



ESTIMATING THE EFFECT OF TECHNOLOGICAL, INSTITUTIONAL, AND INPUT COST DRIVERS ON MAIZE (*ZEA MAYS*) PRODUCTIVITY IN SONGEA DISTRICT, TANZANIA: AN ENDOGENEITY CONTROLLED ANALYSIS

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ABSTRACT: *Maize is a staple crop in the region, and its productivity plays a vital role in ensuring food security and improving the livelihoods of smallholder farmers. Despite the potential for high yields, smallholder farmers face challenges in optimizing production due to factors such as limited access to modern farming technologies, insufficient institutional support, and high input costs. This study estimate the effect of technological factors, institutional factors, and production costs on maize productivity among smallholder farmers in Songea District, Tanzania. The study uses a cross-sectional design with questionnaire to collect data from 397 smallholder maize farmers. To address potential endogeneity the study employs an instrumental variable Two-Stage Least Squares (IV-2SLS) estimation. The results reveal that land size ($p < 0.05$) and credit access ($p < 0.01$) significantly increase productivity. Technological factors, including improved seed adoption, inorganic fertilizer use, integrated pest management, and tractor use ($p < 0.01$), also have strong positive effects on maize output per worker. Similarly, institutional and socio-economic factors such as market access, training attendance, number of hired labor, household size, income, and favorable rainfall conditions ($p < 0.01$) significantly improve maize productivity. In contrast, higher input costs, including fertilizer costs, pesticide costs, and seed costs ($p < 0.01$), significantly reduce productivity. Elasticity estimates from the Cobb–Douglas IV model show that fertilizer use (0.499), land size (0.853), and labor (0.042) positively contribute to maize output. Hypothesis testing confirms diminishing marginal productivity of fertilizer and labor, while land size exhibits constant marginal productivity. The combined elasticity of core inputs suggests that maize production operates under constant returns to scale. Thus, strengthening access to agricultural inputs, credit services, extension programs, and market infrastructure can significantly improve maize productivity and contribute to food security and rural income growth in Tanzania.*

KEYWORDS: Cobb–Douglas, Endogeneity, Institutional Factors, Input costs, Instrumental Variable Regression, Maize Productivity, Technological factors.



INTRODUCTION

Maize is a vital crop for smallholder farmers globally, particularly in sub-Saharan Africa, where it serves not only as a staple food but also as a primary source of income. Maize is the world's most extensively cultivated cereal crop, with global production reaching 1.22 billion metric tons in 2023, marking a 4.2% increase from 1.17 billion metric tons in 2020 (FAO, 2023). It is especially vital in developing regions, where it provides not only food security but also income for millions of smallholder farmers. In sub-Saharan Africa, maize covers about 40% of cultivated land and contributes over 30% of daily caloric intake for more than 300 million people. However, actual yields in the region remain low, averaging just 2.2 tonnes per hectare, far below the global average of 5.8 tonnes/ha, and even further from the potential yield of 10 tonnes/ha under optimal conditions (Ayuba et al., 2025; Otsuka et al., 2024). For example, Nigeria, Africa's largest producer, harvested 11.6 million tonnes in 2023, but this represents minimal progress from 11.0 million tonnes in 2020, highlighting stagnation due to input shortages, climate shocks, and post-harvest losses (Wossen et al., 2023). In contrast, Ethiopia has seen production rise from 7.4 million tonnes in 2018 to 9.6 million tonnes in 2023, which is a 30% increase, aided by improved seed distribution and extension services (Mohammed et al., 2022; Alemu et al., 2024).

In Latin America, technological advancements have driven more gains that are substantial. Brazil recorded an all-time high maize output of 131 million tonnes in 2023, up from 112 million tonnes in 2020 a remarkable 17% growth in just three years as a result of increased adoption of genetically modified (GM) seeds (now used on over 90% of maize area), efficient irrigation, and double-cropping systems (Erenstein et al., 2022; Luna, 2022). Argentina, another major player, produced 59.4 million tonnes in 2023, despite drought-related setbacks, while Mexico saw moderate growth from 26.5 million tonnes in 2020 to 28.2 million tonnes in 2023, driven by localized government support programs. Yet, these national-level gains often mask rural disparities. In Mexico's indigenous farming zones, yields remain under 3 tonnes per hectare, compared to 6–8 tonnes/ha on commercial farms (Klein & Luna, 2022; Lopez Hernandez et al., 2025). Water scarcity, soil degradation, and limited access to credit continue to prevent equitable improvements in yield. This uneven progress globally and within countries emphasises the pressing need for targeted, localized interventions, particularly those that empower smallholder farmers with climate-resilient technologies, affordable inputs, and market access to bridge the persistent productivity gap (Mpala & Simatele, 2024).

