coefficients have a positive relationship with output levels.

Inefficiency = δ0+δ1 Rain water harvest+δ2 Irrigation Practices+δ3 Resistant Livestock Breeds+δ4 Drought Tolerant Crops+δ5Drainage System+δ6Conservation Agriculture+ δ7 Food Storage+δ8 Early maturing Crops ....(7)

The positive estimated coefficients have a positive relationship with inefficiency but the negative estimated coefficient showed a positive relationship with TE.

Multicollinearity test

Multicollinearity occurs when the explanatory variables are highly linearly correlated such that it is quite difficult to differentiate between which independent variable (X) affects the dependent variable (Y) (Farrar and Glauber, 2021). The presence or non-existence of multicollinearity is explained based on the value of the Variance Inflation Factor (VIF). The VIF value of a predictor variable should neither be greater than 10 nor less than 1 (Zach, 2020). It can therefore be concluded that multicollinearity exists if the VIF values exceed 10 or smaller than 1. The results presented in Table 2 showed that there was no multicollinearity since none of the variables had VIF lower than 1 or greater than 10.

Table 1: List and definition of variables

Variable	Definition/Measurements	Expected Sign
Output Model		
Output	Kilograms of sorghum obtained by a farmer in the 2019 season	
Farm Size	Hectares of land cultivated by a farmer in the 2019 season	-
Family Labour	Family member participated in sorghum production 2019 season	-
Hired labour	People hired during the production season of sorghum 2019 season	+
Seed	A kilogram of seed sown in the 2019 season	+
Fertilizer	A kilogram of organic fertilizer used in the 2019 season	+
Adaptation	Adaptation strategies adopted by farmers in the 2019 season	+
Inefficiency model		
Rainwater Harvest	Dummy: 1 if a farmer adopted rainwater harvest and 0 if not	-
Irrigation Practices	Dummy: 1 if a farmer adopted irrigation practices and 0 if not	-
Resistance Livestock Breeds	Dummy: 1 if a farmer adopted resistant livestock breeds and 0 if not	+
Drought Tolerant Crops	Dummy: 1 if a farmer adopted drought tolerant crops and 0 if not	+
Drainage system	Dummy: 1 if a farmer adopted drainage system and 0 if not	-
Conservation Agriculture	Dummy: 1 if a farmer adopted conservation agriculture and 0 if not	+
Food Storage	Dummy: 1 if a farmer adopted proper food storage and 0 if not	-
Early Maturing Crops	Dummy: 1 if a farmer adopted early maturing crops and 0 if not	+
Age	Total number of years of a farmer from birth to the date of interview	-
Education	Total number of years of formal education by a farmer	+
Marital status	Dummy: 1 if a farmer is married and 0 if not	-
Sex	Dummy: 1 if a farmer is male and 0 if not	+
Household size	Total number of family members	+
Home-farm	Distance between the home of a farmer and the farm in kilometres	-
Extension Services	Dummy: 1 if a farmer accesses extension services and 0 if not	+
Farmers Organization	Dummy: 1 if a farmer belongs to a farmers' organization and 0 if not	+
Farming Experience	Total number of farming in years	+
Credit Access	1 if a farmer accessed credit during the cropping season and 0 if not	+

Note: The positive sign (+) means an increase in the variable causes an increase in TE, while a negative sign means an increase in the variable cause a decrease in TE

Table 2: Multicollinearity test

Variable	VIF	1/VIF
household head's Age	1.57	0.637454
Sex of household head	2.52	0.396594
Size of Household	1.29	0.772322
Marital status	2.62	0.382381
Household head's Education Level	1.24	0.803511
Experience in farming	1.78	0.562422
Farmers organization	1.08	0.926044
Distance from home to farm	1.05	0.949190
Extension services availability	1.06	0.939549
Credit access	1.13	0.882769

Results and Discussion

Social-economic and demographic characteristics

The study assessed characteristics of the respondents with the view of understanding demographic and socio-economic profiles. The results presented in Table 3 show typical characteristics of small-scale producers with an average production of 431 kg of sorghum per production season. This average yield is obtained after cultivating an average farm size of 1 hectare, sowing about 6 kg of seeds, applying about 345 kg of organic fertilizer, and using 9 and 5 family members and hired labour respectively.

