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The Level and Determinants of Technical Efficiency of Smallholder Farmers in Maize Intercropping and Monocropping in Tanzania

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Abstract: The study focused on examining and comparing the level and determinants of technical efficiency among maize smallholder farmers in maize intercropping options and maize monocropping in Tanzania on 5595 households (1323 in 2010, 1680 in 2012, 1219 in 2014 and 1373 in 2020) from the 2010/2011 to 2020/2021Tanzania National Panel Surveys data that were considered cross-sectional following the limited panel structure due to sample splitting, attrition and refreshment. By using a one-step Translog stochastic frontier model, the results revealed that, household that intercropped maize and legumes are consistently more technically efficient, with efficiency increasing from an average of 57% in 2010/11 to 76% in 2020/21 relative to54.2% to 67.4% in maize monocropping and 54% to 67% in maize and other crops. Concurrently, the trend was volatile in maize monocropping and decreasing in maize production regardless of the technology (72% to 62% respectively). Throughout the study, male-headed household emerges more efficient than female-headed households. Household joint farming decisions, agriculture as main occupation, livestock ownership reduce inefficiency in maize and legumes and maize monocropping, land ownership, secondary education or above reduce inefficiency in maize monocropping, household size and improved seed reduce inefficiency in maize and legumes, extensions services and irrigation reduce inefficiency in maize and other crops. Farming machinery reduces inefficiency, while environmental shocks and age increase inefficiency in all maize cropping systems. Government should promote maize and legumes intercropping as a strategic method, easy smallholder access to farming machinery, promote household joint decisions and attract young farmers in agriculture through subsidies.

Keywords: Technical efficiency, maize-monocropping, maize-intercropping, Legumes, smallholder-farmers

1.0 Introduction

Technical efficiency means attaining the maximum possible output from a given set of inputs (Farrell, 1957). In agricultural grounds, a farm or farming household is considered relatively more technically efficient if it can produce maximum output from the given similar technology and inputs. Smallholder farmers exhibit low technical efficiency globally, with the rates being relatively higher in North America 76% compared to Asia and Oceania, 74%, Europe 73%, Africa 70% and South America, being the least, 59% (Ruzhani & Mushunje, 2025). This indicates ample room for farmers to improve agricultural productivity from the same available resources by 24 - 41% globally.

Smallholder farmers in Tanzania and other developing countries are already vulnerable to low productivity emanating from reliance on traditional inputs, limited adoption of improved technologies and other systemic constraints (MoA, 2025; Ruzhani & Mushunje, 2025; URT, 2021b). Nevertheless, low productivity originating from low technical efficiency continues to worsen their livelihood (Ruzhani & Mushunje, 2025; Selejio et al., 2018). To increase production, farmers have been opting to adopt unsustainable farming methods such as land clearing to expand farming areas and shifting cultivation, which not only puts the environment at risk but also their livelihood (Selejio et al., 2018).

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Understanding the critical roles of improving agricultural technical efficiency to smallholder farmers' welfare, Tanzanian policies continue to clearly advocate the need of improving agricultural productivity and technical efficiency (MoFP, 2021; URT, 2020). However, the average technical efficiency of smallholder farmers in the country still lags behind the maximum potential (Achandi et al., 2018; Kasambala, 2025; Lutonja, 2023; Ng'Atigwa et al., 2022; Sesabo, 2025). This continues to expose the majority to poor livelihood.

Maize which is the dominant food crop and a significant source of livelihood to the majority, its productivity is approximately 2 tonnes per hectare lower than the maximum potential of 5 tonnes per hectare (Jesse & Ngowi, 2024; Kadigi et al., 2025). Further, while there are increasing efforts in promoting the adoption of intercropping technology as an effective technology in improving crop productivity, little is empirically known regarding the level and determinants of technical efficiency in different maize intercropping options, relative to maize monocropping in Tanzania. Existing studies such as Kasambala (2025), Sesabo (2025), Miho (2017) have focused on maize production in general, only a study by Selejio et al. (2018) differentiated technical efficiency between farming households that applied land conservation technologies including intercropping relative to those who did not adopt it in maize production. Yet it may be misleading to assume that all maize intercropping options are equally technically efficient, hence inappropriate efforts and policies to improve smallholder's livelihood.

Globally, whether intercropped farms are more technically efficient to monocropped farms remains unclear. While studies in Western Africa through the stochastic frontier model established that farmers who intercropped maize were more technically efficient to maize monocropping. A study by Baruwa & Familusi (2019) in Osun State, Nigeria found farmers that intercropping maize and lemon were 75% technically efficient on average, relative to 69% in maize monocropping. Also, Olubunmi-Ajayi et al. (2023) found maize-cassava intercropping were 89% technically efficient, maize-yam 82%, and maize monocropping 76%. On the other hand, a study in Kenya by Kibaara (2005) through stochastic frontier also found farmers who practices maize monocropping were more technically efficient 57.7% relative to those that intercropped maize 48.10%.

On the determinants of technical efficiency to smallholder maize farmers, also the socio- economic, demographic and institutional factors displays mixed results. Age of the household head is insignificant in maize production for both maize intercropping and monocropping (Baruwa & Familusi, 2019; Olubunmi-Ajayi et al., 2023). Similar results were established by Mustapha & Salihu (2015) in maize intercropping. Focusing on maize production regardless of the technology used Kehinde et al. (2024) and Elham et al. (2023) also found the link is insignificant, Tumuri et al. (2024) and Belete (2020) established that older farmers increase technical efficiency, with Tummuri et al. arguing that experienced farmers have proper farm management techniques and are more competitive in allocating farm resources. Differently, Anang et al., (2022) established that young farmers in Ghana were more technically efficient. This makes the role of age uncertain in maize production. Education level of the household head also has mixed impacts: Olubunmi-Ajayi et al. (2023) found that education significantly increased technical efficiency in maize-yam intercropping, but insignificant in maize-monocropping and maize-cassava intercropping. Baruwa & Familusi (2019) established that education is insignificant in both maize monocropping and intercropping. Regardless of the technology used, Belete (2020) found the link was insignificant, Elham et al. (2023) and Anang et al., (2022) found education significantly increased inefficiency, with Anang et al., (2022) pointing that education makes agriculture a part-time activity, thus inefficient. On the contrary, Tumuri et al. (2024) and Kehinde et al. (2024) established that education significantly increased efficiency, with Tumuri et al. (2024) arguing that education provides skills to produce efficiently.

Gender of the household head: according to Baruwa & Familusi (2019) gender is insignificant in explaining technical efficiency in both maize monocropping and maize intercropping. Focusing on maize production regardless of the technology, similar results were established by Kehinde et al. (2024) in Nigeria, while Belete (2020) in Ethiopia found male heads increased technical efficiency relative to their female counterpart, through investing most of their resources such as time in agriculture for it is considered a male-based activity. Household size: a study by Olubunmi-Ajayi et al. (2023) in Nigeria established that household size significantly increased technical efficiency in maize monocropping and intercropping, Baruwa & Familusi (2019) found it is insignificant in both maize monocropping and intercropping, and Mustapha & Salihu (2015) found it significant in maize intercropping. Regardless of the technology used, according to Anang et al. (2022), household size significantly reduces efficiency through in optimal use, and linked it to having more dependents than active labourers. On contrary, a study in Ethiopia by Tumuri et al. (2024) found the link was insignificant, while Elham et al. (2023) and Kehinde et al. (2024) reported that household size significantly increased efficiency in maize production with Kehinde et al. (2024) justifying that households with large household size and few dependents will efficiently utilize family labour to meet their maize consumption.

Farming experience: a study by Olubunmi-Ajayi et al. (2023) reported that farming experience significantly increases technical efficiency in maize-cassava, and was insignificant maize monocropping and maize-yam intercropping, while Baruwa & Familusi (2019) found it insignificant in both maize monocropping and maize intercropping. However, Mustapha & Salihu (2015) reported a positive and significant link in maize intercropping farms in Nigeria. Without considering the technology, Kehinde et al. (2024) and Elham et al. (2023) found experience increased efficiency. Land ownership: according to Belete (2020) and Tumuri et al. (2024) land ownership increases technical efficiency, because it attracts devotion of their maximum time and efforts in their farm production. On the other hand, Baruwa & Familusi (2019) found land ownership security significantly increased technical efficiency in maize intercropping and was insignificant in maize monocropping. Livestock ownership: according to Belete (2020) and Tumuri et al. (2024) households with large number of livestock were technically more efficient in general maize production relative to those with few livestock, both arguing that livestock provides oxen power during farm tilling and threshing, provides manure, used for transportation, and stand as a security in terms of food and income in case of crop failure. On the other hand, Geffersa (2024) reported that livestock ownership is insignificant in explaining maize production. Thus, the impact of resource ownership is also uncertain.