In Africa, maize remains a cornerstone of food security and livelihoods, accounting for over 40% of total cereal production in sub-Saharan Africa and forming the dietary backbone for more than 300 million people (FAO, 2022). However, productivity remains alarmingly low. As of 2023, average maize yields across the continent range from 1.5 to 2.2 tonnes per hectare, significantly below the global average of 5.8 tonnes/ha, and far from the optimal potential of 6–8 tonnes/ha under improved agronomic conditions (FAO, 2023). In Nigeria, the largest maize producer in Africa, production reached 11.6 million tonnes in 2023, yet yields hover around 2.0 tonnes/ha, reflecting only marginal improvements over the past five years (Wossen et al., 2023). Kenya produces approximately 3.7 million tonnes annually, but production fluctuates widely due to erratic rainfall and pest outbreaks, particularly the fall armyworm (Nyakora Masese et al., 2022). Ethiopia, despite challenges, has shown more promising growth, increasing maize output from 7.4 million tonnes in 2018 to 9.6 million tonnes in 2023, a 30% gain attributed to improved seed distribution and government-backed input programs (Asfaw et al., 2024). Across the continent, key constraints continue to suppress productivity,



including low mechanization rates (below 20%), poor access to certified seeds (used by only 30–40% of smallholders), and sub-optimal fertilizer application, often less than 20 kg/ha compared to the global recommendation of 80–100 kg/ha (Benjamin et al., 2024). These challenges underscore the urgent need for sustained investment and policy alignment with Sustainable Development Goal 2 (Zero Hunger), which aims to eliminate hunger and promote sustainable, climate-resilient agriculture by 2030 (UN, 2023). Despite national initiatives such as Nigeria's Growth Enhancement Support Scheme and Ethiopia's Agricultural Transformation Agenda, the persistent yield gap underscores the need for more inclusive, localized interventions to ensure that Africa's smallholder farmers can fully realize maize's potential.

In Tanzania, maize is the most important staple crop, consumed by more than 60% of rural households and serving as a critical source of both food and income (URT, 2023; Utouh, 2024). As of 2023, maize occupies over 45% of the total cultivated area, with more than 4.5 million households engaged in its production. However, maize productivity remains considerably below its potential. The average national yield is just 1.5 tonnes per hectare, compared to a potential yield of 3.5 to 4.0 tonnes/ha under optimal agronomic conditions (NBS, 2022). This significant yield gap is largely due to limited access to improved seed varieties currently adopted by only 35–40% of smallholder farmers alongside low fertilizer use (often less than 10 kg/ha, versus the recommended 50–80 kg/ha), poor soil fertility, and minimal investment in irrigation infrastructure. Only 3.4% of maize-growing land in Tanzania is irrigated, leaving the majority of farmers reliant on increasingly unpredictable rainfall (URT, 2023; Nyange & Ires, 2024). The situation is further exacerbated by climate change, with rainfall variability, late rainfall onset, and prolonged drought periods becoming more frequent, particularly in regions such as Dodoma, Shinyanga, and Singida (Boko et al., 2020).

Despite several efforts to improve agricultural productivity, such as the Agricultural Sector Development Program (ASDP) and the support from the Tanzania Agricultural Development Bank (TADB) to provide financing for inputs, maize productivity in Songea continues to fall short (URT, 2023). These initiatives aim to enhance farmers' access to credit, inputs, and extension services, the adoption of improved agricultural practices remains low, and farmers continue to struggle with low yields due to persistent issues such as poor soil quality, inadequate infrastructure, and unpredictable weather patterns (Kitole, Lihawa & Nsindagi, 2023; Utouh, 2024). In Songea District, maize productivity is reported to be about 30-40% of its potential yield, which is significantly lower than the optimal yield of 3.5 to 4 tons per hectare (NBS, 2022). This highlights the substantial productivity gap despite existing agricultural efforts and interventions. Thus, this paper aims to estimate the effect of technological factors, institutional factors, and input cost factors on maize productivity in Songea District.

THEORETICAL REVIEW

Production Theory

Production theory in economics explains how producers convert inputs into outputs, focusing on the relationship between the factors of production (such as labor, capital, and land) and the resulting output. This theory was formally developed by Alfred Marshall in the late 19th century, with later contributions from economists like John Hicks and Paul Samuelson. It has been widely applied in agricultural economics to understand how different inputs contribute to agricultural output (Marshall, 1890; Hicks, 1932; Samuelson, 1947). In the context of



smallholder maize production in Songea District, this theory helps analyse how factors such as labour, capital, and land influence maize productivity and how these factors can be optimised to increase output.