The socioeconomic characteristics of the farmers show that the average farmer was about 46 years old. This implies that the majority of small-scale farmers were active and energetic working age group who could adopt and practice agriculture innovations including adaptation strategies against CV & C. The level of education of the respondents was low because on average the farmer had 6 years of formal education implying that majority propped out from primary education. The low education level portrayed typical small-scale farmers in rural Tanzania and elsewhere in Sub-Saharan Africa. Because of the extensive livestock keeping, farmers on average moved about 1.68

Table 3: Output, inputs, socioeconomic and demographic characteristics (n= 330)

Variable	Mean	Standard Deviation	Minimum	Maximum
Output & Inputs				
Sorghum output (kg)	431	892	60	1600
Farm size (Hectare)	1	0.51	1	30
Family labour	9	7	4	11
Hired labour	5	4	1	8
Seed (kg)	6	5	1	22
Fertilizer (kg)	345	313	18	1100
Socio-Economic Characteristics				
Age (Years)	46	14	19	90
Education (Years)	6	3	0	13
Home to farm (km)	1.68	1.73	0.25	11
Extension services	0.39	0.48	0	1
Farmers organization	0.12	0.32	0	1
Access to credit	0.11	0.31	0	1

km from home to farm while the farthest farm was 11 km away from farmers' homes. The majority (61%) of the small-scale farmers had no access to extension services particularly for sorghum production. This implies low access to institutional services. Such kind of services are fundamental to improving not only agricultural production but also productivity. Therefore, the conundrum that existed showed policy implication to address it. In addition, 88% were not members of farmer's organizations. This implies that they had limited social capital that is necessary for transfer of agricultural technologies between and among farmer groups. Access to credit was also poor (Table 3). This can be explained by lack of collateral, lack of formal land ownership, and lack of financial institutions in the study area and elsewhere in rural Tanzania.

Farmers' adaptation strategies against climate variability and change

The results in Figure 2 show eight adaptation strategies practiced in the study area. Among which, four were adapted by the majority, including, planting of drought tolerant crops (77%), cultivation of early maturing crops (62.7%), domestication of resistant livestock breeds (54.5%), and conservation agriculture (52.4%). These statistics imply that the most important adaptation strategy was cultivation of drought tolerant varieties like sorghum, and those that matured within a short period of time. These results also imply that farmers were conscious about the impact of CV & C particularly changes in rainfall patterns, which is also reported by Adzawla and Alhassan (2021) and Shirima and Lubawa (2017) in Tanzania.

The results in this study also vindicated Figure 2 keeping of livestock breeds, which were resistant to drought and diseases. Small-scale famers also practiced conservation agriculture as a mechanism to cushion the impact of CV & C. Conservation agriculture was done through mulching, contour farming, and terracing. Similarly, the same adaptation strategies were reported by FAO (2015) and Fagariba *et al.* (2018) in some parts of Tanzania and Ghana, implying that such farmers' adaptation strategies against CV & C impact are becoming widespread in Africa. Their effectiveness may need policy support from the governments, and this is one of the research gaps that need exploration in Tanzania and Africa in general.

Determinants of sorghum production

Three of the input variables in the output model showed positive and significant impact on sorghum production. These variables included farm size, hired labor, and adaptation strategies (Table 4).

Adaptation strategies had highest elasticity of production ($\beta=0.161$, $p=0.042$) (Table 4), implying that an increase in the adaptation strategies against CV & C impact increased sorghum output. These results demonstrate the economic merits of sorghum production and justify the need for small-scale farmers to invest in adaptation strategies to cushion the negative impact of the phenomena. Previous studies including Adzawla and Alhassan (2021) and Zakari *et al.* (2022) in Ghana and Niger respectively showed that the use of more than one adaptation strategies had positive and significant impact on sorghum output because adaptation strategies complement each other