Extension services: Mustapha & Salihu (2015) found that access to extension services significantly increased technical efficiency in Nigeria in maize intercropping farms; similar results were attained by Baruwa & Familusi (2019) in maize intercropping, and the link was insignificant in maize monocropping. On the other hand, Tumuri et al. (2024), by Kehinde et al. (2024) and Elham et al. (2023) established a positive significant link in general maize production; with Belete (2020) establishing the insignificant link in Ethiopia. Kehinde et al. (2024) point that access to extension exposes farmers to better farming technologies and farm management methods that increase efficiency. The link between farmers' access to credit and technical efficiency is also uncertain. A study by Olubunmi-Ajayi et al. (2023) highlighted that access to credit significantly increased technical efficiency in maize monocropping and in maize-cassava, but was insignificant in maize-yam intercropping. Mustapha & Salihu (2015) also found the link was insignificant in maize intercropping. The insignificant link was also established by Adzawla & Alhassan (2021), Anang et al., (2022) and Kehinde et al. (2024) in general maize production, while Belete (2020) and Elham et al. (2023) found it significantly increases efficiency, with Elham et al. (2023) highlighting that credits provide additional farm working capital that facilitates on time purchases of inputs which leads to efficiency.

The impact of off-farm income on technical efficiency is also contradictory. While Mustapha & Salihu (2015) found the positive and significant link in maize intercropping, Geffersa (2024) found that it increases inefficiency, pointing out that engagement in off-farm activity reduces both labour and managerial skills required for maize production. Further, Tumuri et al. (2024) highlight that off-farm income is insignificant in explaining technical efficiency in maize production, which confuses the conclusion about its influence on technical efficiency in maize production. Distance to the market is another factor that is reported to affect technical efficiency in maize production. According to Elham et al. (2023), distance to the market significantly reduces technical efficiency, as the distance limits easy access to farming inputs and extension services. The results are different from Adzawla & Alhassan (2021) and Belete (2020), who established the insignificant link. Household assets are also considered an essential determinant of technical efficiency in maize production. While Kehinde et al. (2024) found that having many assets is insignificant, Geffersa (2024) found it increased technical efficiency to users of traditional maize seeds and is insignificant users of improved seeds, arguing that farmers who did not use improved maize seed will use income from their assets to purchase inputs and increase efficiency.

The role of involving women in key farming decisions on technical efficiency: A study by Seymour (2017) in Bangladesh by using 2011-2012 plot-level survey data covering 4,026 plots from 3,119 households, through a stochastic frontier production function found that, reduced gender differences correlated with a high level of technical efficiency; spouses' joint management of plots, together with male sole control of plots, were significant in influencing efficiency. Similarly, Aung et al. (2021) in Myanmar employed Data Envelopment Analysis to estimate efficiency and bootstrapped truncated regression to estimate determinants of efficiency in 404 smallholder fish farmers. The study found that involving women in decision-making significantly influenced efficient use of inputs and improved the fish farm performance, suggesting the need for interventions to improve technical efficiency. On the other hand, a study by Mobarok et al. (2021) in Bangladesh rice farmers used cross-sectional data and employed a non-parametric Malmquist method and OLS bootstrap regression model on 1197 households. The study found that enhanced women's decision-making power in agriculture was linked to higher levels of farm production, farm efficiency, and technological change, but was insignificant in scale efficiency; thus, it significantly increased production, efficiency and technological change.

Generally, mixed results are evident from the reviewed literature on the level of technical efficiency between maize monocropping and intercropping. Similarly, almost all the determinants of technical efficiency in maize production displayed uncertain results, limiting drawing global conclusion of their impacts on technical efficiency and the formulation of the general policies for improving smallholders' efficiency, which highlights the need for context-specific analysis to improve the performance of smallholder farmers context-wise. In addition, there is scant literature on the impact of involving women in key farming decisions on the technical efficiency, and those that are available are Asian based, making their role less known in Africa and Tanzania in particular and thus limits drawing global conclusions. In addition, most of the reviewed literature used non-parametric models (DEA and Malmquist); this study adds to the literature through the use of a parametric stochastic frontier model, focusing on maize and legumes intercropping, maize and other crops intercropping and maize monocropping in Tanzania.

This study, therefore, compares technical efficiencies in maize and legumes intercropping, maize and other crops intercropping and maize monocropping to see whether legume-based intercropping special benefits, such as being a natural repellent to cycles of pests and diseases, a natural nitrogen fixer in soil, and non-competitive in resource demand (Chitara et al., 2024; Yimer et al., 2025; Zhou et al., 2025) translate into relatively higher levels of technical efficiency. This will provide insightful guidance to agricultural policymakers and stakeholders in allocating resources appropriately to improve technical efficiency while promoting intercropping based on the efficiency gaps, and hence improve smallholders' livelihood. Also, while there are various studies on technical efficiency in Tanzania, examining the current level and its determinants remains of great potential, since available literature displays great variation across regions and crops. Thus, this study takes the advantages of the limited panel structure of the Tanzania National Panel Surveys (TNPS), to establish the country-wise trend and variations from 2010 to 2020 agricultural years.

The rest of the study is organised as follows. Section 2 presents the theoretical and empirical literature; Section 3 explains the methodology of the study (theoretical framework, data used, the dependent and independent variables and the empirical model). Section 4 presents the study findings and discussion of the results, and Section 5 presents the conclusion and policy implications.

2.0 Material and Methods

2.1 Data Source

To achieve this objective, the study uses the four waves of the Tanzania National Panel Surveys (TNPS) which are nationally representative collected in 2010/11, 2012/13, 2014/15, and 2020/21, collected by the National Bureau of Statistics (NBS) in collaboration with the World Bank under the Living Standards Measurement Study–Integrated Surveys on Agriculture (LSMS-ISA) program. The surveys provide fundamental household socio-economic and demographic information, and detailed agricultural data collected at the household level and plot level, specifying crops grown, the agricultural technologies, production inputs, enabling comprehensive analysis of the farming households. The sample sizes for this study are 5595 farming households from 1323 in 2010, 1680 in 2012, 1219 in 2014 and 1373 in 2020 that produced maize as their main crop and harvested as shown in Table 1.

Table 1: Sample size used to achieve the objective of this study

Year	Household Interviewed	Households that produce maize as their main Crop and harvested	Households that intercropped Maize and legumes (MLI)	Households that intercropped Maize and other crops (non-legumes)	Households that practised maize monocropping
2010	3,924	1323	655	209	459
2012	5,010	1680	898	248	534
2014	3,352	1219	690	190	339
2020	4,709	1373	597	142	634
Total		5595	2840	789	1966

Source: NBS, 2014; 2017; 2022, and Author's compilation, 2025

2.2 Data analysis

To analyse the level of technical efficiency and its determinants in maize and legumes intercropping, maize and other crops intercropping and in maize monocropping, following the unbalanced structure of the panel dataset arising from farming household splitting and attrition over survey years (2010/11 to 2012/13) and sample refreshment in the two recent waves 2014/15 to 2020/21 (NBS, 2014; 2017; 2022), the study considers each survey as cross-section and therefore both yearly and pooled analysis are performed. Pooling yearly data improves sample size and increases the accuracy of the results (Wooldridge, 2010). Both descriptive statistics and econometric estimates are performed, and the study also accounted for robust standard errors clustered at the household level to control possible intra-household correlation (StataCorp, 2021; Wooldridge, 2010). The interquartile range (IQR) for univariate data was adopted to control outliers (Agathokleous et al., 2025). IQR is considered appropriate in highly skewed data. Thus, only the right-skewed outliers were identified and handled; this reduced the average mean as most of the household farm income, for example, concentrated to the left (lower end), but a logarithm was used to normalise the difference.