In maize production, a basic production function can be represented by the equation:

$$Q = F(L, K, M)$$

Where:

Q represents the quantity of maize produced,

L stands for labor input (e.g., family labor or hired labor),

K is capital input (e.g., land, machinery, fertilizers, and seeds),

A commonly used form of the production function in agriculture is the Cobb-Douglas production function, which is particularly relevant for studying maize production. It can be expressed as:

$$Q = AL^\alpha K^\beta$$

Here:

A represents the total factor productivity (which includes technology and efficiency),

L is labor input,

K is capital input,

α and β are output elasticities, showing how much output changes with variations in labor or capital.

The assumptions of production theory provide a foundational understanding of the input-output relationship in agricultural production. One key assumption is constant returns to scale, which means that increasing inputs by a certain percentage results in an equal percentage increase in output (Marshall, 1890). However, this may not hold true in smallholder farming, where farmers often experience diminishing marginal returns due to limited land and resources (Alabi & Safugha, 2022). Another assumption is technological efficiency, where technology is considered constant, influencing the output (Hicks, 1939). The assumption of labor and capital substitutability implies that labor and capital can be substituted for each other, but in smallholder agriculture, capital is often a constraint, limiting the ability to replace labor with machinery (Touch et al., 2024). Lastly, the assumption of perfect competition suggests that farmers operate in a competitive market, but smallholder farmers frequently encounter market inefficiencies and price volatility, which complicates their ability to compete effectively (Benea & Ouko, 2025).

Production theory provides a framework for understanding how labor, land, and capital influence maize yields. This theory explains how capital, such as access to fertilizers, improved seeds, and machinery, enhances production. Furthermore, the concept of diminishing marginal returns in production theory is particularly relevant in the context of Songea, where land is often scarce and fragmented. The study examines how increasing inputs, such as labor or



capital affect maize productivity, and it explores whether smallholder farmers experience diminishing returns as they intensify their farming practices. Production theory offers a comprehensive understanding of the factors influencing maize production and is a valuable tool for identifying potential inefficiencies in resource use. By applying this theory, the study offers valuable insights into how agricultural policies and practices can be improved to support smallholder maize farmers in the region.

Empirical Literature Review

Empirical studies across Africa and other developing regions consistently show that the adoption of improved agricultural technologies plays a central role in increasing maize productivity among smallholder farmers. In Ethiopia, Dube and Abebe (2023) applied a Cobb–Douglas production function and found that fertilizer use, extension contact, farm income, labor availability, and land allocated to maize significantly increased maize productivity, while pests, diseases, and soil degradation negatively affected yields. Similarly, Tumuri et al. (2024) examined the technical efficiency of maize production among smallholder farmers in the Sidama region using stochastic frontier analysis and found an average efficiency level of 72.7%, suggesting that maize output could increase by about 27% if farmers used existing resources more efficiently.