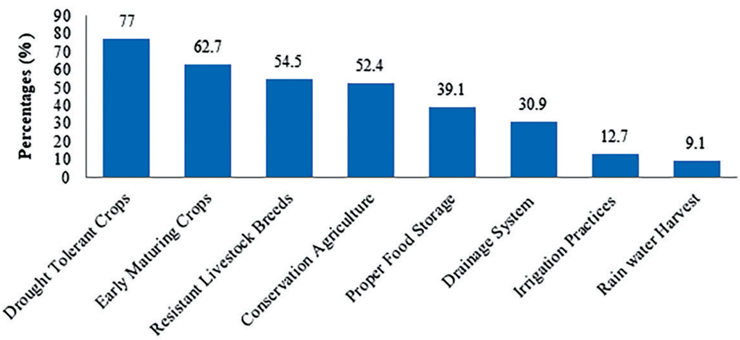

Figure 2: Adaptation strategies (n = 330)

and not substituting each other. This implies that regardless of an ecological zone adaptation strategies are unavoidable for the farmers to survive with CV & C impact.

Farm size showed positive and significant impact on sorghum production (β=0.054, p=0.037) (Table 4). This is interpreted that an increase in farm size increased sorghum output. However, the average farm size was small (1.0 ha), implying that majority of the small-scale farmers practiced farming on a small-scale for subsistence. The size of the farm matters a lot towards quality and quantity of output while keeping other factors constant, and hence efficiency. The results about farm size can also be interpreted that farmers with large farm sizes had prospect to use and allocate maximum available resources efficiently because they do not have land size limitations. Similar results were reported by Alemu and Haji (2016), and Marco (2016) in Ethiopia and Karagwe respectively. Those studies argue that

Table 4: Factors determining technical efficiency of sorghum production

Sorghum Production	Coef.	Std. Err.	z	P>z	Interval]
Output Model					
Farm Size	0.054**	0.050	1.090	0.037	0.152
Family Labor	-0.088	0.078	-1.130	0.260	0.065
Hired Labor	0.130**	0.066	1.970	0.038	0.161
Seed	-0.059	0.059	1.000	0.318	0.175
Fertilizer	-0.065	0.033	-1.980	0.048	-0.001
Adaptation Strategies	0.161**	0.083	1.940	0.042	0.323
cons	6.350	0.331	19.180	0.000	6.999
Inefficiency Model					
Rain water Harvest	0.239	0.284	0.840	0.400	0.795
Irrigation Practices	0.531	0.351	-1.510	0.130	0.157
Resistant Livestock Breeds	0.455	0.207	2.200	0.028	0.860
Drought Tolerant Crops	-0.851**	0.304	2.800	0.005	1.446
Drainage System	-1.160***	0.338	-3.440	0.001	0.498
Conservation Agriculture	-0.387*	0.203	1.910	0.043	0.784
Food Storage	0.013	0.160	0.080	0.936	0.327
Early Maturing Crops	0.419	0.230	1.820	0.069	0.870
Age	0.007	0.006	1.070	0.285	0.019
Sex of Household Head	-1.747***	0.405	-4.320	0.000	0.953
Household Size	-0.120**	0.054	-2.220	0.027	0.014
Marital Status	0.014	0.034	0.420	0.673	0.081
Education	-0.775***	0.270	-2.880	0.004	0.247
Experience	0.011	0.008	1.370	0.171	0.027
Farmers Organization	-0.464*	0.235	-1.970	0.049	0.003
Home-farm	0.151	0.042	3.620	0.000	0.233
Extension Services	-0.961***	0.300	-3.200	0.001	0.372
Credit Access	-0.146*	0.329	-0.440	0.657	0.499
Cons	1.994	0.964	2.070	0.038	3.883

Note: ***, **, * Significant level at 1%, 5% and 10% respectively. Wald Chi^2 (6) = 13.74, Prob > Chi^2 = 0.0327 an increase in sorghum output can be more achieved through an increase in farm size.

The results in Table 4 further show that hired labour positively and significantly contributed to the increase of sorghum output (β=0.130, p=0.038). This implies that households that used hired labour had higher sorghum output than those that only used family labour in the production process. This is attributed to the fact that hired labour acts as an incentive and additional manpower for the household to be more efficient, hence more production. This is in line with previous studies in Ghana and United Kingdom by Kingsmill *et al.* (2019) and Adzawla and Alhassan (2021).