In estimating technical efficiency, the study adopted a parametric stochastic frontier model that takes into account the random disturbances in production, unlike the non-parametric data envelopment analysis (DEA), though both are common methods in estimating efficiency (Coelli, 1996; Lovell, 1993). The choice of the model is based on the stochastic nature of the agricultural production (Campbell & Hand, 1998). Specifically, the Translog stochastic production frontier model is used following the likelihood ratio (LR) test statistics results, where we rejected the null hypothesis that the Cobb-Douglas frontier production function fits the data (all the squared and interaction variables have zero impacts (H_0:δ_ij=0)) as the p-values were strongly statistically significant less than the given 0.05. The Likelihood ratio test is based on equation (1).

$$LR = -2[\ln\{L(H_0)\} - \ln\{L(H_1)\}] \qquad (1)$$

Where $\ln\{L(H_0)\}$ and $\ln\{L(H_1)\}$ indicate the log likelihood values under the null and alternative hypotheses corresponding to the Cobb-Douglas function and the Translog function, respectively (Coelli et al., 2005). The study used one-step maximum likelihood estimation (MLE) approach in STATA 17 as insisted by Battese & Coelli (1995) and Wang & Schmidt (2002) to avoid the endogeneity problem prevailing in the two-step approach.

2.2.1 Theoretical presentation of the model to be estimated

Theoretically, the analysis is based on the stochastic frontier production function analysis (SFA) proposed by Aigner et al., (1977) and Meeusen & van Den Broeck (1977) and modified by Battese & Coelli (1995), and presented as follows;

$$TE_i = \frac{Y_i}{Y_i^*} = \frac{f(X_i;\delta) * \exp(v_i - u_i)}{f(X_i;\delta) * \exp(v_i)} = \exp(-u_i) \qquad (2)$$

Where $f(X_i;\delta) * \exp(v_i - u_i)$ represents the actual-observed ith farming household production accounting for inefficiencies, both random and producer inefficiencies, and $f(X_i;\delta) * \exp(v_i)$ represents the frontier production without inefficiencies within the control of the producer. v_i are the random shocks or disturbances such as natural disasters and climate change that are out of the ith farming household's control, and are assumed to be independently and identically distributed (N (0, σ_v^2) and u_i are the inefficiencies within the ith farming household control, such as in-optimal use of agricultural inputs, and assumed to be a non-negative, with a half-normal distribution (N (0, σ_u^2) and distributed independently of the random shock v_i.

Further, the inefficiencies that are within the ith farming household is based on equation (3);

$$U_i = \gamma_0 + \sum_{j=1}^{n} \gamma_j Z_{ij} + \epsilon_i \qquad (3)$$

Where γ_s are the unknown parameters to be estimated, Z_{ij} is a vector of the jth features characterising the ith farming household responsible for technical inefficiency, such as education and access to credits, and ϵ_i represents the normally distributed random error and U_i stands for the technical inefficiency of the ith farming household in producing maize.

2.2.2 Empirical presentation of the model

Empirically, the estimation is based on the Translog stochastic production frontier model in equation 2, following the LR test explained above.

$$lnY_i = \delta_0 + \delta_1 lnX_{1i} + \delta_2 lnX_{2i} + \delta_3 lnX_{3i} + \delta_4 lnX_{4i} + \delta_5 lnX_{1i}^2 + \delta_6 lnX_{2i}^2 + \delta_7 lnX_{7i}^2 + \delta_8 lnX_{8i}^2 + \delta_9 lnX_{1i} lnX_{2i} + \delta_{10} lnX_{1i} lnX_{3i} + \delta_{11} lnX_{1i} lnX_{4i} + \delta_{12} lnX_{2i} lnX_{3i} + \delta_{13} lnX_{2i} lnX_{4i} + \delta_{14} lnX_{3i} lnX_{4i} + v_i - u_i \qquad (4)$$

Where ln stands for the natural logarithm, Y_i stands for the farm Revenue/income of the ith farming household in Tanzanian shillings (Tshs). The choice of farm revenue over output is based on the complexity of computing representative outputs in a maize intercropped farm with legumes or other crops that differ in measurement. A similar approach was used by Baruwa & Familusi (2019) in Nigeria. X_{1i} stands for the harvested area in acres, X_{2i} stand for the family labour in man-days, X_{3i} stands for the employed farm labour cost in Tanzanian shillings (TSH), X_{4i} stand for the farms resources/inputs costs (fertilizers, herbicides/insecticides, seed) in Tanzanian shillings (TSH). $\delta_0 - \delta_{14}$ are the unknown parameters to be estimated, v_i stand for the random disturbances and u_i represents the technical inefficiency error. Further, in estimating the technical inefficiency empirically, the following model is specified from equation (3);

$$U_i = \gamma_0 + \gamma_1 Z_{1i} + \gamma_2 Z_{2i} + \gamma_3 Z_{3i} + \gamma_4 Z_{4i} + \gamma_5 Z_{5i} + \gamma_6 Z_{6i} + \gamma_7 Z_{7i} + \gamma_8 Z_{8i} + \gamma_9 Z_{9i} + \gamma_{10} Z_{10i} + \gamma_{11} Z_{11i} + \gamma_{12} Z_{12i} + \gamma_{13} Z_{13i} + \gamma_{14} Z_{14i} + \gamma_{15} Z_{15i} + \gamma_{16} Z_{16i} + \gamma_{17} Z_{17i} + \gamma_{18} Z_{18i} + \gamma_{19} Z_{19i} + \gamma_{20} Z_{20i} + \gamma_{21} Z_{21i} + \epsilon_i \quad (5)$$

Where U_i represents the technical inefficiency of the ith farming household in producing maize or maize and legumes or maize and other crops intercropped. $\gamma_0 - \gamma_{21}$ stand for the coefficients of unknown parameters to be estimated, $Z_{1i} - Z_{21i}$ stand for the variables that characterise the ith farming household and are responsible for the technical inefficiency and ϵ_i stands for the random disturbances. Z_{1i} stands for the age of the household head in years, Z_{2i} represents the household size in numbers, Z_{3i} stand for female sole farming decisions; binary (1 if yes, 0 otherwise), Z_{4i} represents household joint farming decisions; binary (1, yes, 0 otherwise), Z_{5i} is access to extension services; binary (1 if yes, 0 if no), Z_{6i} stands for if the farming household owns land cultivated; binary (1 if yes, 0 if no), Z_{7i} represents the household head level of education; binary (1 if secondary and above education, 0 if primary or less education), Z_{8i} represents a household that considers agriculture as their main activity; binary (1 if yes, 0 if no), Z_{9i} stands for the household value of their farm machinery; continuous and in Tanzanian shillings, Z_{10i} represents the household with wage income, Z_{11i} represents a household with a business/self-employed job, Z_{12i} stands for the household use of irrigation on their farm, Z_{13i} stands for the household ownership of livestock; $Z_{10i} - Z_{13i}$ are binary (1 if yes, 0 if no), Z_{14i} represents the number of plots owned by the farming household; continuous (in numbers), Z_{15i} stands for the ith farming household distance to the market; continuous (in kilometres), Z_{16i} stands for the household's access to credits, Z_{17i} represents whether the household received financial assistance from the government or a non-government organisation, Z_{18i} stands for if the household experienced any environmental shocks such as pests, floods or droughts, Z_{19i} represents whether the household used pesticides/insecticides, Z_{20i} stands for if the household used improved seeds, and Z_{21i} represents whether the ith farming household used fertilisers in their farms $Z_{16i} - Z_{21i}$ are binary taking the value of 1 if yes and 0 if no, respectively.

Besides, we adopted a paired-sample statistic test to analyse existence of differences in mean technical efficiency between in each maize cropping system across years and gender, with the null hypothesis of absence of mean differences between the paired observations, where if the p-value is less or equal the given 0.05 critical value, we reject the null hypothesis as used by Oyetunde-Usman & Olagunju (2019) and Oyakhilomen et al. (2015) in food security.

3.0 Results and Discussions

The first section of this part presents the descriptive statistics based on the socio-economic, demographic, and access to institutional services, and the second section presents the factors affecting production, the distribution level, and mean differences of technical efficiency between paired observations and factors behind the technical inefficiency in maize and legumes intercropping, maize monocropping and maize and other crops intercropping.

3.1 Descriptive statistics

The socioeconomic, demographic and status of accessing social institutions' services of smallholder maize farming households in Tanzania are presented in Table 2. The average age of the household head is relatively high in maize intercropping households, 47-50 years in maize and legume intercropping, 47-53 years in maize and other crops intercropping, compared to 44-47 years in maize monocropping. This is expected as more experienced farmers are more likely to intercrop to minimise production risks relative to younger ones. However, in all maize cropping systems, the age range indicates the presence of experienced and active household heads that may increase technical efficiency (Tumuri et al., 2024).