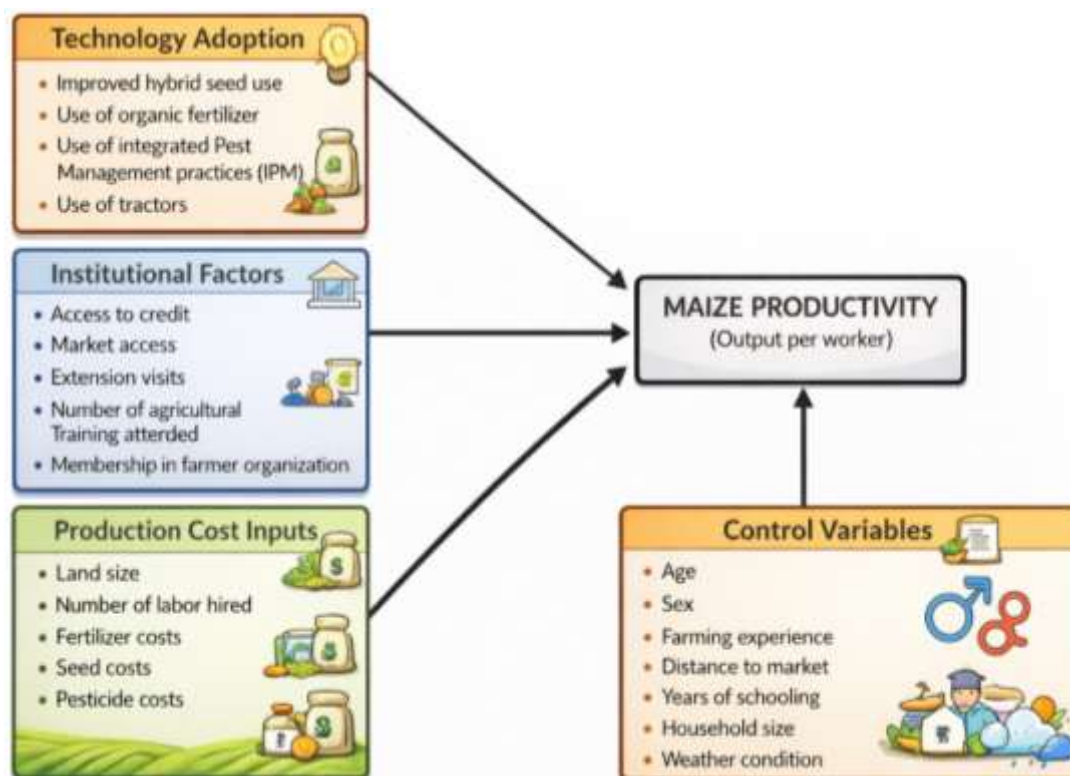
Technology adoption also includes the use of climate-smart agricultural practices aimed at improving productivity while addressing climate risks. In Ghana, Asante et al. (2024) investigated the adoption of climate-smart agriculture technologies, specifically row planting, zero tillage, and drought-tolerant maize seeds, using a multinomial endogenous switching regression model. The study found that adopting multiple climate-smart technologies significantly increased maize yields and net farm income, with the combined adoption of all three technologies producing the highest yield gains. In Eswatini, Mncube et al. (2023) conducted on-farm experiments and survey analyses to evaluate fertilizer regimes and weed management practices in smallholder crop–livestock systems. The study found that maize yields were significantly influenced by factors such as household size, land area cultivated, herbicide application timing, and fertilizer regimes. The results further showed that the application of inorganic fertilizer produced significantly higher maize yields compared to manure-only systems, although manure application produced favorable economic benefits due to lower input costs and improved soil conditions. In addition to agronomic and technological factors, demographic characteristics and climate-related variables significantly influence maize production outcomes. Using statistical modelling to analyse rainfed maize production in Kenya, Oluoch et al. (2022) found that agronomic factors such as fertilizer use, certified seed adoption, and extension services had stronger effects on maize yields than demographic factors alone. Importantly, these agronomic improvements were found to partially offset the negative impacts of climate variability on maize productivity. Similarly, Utonga (2022) analysed determinants of maize yield among small-scale farmers in Mbinga District, Tanzania, using multiple regression analysis and reported that farm size, quantity of seed, fertilizer use, and labor input significantly influenced maize yields. The study recommended improved access to quality agricultural inputs and financial services to enhance smallholder productivity.

Institutional and socio-economic support mechanisms also play a vital role in improving maize production and productivity. In Ethiopia, Abate (2024) used a probit regression model to analyse determinants of improved maize seed adoption and found that access to credit, irrigation, and fertilizer significantly increased the likelihood of adopting improved maize



varieties. Conversely, larger landholding size reduced the probability of adoption, possibly due to the higher financial costs associated with adopting modern technologies across larger plots. Similar findings were reported in Tanzania, where Malimi (2023) demonstrated that agricultural input subsidies and extension services significantly increased both land productivity and labor productivity among maize farmers by promoting the adoption of improved farming technologies and practices. In Uganda, Midamba et al. (2025) analyzed gender differences in maize productivity using total factor productivity analysis and found that female-headed households were approximately 24.3% less productive than male-headed households. The study identified access to inputs, education, market information, farm size, and non-farm income as significant determinants of maize productivity. Economic analyses of maize farming further demonstrate that profitability and productivity are closely linked to farmers' socio-economic characteristics and market access. In Oyo State, Nigeria, Oke et al. (2022) found that maize farming generated positive returns on investment; however, factors such as farming experience, access to credit, input costs, and market access significantly influenced production levels and profitability among smallholder farmers. Likewise, Tesema (2022) found that farmers in Ethiopia operating under traditional farming systems exhibited production inefficiencies due to limited access to modern inputs and technologies, underscoring the importance of institutional support and improved farming practices to enhance productivity. Ye et al. (2023) examined the impact of agricultural subsidy reforms on maize green total factor productivity in China and found that market-oriented reforms significantly improved green agricultural productivity by driving technological progress and reducing reliance on environmentally harmful inputs, such as excessive fertilizers and pesticides. Similarly, Masese et al. (2022) demonstrated that maize production in Kenya responds strongly to market incentives and improved seed availability, although inefficient use of fertilizers and limited mechanization can reduce productivity when farmers lack adequate technical knowledge. Although these existing studies document significant associations between technology adoption, institutional factors, production factors, and maize productivity, a critical gap lies in their failure to test for potential endogeneity using instrumental variable techniques such as Two-Stage Least Squares (2SLS). Without IV-2SLS estimation, issues of reverse causality, omitted variables, and selection bias remain unaddressed, thereby weakening causal validity and producing potentially inconsistent parameter estimates.