Factors affecting technical efficiency of sorghum production

The second part of Table 4 displays the impact of adaptation strategies on the TE of sorghum production controlled by socio-economic and demographic characteristics. Nine out of eighteen factors showed significant impact on TE, six of them were adaptation strategies, and three were socio-economic and demographic characteristics, implying that apart from adaptation strategies, some socio-economic and demographic characteristics are also fundamental for improving TE in agricultural production, which also need consideration at a policy level.

Adaptation strategies

Six strategies showed significant impact on TE of sorghum production. They include use of drought-tolerant varieties, use of drainage systems, and conservation agriculture (CA), membership in farmer organizations, access to extension services and access to credit. Planting of drought-tolerant crops contributed to TE (β = -0.851, P-value: 0.005) of sorghum production. These were extensively promoted adaptation strategies due to the unpredictable rainfall in recent years that is often accompanied by prolonged drought. The drainage system showed negative significant impact on TE (β = -1.160, p-value; 0.001) (Table 4). This implies that small-scale farmers who practiced drainage systems were more efficient than those who did not. A drainage system involves an effective way of controlling floods through construction of ridges or furrows around farm plots. This is an effective way of improving soil structure and soil fertility.

Expectedly, small-scale farmers who adapted conservation agriculture showed efficiency with a coefficient of -0.387 and a p-value of 0.053. This involved mulching to maintain moisture, contours, and terracing farming to control soil erosion, and minimal tillage of the farm. To that effect, it improved TE of sorghum production. These results are in line with the previous studies including Roco *et al.* (2017) and Adzawla and Alhassan (2021) in Ghana and Chile respectively.

Households with membership in farmer organizations contributed positively and significantly to TE of sorghum production with a coefficient of -0.464 and p=0.049 (Table 4). Farmer organizations play a crucial role in accessing financial support as capital from the government and non-governmental institutions for purchasing some production inputs, which in turn increases TE. Members of farmer organizations had an opportunity to access information, and technology transfer through extension services and even among members themselves through interaction and peer learning processes. Adzawla and Ahassan (2021) and Haile *et al.* (2018), also found similar results in northern Ghana and Ethiopia respectively, implying that farmer organizations are critical for improving production efficiency.

The output of the inefficiency model show that extension service impacted significantly on TE of sorghum production (β = -0.961, p=0.001) (Table 4). This implies that the more small-scale farmers access to extension services, the less the inefficient in agricultural production. This is in line with the work done in Ethiopia by Keba and Milkias (2020) and Haile et al. (2018) who argued that farmers' frequent contacts with extension officers facilitated flow of new ideas on agricultural production.

Access to credit was showed negative sign of inefficiency, hence positive to efficiency (β = - 0.146 and p=0.657) (Table 3.2). This implies that households who had access to credit were efficient in terms of sorghum production than their counterparts. Access to credit reduces farmers' financial difficulties and provide capital to purchase inputs. Chepng'etich *et al.* (2015) and Shumet (2019) in Ethiopia and Kenya respectively also reported similar results.

Socio-economic and demographic characteristics

Three variables significantly contributed to TE of sorghum production. This includes sex of a household head, household size, and level of education of the household head. With regard to sex of the household heads, male-headed households (MHH) positively and significantly contributed to TE of sorghum production with a coefficient of -1.747 and p-value of 0.000 (Table 4). This means that MHH were efficient in the production of sorghum compared to female headed households (FHHs). This is explained that women had limitations on access to information and technologies due to customs, traditions, social norms, and some religious beliefs (Udoh *et al.,* 2020). Traditionally, female do not own productive assets like land thus contributing to low access to credit facilities making them difficult to afford inputs such as seeds, fertilizers, and use of agricultural techniques for production. Similar results were reported by Muhammad (2016).

About household size, it contributed positively and significantly to TE of sorghum production with a coefficient of -0.120 and p-value of 0.027 (Table 4). This suggests that larger households were more efficient. It can be interpreted that larger households provided additional labour force for farming than smaller households. Put differently, a large household increases labour availability for farming, which is usually associated with production efficiency. These results concur with Sedebo *et al.* (2021) and Marie *et al.* (2020) in Ethiopia, who reported that farming operations are labour intensive by nature, therefore it is plausible that a large household can perform farming tasks efficiently and timely.