It is also evident that households that intercrop maize have a higher household size, around 6 people in maize and legumes intercropping and maize and other crops intercropping, while in maize monocropping, are approximately 5 throughout the study time (2010-2020). This possibly reflects more technically efficient intercropping options, as argued by Elham et al. (2023) and Mustapha & Salihu (2015), that large household size is an essential source of readily available farm family labour, reflecting itself in improving farm efficiency. Education improves the human capital at the individual and national levels. However, the rate of households' heads with secondary education and above is still very low in Tanzania. This study established that only 6 to 10%, 5 to11% and 6 to12% of the farming household heads in maize and legumes, maize and other crops intercropping, and in maize monocropping had attained secondary or above education, respectively, over the study period. Highly educated farmers are more likely to allocate resources efficiently due to increased capacity and exposure (Belete, 2020) and thus are expected to influence technical efficiency.

Moreover, more than 84%, 86% and 79% of the household heads in maize and legumes, maize and other crops intercropping, and in maize monocropping, respectively, consider agriculture as their main occupation over the study time. Agriculture as the main means of livelihood is expected to positively influence technical efficiency to increase farm productivity and improve their livelihood. In addition, in all maize cropping systems and over the study time, more than 40% of the household heads engaged in wage employment and more than 30% in other self-employed activities. The rate of engagement in the non-farm activities displays improvement over time from 2010 to 2020; this may either improve farm technical efficiency by financing it or be detrimental by reducing resources like the labour force.

Regarding land ownership, about 88-95% of farming households cultivated their own land in maize and legumes, relative to 87-95% in maize and other crops intercropping and 80-93% in maize monocropping, but the rates of land ownership decrease over time in all maize cropping systems in this study. The majority of the maize and legumes farming household own livestock in this study, 39-51% relative to 36-48% in maize and other crops intercropping and 30-38% in maize monocropping. Owning livestock facilitates timely farm management, such as ploughing, threshing, and sometimes as a transportation means (Tumuri et al., 2024), which is expected to increase farm efficiency. Also, ownership of land may positively influence efficiency as land owners may devote their maximum time and efforts to production (Belete, 2020; Tumuri et al., 2024).

Access to institutional services is essential in the development of the agricultural sector. According to Elham et al. (2023), access to credits reduces farm financing shortage, and access to extension increases their confidence in production, and exposes farmers to cheap farm inputs, thus improving farm economic efficiency. Over the study period 2010-2020, only 12.9%, 13.2% and 12.3% of the farming households accessed extension services in maize and legume, maize and other crops intercropping and in maize monocropping, respectively. Less than 30% accessed credits in all maize cropping systems and about 18%, 22% and 14% received financial assistance from the government or non-government organisation, respectively.

Regarding the use of agricultural inputs, it is evident that the application of improved seeds and herbicides has increased in all maize cropping systems in this study, but the rates are higher in maize and legumes intercropping, even when using fertilisers. The proportion of farming households that applied improved seeds has increased from 17% in 2010 to 51% in 2020 in maize and legumes intercropping, from 11% to 46% in maize and other crops intercropping and from 14% to 44% in maize monocropping, respectively. Application of herbicides increased from 13% to 26% in maize and legumes intercropping, from 8% to 20% in maize and other crops intercropping, and from 7% to 19% in maize monocropping, respectively. Only 39% of the farming households in maize and legumes intercropping applied fertilisers compared to 33% in maize and other crops intercropping and 32% in maize monocropping. In addition, the adoption of irrigation technology is very low, 1.3% of the over the study period in maize and legumes intercropping, 3.3% in maize and other crops intercropping, and about 1.5% in maize monocropping households. Application of these technologies is hypothesised to positively influence technical efficiency.

Moreover, it is evident that for smallholder farmers to access markets, on average, they have to travel around 8 kilometres in all maize cropping systems in this study. Easy access to markets increases efficiency by enabling timely access to production inputs and extension services (Elham et al., 2023); thus, 8 kilometres on average may be detrimental to improving efficiency. On average, farming households own two field plots over the study time. More farmland may imply a greater management burden that might reduce efficiency.

Involvement of women in key household farming decisions shows a decreasing trend in all maize cropping systems in this study. In maize and legumes intercropping the rate has decreased from 66% in 2010 to 60% in 2020, in maize and other crops intercropping decreased from 68% to 56% and in maize monocropping from 60% to 46%, and in general the rates are higher in farming household that practiced maize and legumes intercropping 63%, followed by those in maize and other crops 61% and the least is 55% in maize monocropping. Female sole decisions, on the other hand, have been increasing over time, from 16% in 2010 to 22% in 2020 in maize and legumes intercropping, from 18% to 23% in maize and other crops intercropping and from 16 to 20% in maize monocropping, respectively. Household joint decision is linked to increased spouses

Table 2: Socio-economic characteristics, demographic features and access to institutional services of maize farming households

	Maize and legumes intercropping					Maize and other crops intercropping					Maize monocropping				
VARIABLES	2010	2012	2014	2020	pooled	2010	2012	2014	2020	pooled	2010	2012	2014	2020	pooled
Agriculture main occup	0.853	0.844	0.865	0.881	0.859	0.866	0.903	0.879	0.873	0.882	0.824	0.813	0.796	0.812	0.812
Secondary+ Education	0.0550	0.0668	0.0812	0.0955	0.0736	0.0718	0.0605	0.0474	0.113	0.0697	0.0588	0.0730	0.115	0.104	0.0870
Wage income	0.209	0.488	0.529	0.570	0.451	0.244	0.395	0.558	0.577	0.427	0.163	0.479	0.537	0.568	0.444
Business/self-employment	0.122	0.421	0.413	0.429	0.352	0.129	0.379	0.400	0.415	0.324	0.129	0.410	0.540	0.454	0.381
Land ownership	0.951	0.934	0.916	0.876	0.921	0.952	0.944	0.874	0.873	0.916	0.928	0.893	0.829	0.797	0.859
Livestock ownership	0.516	0.438	0.461	0.390	0.451	0.431	0.484	0.363	0.430	0.431	0.377	0.335	0.298	0.339	0.340
Environmental shocks	0.405	0.388	0.454	0.283	0.386	0.397	0.419	0.463	0.282	0.399	0.414	0.316	0.348	0.270	0.330
Access Extension service	0.168	0.114	0.132	0.107	0.129	0.148	0.117	0.132	0.134	0.132	0.137	0.0974	0.174	0.106	0.123
Improved seed	0.171	0.398	0.461	0.508	0.384	0.110	0.363	0.484	0.458	0.342	0.144	0.416	0.460	0.438	0.367
Irrigated Land	0.0168	0.0145	0.0145	0.00670	0.0134	0.0478	0.0524	0.00526	0.0141	0.0330	0.0218	0.0187	0.0118	0.00789	0.0148
Herbicides use	0.125	0.0891	0.129	0.260	0.143	0.0766	0.125	0.132	0.197	0.127	0.0719	0.0618	0.0885	0.192	0.111
Fertilizer use	0.405	0.361	0.375	0.447	0.393	0.321	0.331	0.274	0.408	0.328	0.224	0.331	0.307	0.383	0.319
Market distance	9.861	9.262	6.973	5.624	8.079	9.593	9.199	7.540	5.873	8.305	10.79	10.60	7.125	5.688	8.462
Field land owned	2.246	2.214	1.732	1.733	2.003	2.316	2.161	1.705	1.651	2.001	2.139	2.092	1.485	1.484	1.802
Household Size	5.678	5.656	5.584	5.819	5.678	5.622	5.919	5.526	6.310	5.816	5.288	5.408	5.062	5.562	5.370
Age	49.06	49.64	46.74	49.61	48.80	49.99	53.05	47.41	50.11	50.35	46.79	45.24	44.01	46.63	45.84
Received financial assistance	0.473	0.131	0.0725	0.0469	0.178	0.483	0.165	0.116	0.0704	0.221	0.355	0.0993	0.0619	0.0662	0.142
Access credit	0.382	0.209	0.249	0.276	0.283	0.302	0.185	0.263	0.258	0.341	0.321	0.204	0.263	0.205	0.253
Female sole decisions	0.156	0.177	0.219	0.209	0.189	0.177	0.222	0.195	0.225	0.204	0.174	0.157	0.192	0.203	0.182
Household joint decisions	0.660	0.634	0.609	0.595	0.625	0.675	0.597	0.589	0.563	0.610	0.599	0.605	0.555	0.457	0.547
Harvested Area(acres)	2.206	2.182	2.333	1.871	2.159	1.879	1.906	2.215	1.804	1.955	1.663	1.648	1.518	1.528	1.590