Conceptual Framework



Source: *Empirical Reviews*

MATERIALS AND METHODS

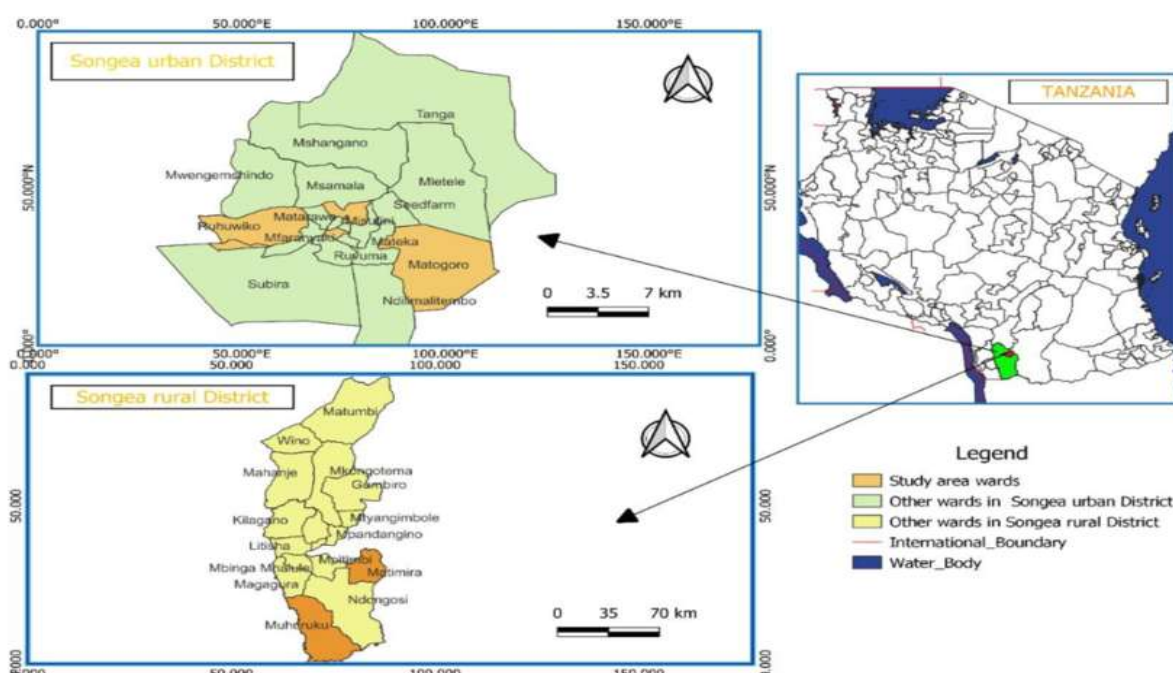
This study utilised a cross-sectional research design. A cross-sectional design is appropriate when the objective is to collect data from a population at a single point in time or over a short period, providing a snapshot of the situation. In the context of this study, the cross-sectional design allowed for an in-depth examination of the factors influencing maize production in Songea District, Tanzania, without the need for long-term observation. This design is commonly used in agricultural research, where the aim is to describe and understand current conditions and relationships between variables (Bryman, 2021).

Study area

The study was conducted in Songea District, Tanzania, as it is a critical region for maize production in the country. Songea is known for its smallholder farming practices, and maize is a staple crop for local farmers. Songea District, located in the Ruvuma Region of southern Tanzania, is situated at approximately 10°41'S latitude and 35°39'E longitude. This district, encompassing both urban and rural areas, serves as the administrative and economic hub of the region. Agriculture is the cornerstone of Songea's economy, with over 80% of households engaged in farming activities. Maize is the predominant crop, cultivated extensively across the district. In the 2024/2025 agricultural season, the National Food Reserve Agency (NFRA) procured over 72,000 tonnes of maize from farmers in Songea, underscoring the district's

significant role in Tanzania's food security (NBS, 2022; URT, 2022). Other key crops include beans, cassava, millet, sunflower, and various fruits such as mangoes and bananas.