The coefficient on education level was positive and showed significant impact on TE of sorghum production (β = -0.775; p-value of 0.004) (Table 4). This is interpreted that education level increases households' capacity to utilize existing agricultural technologies and attain higher efficiency levels. Households with literate household heads showed better efficiency than their counterparts. This implies that as the education level increases, information acquisition and adoption of modern agricultural technologies that eventually contribute to TE of production, also increases. This positive relationship was also observed in the southern Ethiopia by Haile *et al.* (2018) and Sedebo *et al.* (2021), who argued that formal education improves human capital because of an increased capacity to choose among available production techniques, and properly allocate homemade and purchased inputs. Therefore, it is apparent that adaptation strategies are essential in the era of CV &C. Even though, farmers' efficiency to improve agricultural production is also sustained by socio-economic and demographic characteristics like sex of the household head, household size and education level of the household head.

Technical efficiency scores of small-scale farmers

The findings on efficiency scores show that there were a wide range of differences in TE among sorghum small-scale farmers in the study areas. The TE among small-scale farmers ranged from 17.56% to 96.77% (Table 5). The mean TE of sampled small-scale farmers during the survey period was 70.62%. This wide variation in small-scale farmer TE levels is in line with a previous study in southern Ethiopia (Haile *et al.,* 2018).

Table 5: Summary statistics of estimated technical efficiencies

Description	Technical efficiency estimates
Minimum	0.1756
Maximum	0.9677
Mean	0.7062
Standard deviation	0.205
Skewness	-1.407

The wide disparity in TE levels among small-scale sorghum producers implies that there was a room for improving the existing level of sorghum production by enhancing the level of farmers' TE. Furthermore, the mean level of TE suggests that the level of sorghum output of sampled small-scale farmers can be increased if appropriate policy measures are considered. In other words, there is a likelihood to increase sorghum production through promotion of effective adaptation strategies.

Table 6 show that 46.37% of the sampled small-scale farmers operated below the overall mean level of TE, while 32.12% operated at the TE level above 90%. Furthermore, findings show that more than half (53.63%) of the small-scale sorghum producers operated above the overall mean level of TE. This implies that a large number of farmers were less efficient in terms of sorghum production and therefore needed policy support to be able to adapt and successfully leave with CV & C impact. These findings are in line with Haile *et al.* (2018) and Sienso *et al.* (2021) in Ethiopia and Ghana respectively.

Table 6: Frequency distribution of the range of individual technical efficiency levels

Range of TE (%)	Frequency	Percent
≥ 40	19	5.76
41 – 50	31	9.39
51 – 60	47	14.25
61 – 70	56	16.97
71 – 80	37	11.21
81 – 90	34	10.30
≤ 91	106	32.12
Total	**330**	**100**

Conclusions and Recommendations

Adaptation strategies against CV & C impact and TE are critical for agricultural production, particularly in semi-arid environments like Manyoni, in the era when CV & C are widespread. In this study, CV & C adaptation strategies were effective in improving sorghum production efficiency in Manyoni district. Six out of eight CV & C adaptation strategies improved TE of sorghum production. This includes use of drought tolerant varieties, use of drainage systems, conservation agriculture, availability of extension services, credit accessibility and membership in farmer organizations.

Overall, farmers TE levels were high, and this should be maintained and improved. This is possible through policy development that promote and support farmers' adaptation strategies against CV &C focusing on those with significant impact on TE of crop production. Since small-scale farmers seek to maximize output and so surviving with the negative impacts of CV & C, it is essential for them to adapt more than one adaptation strategies, particularly those, which showed significant impact.

Specifically, a policy should focus on improving extension services in rural Tanzania to facilitate dissemination of new agricultural technologies. Currently, Tanzania faces a number of challenges with regard to extension services. Some of the challenges are related with poor efficiency of the extension officers themselves while others are administrative. Although extension officers work in the agricultural sector, they are under the President's Office Regional Administration and Local Government. With that they have been reported in different parts of Tanzania dealing with administration at a village level instead of technically supporting farmers to efficiently produce. It should be also a policy issue to encourage farmers to form and join farmers' organizations and or cooperatives. On credit access, funds should be allocated (special fund) for the small-scale farmers to access credit with no or minimal stringent conditions.

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