Family labor (mandays)	108.0	110.0	108.5	84.02	103.7	102.9	104.6	98.66	82.71	98.78	82.90	79.82	69.91	56.91	71.44
Value of quantity harvested (Tsh)	376,564	553,746	654,869	696,529	567,465	308,598	478,433	629,527	705,709	510,734	166,859	275,484	311,502	410,690	291,915
Value Farm machinery (Tsh)	19,693	24,239	48,007	42,245	32,751	17,238	26,736	44,033	45,175	31,704	15,931	19,953	31,384	31,818	24,811
Obs.	655	898	690	597	2840	209	248	190	142	789	459	534	339	634	1966
Wages (Tsh)	32464.78	31500.49	69391.05	64687.53	49161.32	31714.33	32122.37	77792	58690.02	51128.89	32196.15	34674.79	65121.68	61485.69	49753.11
Obs.	230	363	321	242	1156	63	98	99	59	319	130	180	148	232	690
Input_costs (Tsh)	28010.01	43493.73	47251.13	68134.59	46974.76	23797.96	40123.49	36085.64	65678.09	40633.67	22854.74	39681.65	37925.34	60232.97	43897.29
Obs.	432	564	457	474	1927	98	150	116	90	454	190	272	219	395	1076

Source: Author’s own computation using STATA 17 and general household commitments to farm management, thus expected to positively impact technical efficiency.

Focusing on factors of production, on average, farming households in maize and legumes intercropping harvest on a larger area (2.16 acres) compared to 1.95 acres in maize and other crops intercropping and 1.59 acres in maize monocropping over the study period. In maize and legumes intercropping, family labour spends relatively more man-days than in other maize cropping systems in this study. Over the study period, family labour spent 2 to 10 more man-days in maize and legumes intercropping than in maize and other crops intercropping, and spent 25 to 39 more man-days than in maize monocropping. This indicates that despite intercropping in general being a labour-intensive practice, intensity differs with the type of crops intercropped. The value of quantity of crops harvested has increased from 2010 to 2020 in all maize cropping systems in this study, however farming households in maize and legumes intercropping had higher average value of quantity harvested (farm revenue) increasing from around 376564 Tshs to about 696529 Tshs from 2010 to 2020 relative to from around 30858 Tsh to about 705709 Tsh in Maize and other crops intercropping and from 166859Tsh to about 410690 Tsh in maize monocropping respectively. The value of farm machinery has increased over time, and is higher for farming households in maize and legumes intercropping, around 32,751Tsh over the study period, compared to 31,704Tsh in maize and other crops intercropping and 24,811Tsh in maize monocropping. Average wages have increased from 32464.78Tsh in maize and legumes intercropping in 2010 to 64687.53Tsh in 2020, compared to from about 31714Tsh to 58690 Tsh in maize and other crops intercropping and from 32196.15Tsh to 61485.69Tsh in maize monocropping, respectively. The cost of inputs has also increased from 2010 to 2020 in all maize cropping systems in this study, with farming households in maize and legumes intercropping spending more on average relative to other maize cropping systems.

3.2 Econometric results

3.2.1 Results from the stochastic frontier production function

The first part results from the maximum likelihood estimation of the Translog stochastic production frontier function and is presented in the first part of Table 3. The coefficient values of area harvested in both maize intercropped farms and maize monocropping farms are positive and strongly significant at 1% level. This indicates that the production of smallholder farmers significantly increases with the harvested area, both when maize is planted as a sole crop and when intercropped with legumes or with other non-leguminous crops. Of all the factors of production, harvested areas have the highest impact, which proves their potential in maize production. The potentiality of harvested/planted area in increasing output in Tanzania was also reported by Lutonja (2023) and Ng’Atigwa et al. (2022). However harvested area square strongly significant and reduces the production in maize monocropping and maize and legumes intercropped farms, possibly the reason being farm management burden.

Family labour is positive and statistically significant at 1% level in influencing production output in farming households that practice maize monocropping, and doubling family labour significantly increases production in farming households that intercrop maize. This indicates increase in time devoted by family members to maize production significantly increases production. The results tally the findings of Adzawla and Alhassan (2021), asserting that family labour is the main source of labour to smallholder farmers, and therefore ensures constant labour availability, which increases farm output. Wage costs are negative and statistically significant at 1% level in all maize cropping systems (maize monocropping, maize and legumes, and maize and other crops intercropping), suggesting that, as the cost of hiring labour increases, farmers may reduce farm labour, thus decreasing production output and hence revenue. On the other hand, doubling wages significantly increases farm output. This possibly reflects that higher wages motivate farm labourers' efficiency in managing the farm even without supervision, hence more output.

Similar to the findings of Selejio et al. (2018) in Tanzania, the study established a negative and statistically significant impact of inputs (fertilisers, seed and herbicides/insecticides) costs at 1% level in all maize cropping systems (maize monocropping, maize and legumes, and maize and other crops intercropping). Implying that, as costs of production inputs increase, they tend to decrease production output, hence revenue, especially for farmers with inadequate funds to finance enough agricultural inputs. A study by Ng’Atigwa et al. (2022) also found a significant negative link between the cost of fertiliser and production. However, doubling input costs was found to be positive and statistically significant in both maize intercropping and monocropping systems. Possible justification is that doubling input costs may reflect much better inputs and hence more production and returns. Further, the study confirms the significant negative impact of interactions of variables such as harvested area* family labour, and harvested area * input costs in maize and legumes, harvested area* family labour, family labour * input costs, and wages * input costs in maize and other crops intercropping and family labour * input costs in maize monocropping. All these suggest that these variables should not be increased simultaneously in production.

Table 3: Stochastic Frontier Production Results (first part)

Ln(Revenue)	Maize monocropping	Maize and legumes Intercropping	Maize and other crops intercropping	Maize General
FRONTIER Function				
Ln(Harvested Area)	1.733***	1.861***	1.579***	1.820***
	(0.168)	(0.135)	(0.295)	(0.112)
Ln(Family labor)	0.370***	0.111	-0.0527	0.194***
	(0.0906)	(0.0843)	(0.148)	(0.0702)
Ln(Wages cost)	-0.0811**	-0.0872***	-0.101**	-0.0740***
	(0.0372)	(0.0258)	(0.0508)	(0.0202)
Ln(Inputs costs)	-0.136***	-0.168***	-0.116***	-0.129***
	(0.0243)	(0.0202)	(0.0416)	(0.0160)
Ln(Harvest area sq)	-0.226***	-0.134***	0.0573	-0.151***
	(0.0448)	(0.0328)	(0.0852)	(0.0266)
Ln(Family labor sq)	-0.0147	0.0219**	0.0638***	0.0189**
	(0.0120)	(0.0100)	(0.0209)	(0.00866)
Ln(wages cost sq)	0.0137***	0.0101***	0.0122***	0.0108***
	(0.00319)	(0.00207)	(0.00414)	(0.00159)
Ln(Inputs costs sq)	0.0208***	0.0206***	0.0244***	0.0203***
	(0.00207)	(0.00149)	(0.00340)	(0.00121)
Ln(Harvested area*Family labor)	-0.0352	-0.119***	-0.198***	-0.0958***
	(0.0354)	(0.0289)	(0.0759)	(0.0248)
Ln(Harvested area*Wages cost)	-0.000720	-0.00700	-0.00657	-0.00456
	(0.00917)	(0.00583)	(0.0119)	(0.00518)
Ln(Harvested area*inputs costs)	-0.00355(0.00786)	-0.0131**(0.00590)	-0.00421(0.0120)	-0.0122***(0.00466)
Ln(Family labor*wages cost)	-0.00677(0.00452)	0.00322(0.00335)	0.00282(0.00695)	-0.000180(0.00298)
Ln(Family labor*inputs costs)	-0.0105***(0.00387)	-0.00405(0.00358)	-0.0199***(0.00683)	-0.00874***(0.00273)
Ln(wages costs*inputs costs)	-0.00118(0.000765)	-0.000435(0.000612)	-0.00255**(0.00120)	-0.00105**(0.000460)
Constant	9.537***(0.227)	10.68***(0.219)	10.87***(0.348)	10.08***(0.179)
lnsig2v Constant	-0.709***(0.106)	-0.701***(0.0489)	-0.647***(0.117)	-0.565***(0.0583)

Source: Author's own computation using STATA 17 using 2010-2020 TNPS dataset Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

3.2.2 The estimated level of technical efficiency

The distribution results of the level of technical efficiency are presented in Table 4(a) and exhibit great variation in technical efficiency within and across the maize farming system. The reason behind the variation in efficiency may be due to differences in smallholder farmers' in terms of farms and farming household characteristics and the technology used that influence how efficiently resources available were utilised. The results confirm that farming households that intercropped maize and legumes are, on average, more technically efficient throughout the study period (2010-2020) and display a consistent increment in efficiency over time, as shown also in Figure 13. In maize and legumes, technical efficiency has increased from 57% in 2010 to 76% in 2020, with the overall average of 67.3% relative to from 54.2% to 67.4% with an overall average of 62.6% in maize monocropping, and an increment from 54% to 67% with study time overall average of 62.2% in maize and other crops intercropping. This indicates that, by 2020, the gap to maximum efficiency is relatively lower in maize and legumes, 24%, relative to 32.6% in maize monocropping and 33% in maize and other crops intercropping, if they utilise the same resources available to them.