The district's economic activities are not limited to agriculture. Small and medium-sized enterprises (SMEs) in Songea engage in various industries, including furniture manufacturing, metalworking, and other artisanal crafts. These enterprises contribute to the local economy by providing employment and supporting trade, primarily through the sale of agricultural products. Given the centrality of agriculture to Songea's economy, understanding the determinants of maize production is crucial. Factors such as access to credit, land size, input usage, and climatic conditions play significant roles in influencing productivity.



Source: Mlawa, Abdallah & Mwakalukwa, 2023

Sample Size and Sampling Technique

Sample Size

The sample size for this study was determined using statistical formulas that account for the finite population size, desired confidence level, and margin of error. Based on the population size of smallholder farmers in Songea District, a sufficiently large sample was chosen to ensure the results are statistically significant and reliable. The formula for Yamane was used to obtain the sample;

$$n = \frac{N}{1 + N(e)^2}$$

Where:

n = Sample size

N = Total population



e = Margin of error (0.05 for a 95% confidence level)

$$n = \frac{57084}{1 + 57084(0.05)^2}$$

$$n = 397$$

Table 1: Sample size Distribution

Ward	Population of Maize Farmers	Sample size
Matumbi	11,451	80
Gumbiro	5,726	40
Wino	11,451	80
Mahanje	11,451	79
Mpandangindo	17,005	118
Total	57084	397

Source: Songea District Council, 2025

Sampling Techniques

This study employed multistage sampling, a technique that involves selecting participants in stages. Initially, the study randomly selected wards from Songea District. Then, within each selected ward, households were chosen using simple random sampling. This multistage approach ensures a representative sample across different wards, accounting for regional variations in farming practices and resources. Multistage sampling is appropriate as it enables the inclusion of diverse farming conditions within the district while maintaining a manageable and cost-effective data collection process (Bryman, 2021).

Data Collection Instruments

Data for this study were collected through structured questionnaires. The questionnaires contained closed-ended questions and were distributed to 397 farmers to quantify various factors affecting maize productivity. Using structured questionnaires allows for the efficient gathering of data from a large number of respondents, enabling statistical analysis. The questions focused on socioeconomic factors, access to resources, technology adoption, and market conditions, among others. To ensure clarity and accuracy, the questionnaire was pre-tested in a similar setting before the main data collection process began.

Table 2: Measurement of Variables

Variable	Description / Definition	Measurement Scale	Expected Sign
Maize Productivity	Output generated per unit of labor (Total maize output divided by total labor used)	Continuous (Kg per worker)	
Independent Variables			
Farmer's Age	Age of household head engaged in maize production	Continuous (Years)	±



Gender	Sex of the household head	Dummy (1 = Male, 0 = Female)	±
Farming Experience	Years engaged in maize farming	Continuous (Years)	+
Distance to Market	Distance from farm to nearest maize market	Continuous (Km)	-
Years of Schooling	Number of years a farmer attended school	Continuous (Years)	+
Household Income	Total annual household income	Continuous (TZS)	+
Households size	Total number of household members in the family	Continuous	+
Weather Conditions	Climatic conditions during maize growing season	Dummy (1 = rainfall seasonal, 0 = dry season)	+
Improved Hybrid Seeds Use	Use of certified or hybrid maize varieties	Dummy (1 = Used, 0 = Not used)	+
Inorganic Fertilizer Use	Quantity of chemical fertilizer applied	Continuous (Kg per hectare)	+
Integrated Pest Management (IPM)	Use of pest control practices	Dummy (1 = Used, 0 = Not used)	+
Use of Tractors	Using tractor for Mechanized land preparation	Dummy (1 = Used, 0 = Not used)	+
Access to Credit	Access to agricultural credit	Dummy (1 = Yes, 0 = No)	+
Market Access	Farmer access to maize markets	Dummy (1 = Access, 0 = No access)	+
Extension Visits	Number of contacts with extension officers	Count (Number per season)	+
Agricultural Training Attended	Number of training programs attended	Count (Number per season)	+
Membership in Farmer cooperative/association	Membership in cooperative/association	Dummy (1 = Member, 0 = Non-member)	+
Land Size	Area cultivated under maize	Continuous (Acres or Hectares)	+
Number of Labor	Labor number used in maize production	Continuous	+
Fertilizer Costs	Costs of purchasing fertilizer	Continuous	+
Seed Costs	Costs of seed purchases	Continuous	+
Pesticide Costs	Costs of pesticides purchases	Continuous	+



Empirical Model

This study employs the Two-Stage Least Squares (2SLS) method. The 2SLS method is especially valuable for addressing concerns about endogeneity, which can arise from simultaneous causality or omitted variable bias. This is critical in the case of maize productivity, where certain factors such as access to credit, land size, or use of inputs may be correlated with unobserved factors influencing productivity (e.g., farmers' age, gender, farming experience, distance to the market, education level, income, weather conditions).