From 2010 to 2020, fewer farming households had technical efficiency less that 50% in maize and legumes intercropping (2% in 2020), relative to 10% and 11% in maize monocropping and maize and other crops intercropping, respectively. Similarly, the majority of maize and legumes had technical efficiency of at least 80%, which is visible from 2014. In 2020, for example, 39% in maize and legumes had at least at least 80% level of technical efficiency relative to 13% and 18% in maize monocropping and maize and other crops, respectively. This is also reflected in the pooled data, where more than 20% of farming households in maize and legumes had at least 80% level of efficiency compared to 7% and 14%, respectively.

The study expected the level of technical efficiency of maize intercropped farms to be higher than that of maize monocropping. This is satisfied in maize and legumes intercropping relative to maize monocropping and tallies the findings in Western Africa by Olubunmi-Ajayi et al. (2023), Baruwa & Familusi (2019) and Mustapha & Salihu (2015). On the other hand, higher results in maize monocropping relative to maize and other crops intercropping in 2010, 2012, 2020 and in the pooled model were unexpected; nevertheless, the results are similar to the findings established by Kibaara (2005) in Kenya. This implies that, whether intercropping is more technically efficient than monocropping, it depends on the complementarity of the intercropped crops.

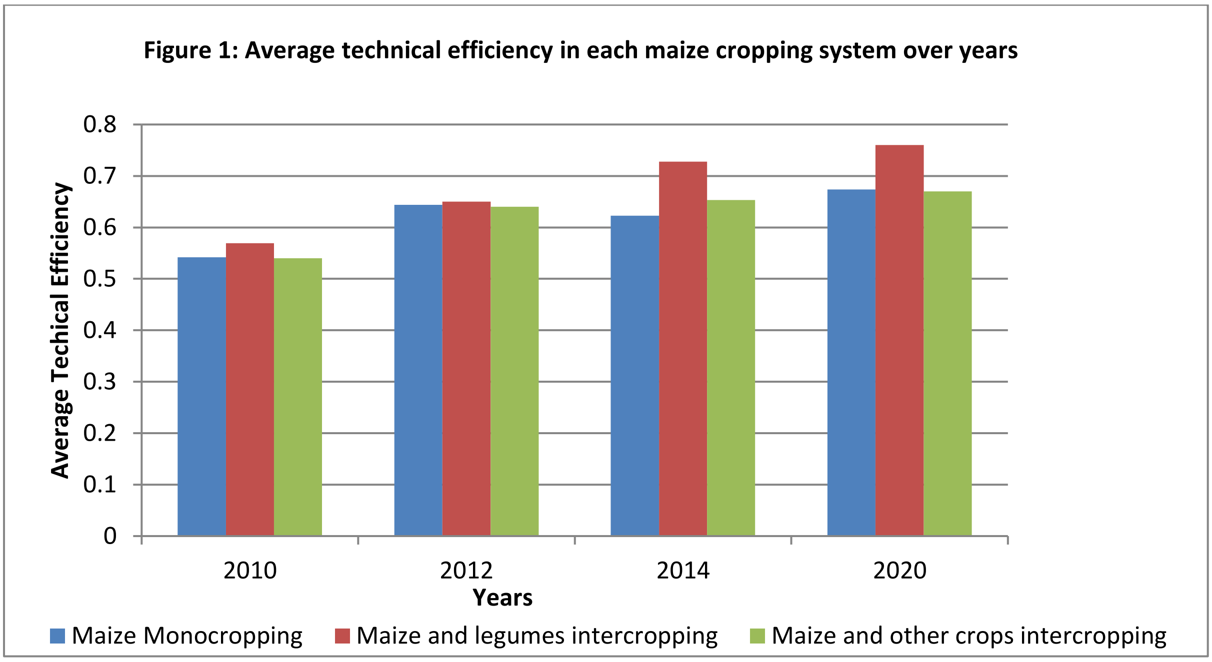
Table 4a: Distribution of the level of technical efficiency in maize cropping systems

		Maize Monocropping		Maize and Legumes Intercropping		Maize and other crops Intercropping	
	Technical Efficiency	Frequency	%	Frequency	%	Frequency	%
	<0.50	161	35.08	209	31.91	76	36.36
2010	0.50-0.69	233	50.76	306	46.72	96	45.93
	0.70-0.79	61	13.29	113	17.25	27	12.92
	>=0.80	4	0.87	27	4.12	10	4.78
Obs.	459			655			209
Mean TE	**0.542**			**0.569**			**0.540**
2012	<0.50	79	14.79	123	13.7	48	19.35
	0.50-0.69	242	45.32	408	45.43	96	38.71
	0.70-0.79	178	33.33	244	27.17	68	27.42
	>=0.80	35	6.55	123	13.7	36	14.52
Obs.	534			898			248
Mean TE	**0.644**			**0.650**			**0.640**
2014	<0.50	61	17.99	30	4.35	26	13.68
	0.50-0.69	163	48.08	215	31.16	79	41.58
	0.70-0.79	101	29.79	238	34.49	49	25.79
	>=0.80	14	4.13	207	30	36	18.95
Obs.	339			690			190
Mean TE	**0.623**			**0.728**			**0.653**
2020	<0.50	65	10.25	12	2.01	16	11.27
	0.50-0.69	231	36.44	120	20.1	61	42.96
	0.70-0.79	256	40.38	231	38.69	40	28.17
	>=0.80	82	12.93	234	39.2	25	17.61
Obs.	634			597			142
Mean TE	**0.674**			**0.760**			**0.670**

Pooled	<0.50	366	18.62	374	13.17	166	21.04
	0.50-0.69	869	44.2	1049	36.94	332	42.08
	0.70-0.79	596	30.32	826	29.08	184	23.32
	>=0.80	135	6.87	591	20.81	107	13.56
Obs.	1966			2840			789
Mean TE	**0.626**			**0.673**			**0.622**

Source: Author's own computation using STATA 17 on the 2010-2020 TNPS dataset

The results differ from the distribution of technical efficiency in maize production in general, regardless of whether the farm is maize intercropped or monocropped, as shown in Table 4(b). The distribution is volatile as in maize monocropping in Table 4(a), and exhibits a decreasing trend from 2010 to 2020, different from when technical efficiency is estimated based on the technology used, especially in maize intercropping options that displayed a consistent increasing trend as shown in Table 4(a) and Figure 1.



Source: Author's own computation using STATA 17 and Microsoft Excel using 2010-2020 TNPS dataset

Figure 1: Average technical efficiency in each maize cropping system over the years

Table 4b: The distribution of technical efficiency regardless of maize cropping systems

	2010		2012		2014		2020		Pooled	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%
<0.50	76	5.74	248	14.76	354	29.04	292	21.27	904	16.16
0.50-0.69	408	30.84	795	47.32	549	45.04	615	44.79	2560	45.76
0.70-0.79	474	35.83	399	23.75	273	22.4	376	27.39	1601	28.61
>=0.80	365	27.59	238	14.17	43	3.53	90	6.55	530	9.47
Obs.	1323		1680		1219		1373		5595	
Mean TE	**0.72**		**0.65**		**0.58**		**0.62**		**0.64**	

Source: Author's own computation using STATA 17 on the 2010-2020 TNPS dataset

Focusing on the paired-sample test, in Table 5, the results indicate a statistically significant difference in means technical efficiency between 2010 and 2020 in all maize cropping systems in this study, with the significant improvement in efficiency being relatively high in maize and legumes intercropping by 19 % relative to 13.3% in maize monocropping and 13.1% in maize and other crops intercropping. On the other hand, focusing on 2010-2020 pooled data in Table 6, male-headed households in all maize cropping systems in this study are more technically efficient than female-headed households. In maize monocropping, male-headed households are 64% technically efficient compared to women, 59%. In maize and legumes, male-headed households are 69% technically efficient relative to 63% in female-headed households, and in maize and other crops, intercropping male-headed households are 64% technically efficient compared to 58% in female-headed households.