The use of 2SLS is crucial because some variables influencing maize productivity may be endogenous. For instance, access to credit (which affects the ability to purchase seeds and fertilizers) could be influenced by a farmer's income or previous crop yield, which, in turn, may be influenced by maize productivity itself. If we were to estimate the relationship using a simple Ordinary Least Squares (OLS) model or a Logit Regression, as used by Setonga & Omary (2024), the estimates would likely be biased and inconsistent due to this endogeneity. By using instrumental variables (IVs) in the first stage of the 2SLS procedure, the method corrects for this bias, providing consistent and reliable estimates of the determinants of maize productivity.

Step 1: The First Stage

In the first stage of 2SLS, instrumental variables that are correlated with the endogenous explanatory variables but are uncorrelated with the error term were used. These instrumental variables serve as predictors for the endogenous variables. For example, consider the model for maize production P_{maize} (dependent variable), where various determinants, including potentially endogenous variables such as access to credit (X_1), land size (X_2), and Fertiliser use (X_3), are included:

$$P_{maize} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \epsilon$$

Where:

P_{maize} = Maize productivity (measured in output per worker/APL)

X_1, X_2, X_3 = Endogenous variable (e.g., access to credit, land size, fertiliser use)

ϵ = Error term

To address the endogeneity of X_1 (access to credit), X_2 (land size), and X_3 (fertiliser use) researcher first predict this variable using instrumental variables that are related to access to credit but are assumed not to directly influence maize productivity (i.e., they are uncorrelated with the error term ϵ):

$$X_1 = \gamma_0 + \gamma_1 Z_1 + \gamma_2 Z_2 + \gamma_3 Z_3 + v$$

Where: Z_1, Z_2 are the instrumental variables for access to credit (e.g., farmer's years of schooling, distance to the market, Membership in farming cooperatives, extension visits), which affect X_1 but are assumed not to directly influence maize productivity, not correlated with the error term ϵ).

v = is the error term in the first stage.



These instrumental variables help isolate the variation in access to credit, land size, and fertiliser use that is not correlated with the unobserved factors affecting maize productivity. The instrumental variables are expected to affect X_1 , X_2 , and X_3 but are assumed not to directly impact maize productivity.

Step 2: The Second Stage

In the second stage of the 2SLS method, the predicted values \widehat{X}_1 , \widehat{X}_2 and \widehat{X}_3 from the first stage are substituted into the original regression model. In this case, the endogenous variables are credit access, land size, and fertilizer use. After estimating the first-stage regressions using the instruments (education years, distance to market, membership in farmer organizations, and extension visits), the predicted values are generated. These predicted values replace the original endogenous variables in the second-stage regression.

$$P_{maize} = \beta_0 + \beta_1 \widehat{X}_{1l} + \beta_2 \widehat{X}_{2l} + \beta_3 \widehat{X}_{3l} + \epsilon$$

Where:

\widehat{X}_1 , \widehat{X}_2 and \widehat{X}_3 = The predicted values of access to credit, land size, and fertiliser use obtained from the first stage

$\beta_1, \beta_2, \beta_3$ = Coefficients to be estimated

ϵ = Error term

By using the predicted values, which are uncorrelated with the error term ϵ , this second-stage regression provides consistent and unbiased estimates of the determinants of maize productivity.

However, in estimating the elasticities, the Cobb-Douglas production function for maize output is expressed as;

$$Y_i = AL_i^{\beta_1} K_i^{\beta_2} T_i^{\beta_3} X_i^{\beta_4} Z_i^{\beta_5} \epsilon^{\epsilon_i}$$

where Y_i denotes maize output for farmer i , A represents total factor productivity, L_i is labor input, K_i represents capital inputs such as machinery, T_i is land size cultivated, X_i represents intermediate inputs such as fertilizer, seed, and pesticides, Z captures institutional and technological factors (credit access, extension services, market access, and technology adoption), and ϵ_i is a random error term capturing unobserved influences on production.

The Cobb–Douglas production function is transformed into a log-linear specification by taking natural logarithms on both sides:

$$\ln Y_i = \beta_0 + \beta_1 \ln L_i + \beta_2 \ln K_i + \beta_3 \ln T_i + \beta_4 \ln X_i + \beta_5 \ln Z_i + \epsilon_i$$

This transformation converts the nonlinear production relationship into a linear regression model where the coefficients represent output elasticities with respect to each input. In the context of smallholder maize production, the empirical model expands the input vector to include production inputs, institutional variables, demographic characteristics, and cost variables affecting productivity.