Table 1: Two-sample t-test of mean difference of technical efficiency between years (2010 and 2020) in different maize farming systems

	Variable	Observations	Mean	Std.err.	Std.dev	t-statistic	P-value
Maize monocropping	2010	459	0.542	0.007	0.155	-15.150	0.000
	2020	634	0.674	0.005	0.134		
	Combined	1093	0.619	0.005	0.157		
	Mean difference		-0.133				
Maize and Legumes Intercropping	2010	655	0.569	0.006	0.150	-26.244	0.000
	2020	597	0.760	0.004	0.100		
	Combined	1252	0.660	0.005	0.160		
	Mean difference		-0.191				
Maize and other crops intercropping	2010	209	0.540	0.012	0.175	-7.547	0.000
	2020	142	0.670	0.011	0.133		
	Combined	351	0.593	0.009	0.172		
	Mean difference		-0.131				

Source: Own computation using STATA 17 on the 2010-2020 TNPS dataset

Table 6: Two-sample t-test of mean difference of technical efficiency from pooled by gender in different maize farming systems

	Variable	Observations	Mean	Std.err.	Std.dev	t-statistic	P-value
Maize monocropping	Female	465	0.586	0.007	0.157	-6.718	0.000
	Male	1501	0.639	0.004	0.144		
	Combined	1966	0.626	0.003	0.149		
	Mean difference		-0.053				
Maize and Legumes Intercropping	Female	725	0.628	0.006	0.158	-9.713	0.000
	Male	2115	0.689	0.003	0.143		
	Combined	2840	0.673	0.003	0.149		
	Mean difference		-0.061				
Maize and other crops intercropping	Female	221	0.579	0.011	0.163	-4.629	0.000
	Male	568	0.639	0.007	0.164		
	Combined	789	0.622	0.006	0.166		
	Mean difference		-0.060				

Source: Own computation using STATA 17 on the 2010-2020 TNPS dataset

3.2.3 The determinants of the technical inefficiency model

The second portion of the estimates stochastic frontier production function displays the factors responsible for the technical inefficiency in maize farming households in Tanzania, as shown in Table 7. Focusing on how they influence technical inefficiency in farming households that intercropped maize and legumes relative to those that practised maize monocropping and those that intercropped maize and other crops. The positive coefficient estimated implies the variable increases technical inefficiency, and vice versa. Age of the household head is positive and statistically significant at 1% level in influencing technical inefficiency to farming households that intercropped maize and legumes and to maize monocropping households. Meaning, as the household head gets older, technical efficiency declines. The results are similar to the findings in Tanzania by Selejio et al. (2018) and Lutonja (2023), and in Indonesia by Hanani et al. (2024), with Selejio et al. arguing that agriculture is a labour-intensive activity, and the older the farmer, the less physical energy to efficiently manage the farm, and Hanani et al., asserting that older farmers' reliance on inherited outdated ways of farming relative to young farmers reduces efficiency.

Household size is negative and significant at 5% level in maize and legume intercropping, indicating that an increase in household size by one member in smallholder farming households in Tanzania is associated with decreasing technical inefficiency. Possible reason being, smallholder farmers in the country strongly depend on family labour for farming activities, thus having more household members ensures constant and timely labour availability and hence improves technical efficiency. The results are in line with the findings of Elham et al. (2023), Olubunmi-Ajayi et al. (2023) and Selejio et al. (2018).

Household joint decisions significantly reduce technical inefficiency in farming households that intercropped maize and legumes and those that practised maize monocropping. The variable is statistically significant at 5% and 10% levels, respectively. Despite its moderate and weak significance level, it remains potential in explaining technical efficiency. Implicitly, a farming household that jointly makes farming decisions is subjected to increased technical efficiency. This is possibly influenced by strong household commitments to efficient farm management emerging from being involved in farming decisions, but also involvement widens effective farming ideas and resources from each one's social capital. The results are supported by the findings of Seymour (2017) in Bangladesh and Aung et al. (2021) in Myanmar, both establishing that household joint farm management/decisions significantly increase technical efficiency. Involving women in household farming decisions improves household allocation of resources (Aung et al., 2021 & Doss, 2013).

Access to extension services has a negative impact, as expected in all maize cropping systems; however, it is only statistically significant at 5% in maize and other crops intercropping. Implicitly, holding other factors constant, farming households that intercropped maize and other crops and had access to extension services reduced technical efficiency by 12.8% relative to those that did not access the service. Access to extension services provides farmers with the necessary information regarding better agricultural inputs, farming technologies and exposes farmers to potential markets. Our results differ from the findings of Lutonja (2023) in Tanzania, who established that access to extension services significantly increased inefficiency in all crops grown by smallholder farmers in the country. However, our results tally the findings in maize production by Elham et al. (2023) in Afghanistan, Tumuri et al. (2024) in Ethiopia and Kehinde et al. (2024) in Nigeria.

The impact of land ownership on maize production displays mixed results. While land ownership significantly reduces inefficiency in maize monocropping at the 10% level, it also significantly increases technical inefficiency for farming households that intercrop maize and other crops at 10%. Similar contradicting results were attained by Selejio et al. (2018) in Tanzania between adopters and non-adopters of land conservation technologies. This possibly reflects management burdens in intercropping relative to maize monocropped farms.

Agriculture, as the main occupation of the farming household, has the expected negative sign in all maize monocropping, maize and legumes and maize and other crops intercropping. However, it is statistically significant in maize monocropping at 10% and in maize and legumes intercropping at 5% level. Indicating that, farming households that consider agriculture as their main occupation reduce technical inefficiency by 3.2% and 4.0%, respectively, relative to those who do not. This implies that, agriculture being the main occupation, it is also the main source of not only food but also cash to the farming household, and thus they will efficiently invest their resources, such as labourers, and time in farming production, and hence increase efficiency. The results are consistent with the findings of Achandi et al. (2018) in Tanzania, and Boubacar & Huiqiu (2016) in Niger. According to Boubacar & Huiqiu, high efficiency reflects relatively active involvement in agriculture.

Table 7: Stochastic frontier second portion of the determinants of technical Inefficiency in maize cropping systems 2010-2020

Technical Inefficiency	Maize Monocropping	Maize-Legumes Intercropping	Maize-Other crops Intercropping	Maize general
Age	0.0196***	0.0115***	0.00675	0.0111***
	(0.00520)	(0.00384)	(0.00689)	(0.00272)
Household Size	0.0180	-0.0563**	-0.0390	-0.0112
	(0.0255)	(0.0270)	(0.0418)	(0.0188)
Female sole decisions	0.0778	-0.00688	0.267	-0.0828
	(0.182)	(0.178)	(0.312)	(0.120)
Household joint decisions	-0.175*	-0.347**	-0.109	-0.319***
	(0.049)	(0.152)	(0.266)	(0.104)
Access Extension services	-0.249	-0.172	-1.276**	-0.222
	(0.208)	(0.210)	(0.559)	(0.171)
Land ownership	-0.413*	-0.277	0.977*	-0.362**
	(0.222)	(0.235)	(0.579)	(0.164)
1.Secondary+ Education	-0.694**	0.0503	-0.0708	-0.294*
	(0.304)	(0.236)	(0.438)	(0.164)
Agriculture main occupation	-0.317*	-0.400**	-0.291	-0.338***
	(0.170)	(0.163)	(0.321)	(0.114)
ln(Value of Farm Implements)	-0.113***	-0.242***	-0.319***	-0.205***
	(0.0375)	(0.0461)	(0.0768)	(0.0281)
Wage income	-0.0916	0.151	0.158	-0.0166
	(0.137)	(0.131)	(0.223)	(0.0914)
Business/self-employment	-0.107	0.0126	0.0721	0.0490
	(0.142)	(0.135)	(0.233)	(0.0948)
Irrigated land	-0.883	-0.265	-2.076**	-1.173*
	(0.910)	(0.572)	(0.970)	(0.702)
Livestock ownership	-0.670***	-0.430***	0.357	-0.502***
	(0.228)	(0.140)	(0.240)	(0.124)
Number of field land owned	0.0660	0.0398	0.0524	0.0719*
	(0.0629)	(0.0538)	(0.0931)	(0.0379)
Market distance	-0.0110	-0.00418	-0.00785	-0.00450
	(0.00740)	(0.00677)	(0.0120)	(0.00469)
Access credit	0.247	0.0886	-0.0505	0.0828
	(0.179)	(0.154)	(0.265)	(0.106)
Received financial assistance	-0.0616	0.0952	-0.0282	-0.0603
	(0.175)	(0.148)	(0.251)	(0.101)
Environmental shocks (pests, flood, drought)	0.642***	0.386***	0.0717	0.416***

	(0.169)	(0.122)	(0.212)	(0.0913)
Herbicides/insecticides use	-0.305	-0.247	0.504	-0.203
	(0.264)	(0.214)	(0.351)	(0.162)
Improved seed use	-0.152	-0.242*	0.591**	-0.0432
	(0.152)	(0.143)	(0.255)	(0.104)
Fertilizer use	0.346*	0.0522	-0.320	0.119
	(0.185)	(0.144)	(0.291)	(0.113)
2012.year	-0.451**	-0.550***	-0.898***	-0.668***
	(0.224)	(0.197)	(0.344)	(0.137)
2014.year	-0.208	-1.129***	-1.000**	-0.913***
	(0.241)	(0.248)	(0.389)	(0.208)
2020.year	-0.712***	-1.474***	-1.078**	-0.925***
	(0.251)	(0.301)	(0.489)	(0.211)
Constant	0.408	2.494***	1.983**	2.056***
	(0.517)	(0.504)	(0.901)	(0.304)
sigma_v	0.702	0.704	0.724	0.754
	(0.037)	(0.017)	(0.042)	(0.022)
Observations	1,966	2,840	789	5,595
Mean TE	**0.626**	**0.673**	**0.622**	**0.637**
Min TE	0.0412	0.0474	0.0526	0.0642
Max TE	0.891	0.919	0.941	0.895

Source: Author's own computation using STATA 17

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

The value of the farming household's farm implements/machinery is negative and statistically significant at 1% level in all maize cropping systems. The value of farm implements or machinery describes how wealthier the household is. Therefore, an increase in the value of farming implements positively affects efficiency. Meaning farming households with high-value farming implements, such as tractors, are associated with higher technical efficiency relative to those with low-value farm implements. The results are supported by the findings of Ajayi & Olutumise (2018), asserting that financially well-off families are capable of financing farming technology and thus efficiency. However, the results differ from the findings of Kehinde et al. (2024) and Oyetunde-Usman & Olagunju (2019), who established the insignificant link between household assets and efficiency.

Having livestock significantly influences efficiency in farming. This is evident by a negative and significant impact of livestock ownership in maize and legumes intercropping and in maize monocropping at 1% level, respectively. This indicates that having livestock increases farmers' technical efficiency significantly relative to not having one. The results are consistent with the findings of Tumuri et al. (2024) and Belete (2020), both arguing that having livestock ensures timely farm preparation, such as threshing and ploughing, provides manure fertiliser, can be used for transportation, acts as a security means to farming households in response to crop failure, thus increasing efficiency in maize production.

Interestingly, we found experience of environmental shocks, such as drought, flood, pests and diseases significantly reduced efficiency at 1% level in maize and legumes intercropping and in maize monocropping, respectively. Implicitly, this means that farming households that experienced environmental shocks are linked to reduced efficiency relative to those that did not. Environmental shock may destroy inputs of production (an increase in the price of inputs or farm land destruction), discourage farmers' investments in efficiency-enhancing technology in fear of unexpected environmental shocks, and may also disrupt production routine, thus increasing inefficiency. Our findings are consistent with Adeosun et al. (2025) in Cameroon, who established the negative and significant link between technical efficiency and climate change vulnerability index, and Birhanu et al. (2022) in Ethiopia, who found that stress incidence associated with bad climate change significantly reduced efficiency.

Further, the study found that the application of fertilisers significantly increases technical inefficiency in maize monocropping. Similar results were established by Achandi et al. (2018) in Tanzania, asserting that low education among smallholder farmers may be a reason for inoptimal use. In addition, considering 2010 as a reference year, the study found the coefficients of years 2012, 2014, and 2020 are all negative and strongly statistically significant in maize and legumes intercropping, and strongly (1%) and moderately (5%) significant in maize monocropping and in maize and other crops intercropping indicating that smallholder farming household improves technical efficiency in maize production over time, and the impact is relatively strong in maize and legumes which indicates improvement in the maize production from 2010 to 2020. This possibly reflects increased exposure, adoption of improved farming technologies, and a relative increase in extension services in the decade.

4.0 Conclusion

In analysing the level and the determinant of technical efficiency of smallholder farming households of maize and legumes intercropping relative to those that practised maize monocropping and maize and other crops intercropping, the Translog stochastic frontier production function was chosen following the likelihood ratio (LR) test statistics. The study used a one-step analysis of both the stochastic frontier model and the determinants of technical inefficiency model to avoid the possible endogeneity problem. In addition, the study accounted for robust standard errors clustered at household levels to control for any possible intra-household correlation and heteroskedasticity using STATA17. Results indicate that farming households that intercropped maize and legumes were more technically efficient over the study time (2010 to 2020), with maize and other crops intercropping and maize monocropping exhibiting almost similar rates. Technical efficiency consistently increased from 57% in 2010 to 76% in 2020 in maize and legumes intercropping, relative to from 54% to 67% in maize and other crops intercropping, and from 54.2% to 67.4% in maize monocropping (with volatility in-between) respectively, different from technical efficiency in maize production regardless of whether maize was intercropped or not that displayed a volatile and decreasing trend between 2010 and 2020. In maize and legumes intercropping, few farming households had technical efficiency less than 50% from 2010 to 2020, and the majority had technical efficiency of at least 80%, especially from 2014 to 2020, relative to proportions of farming households in maize monocropping and maize and other crops intercropping. Over all maize cropping systems, male-headed households were more technically efficient to female headed households, and the results revealed a statistically significant difference in mean technical efficiency across all maize cropping systems between 2010 and 2020 and across household head gender. Age of the household head significantly increased technical inefficiency in maize and legumes intercropping, and in maize monocropping, household size significantly reduced technical inefficiency in maize and legumes intercropping and is negative in maize and other crops intercropping. Household joint farming decision significantly reduces inefficiency in maize and legumes intercropping and in maize monocropping, and insignificantly reduces inefficiency in maize and other crops intercropping. Access to extension services reduces inefficiency in all maize cropping systems, but it significantly reduces inefficiency in maize and other crops intercropping. Land ownership significantly reduced inefficiency in maize monocropping and increased inefficiency in maize and other crops intercropping, and insignificantly reduced inefficiency in maize and legumes intercropping. Having at least secondary education significantly reduced inefficiency in maize monocropping and insignificantly reduced inefficiency in maize and other crops intercropping. Agriculture as the main occupation reduced inefficiency in all maize cropping systems, but it is only significant in maize monocropping and in maize and legumes intercropping. Farming implements/machinery significantly reduced technical inefficiency in all maize cropping systems. Application of irrigation reduced inefficiency in all maize cropping systems but significantly reduced technical inefficiency in maize and other crops intercropping. Livestock ownership significantly reduced technical inefficiency in maize monocropping and in maize and legumes intercropping. Environmental shocks such as drought and flood increased technical inefficiency in all maize cropping systems, but significantly increased inefficiency in maize monocropping and in maize and legumes intercropping. Use of improved seed significantly reduced technical inefficiency in maize and legumes intercropping and increased it in maize and other crops intercropping, meaning it is optimally used in maize and legumes intercropping and inoptimal used in maize and other crops intercropping. Application of fertilisers significantly increased technical inefficiency in maize monocropping, suggesting ineffective use of fertilisers among smallholder farmers.

The results suggest that policies should prioritise maize and legume intercropping since it improves technical efficiency more compared to maize monocropping and maize and other crops intercropping, as from 2010 to 2020, technical efficiency increased by 19% in maize and legume intercropping relative to the increment of about 13% in maize monocropping and in maize and other crops intercropping, respectively. In 2020, for example, technical efficiency in maize and legumes intercropping was relatively higher by around 9% to maize monocropping and maize and other crops intercropping. In addition, policies should promote household joint decisions, facilitate access to farming machinery such as tractors, irrigation pumps, and power tillers, but also should facilitate the adoption of resilience methods to climate change and educate farmers to optimally use them to free farmers from climate change stresses that increase technical inefficiency.

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Conflict of Interest
The authors declare no conflicts of interest.

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