Thus, the empirical production function for maize productivity can be specified as

ln ln (Maize Productivity)

$$\begin{aligned}
 &= \beta_0 + \beta_1 \ln \text{InorgFertilizer}_i + \beta_2 \ln \text{labor}_i + \beta_3 \ln \text{Landsize}_i \\
 &+ \beta_4 \ln \text{SeedCost}_i + \beta_5 \ln \text{FertiliserCost}_i + \beta_6 \ln \text{TractorUse}_i + \beta_7 \ln \text{Income}_i \\
 &+ \beta_8 \ln \text{IPM}_i + \beta_9 \ln \text{Pestcosts}_i + \beta_{10} \ln \text{ImprovedSeed}_i \\
 &+ \beta_{11} \ln \text{MarketAccess}_i + \beta_{12} \ln \text{Training}_i + \beta_{13} \ln \text{Creditaccess}_i \\
 &+ \beta_{14} \ln \text{Hhsize}_i + \beta_{15} \ln \text{Weathercond}_i + \varepsilon_i
 \end{aligned}$$

Where maize productivity is measured as the logarithm of maize output per worker. The explanatory variables represent production inputs, farm characteristics, and institutional conditions influencing maize output.

Therefore, estimating maize productivity using Ordinary Least Squares (OLS) produces biased and inconsistent estimates if some explanatory variables are endogenous. Endogeneity arises when explanatory variables are correlated with the error term, typically due to reverse causality, measurement error, or omitted variables (Wooldridge, 2019; Greene, 2018). In contrast, the Two-Stage Least Squares (2SLS) method addresses this issue by using instrumental variables (IVs) that are correlated with the endogenous explanatory variable but not with the error term (Angrist & Pischke, 2008). By utilizing IVs, 2SLS eliminates the bias introduced by endogeneity, providing consistent and reliable estimates of the effect of these factors on maize productivity (Stock & Watson, 2020). Therefore, the 2SLS method is preferable in this context, as it ensures that the estimated relationships between determinants and maize productivity are not confounded by unobserved variables, accurately reflecting the true influences on output.

Validity and reliability

Validity and reliability were rigorously addressed to ensure methodological soundness and empirical credibility. Validity was strengthened through careful operationalization of variables consistent with established agricultural production theory and prior empirical studies on smallholder productivity in Sub-Saharan Africa. Content validity was ensured by grounding the survey instrument in peer-reviewed literature and consulting subject-matter experts in agricultural economics and rural development to confirm comprehensive coverage of technological, institutional, and cost-related determinants. Construct validity was reinforced by aligning measurement indicators with theoretically defined constructs such as technology adoption, market access, and production efficiency. External validity was enhanced through the use of a representative sample of smallholder maize farmers in Songea District, allowing cautious generalization to comparable agro-ecological zones in Tanzania. Reliability was promoted through a pilot study conducted in a similar rural setting to test clarity, consistency, and instrument stability, followed by necessary revisions. Standardized data collection procedures and trained enumerators minimized measurement error and enhanced consistency across respondents.

Ethical considerations

Ethical considerations were strictly observed throughout the research process to safeguard participants and maintain research integrity. Ethical clearance was obtained from the Songea District Council prior to fieldwork to ensure compliance with accepted standards in social science and agricultural research. Informed consent was obtained from all respondents after clearly explaining the study's objectives, procedures, and voluntary nature of participation.



Confidentiality was preserved through anonymization of personal identifiers. Participants retained the right to decline or withdraw from the study at any stage without penalty. The study ensured transparency in data analysis and reporting, avoiding fabrication, falsification, or plagiarism.

RESULTS

Descriptive statistics for smallholder farmers in maize production

This section presents descriptive statistics of the technological, institutional, and cost determinants of smallholder farmers in maize productivity in Songea District, Tanzania. Table 1 summarizes the descriptive statistics for continuous variables and categorical variables. These statistics provide insights into the central tendencies, frequencies, and percentages of these factors among the 397 small-scale maize farmers in Songea District.

Table 1: Descriptive Statistics for study variables

<i>Variable</i>	<i>Category</i>	<i>Frequency</i>	<i>Percent (%)</i>	<i>N=397</i>
Gender	Female	108	27.20	
	Male	289	72.80	
Weather Conditions	Dry Season	143	36.02	
	Rainfall Season	254	63.98	
Market Access	No Access	199	50.13	
	Access	198	49.87	
Access to Credit	No Access	139	35.01	
	Access	258	64.99	
Integrated Pest Management (IPM)	Not Used	133	33.50	
	Used	264	66.50	
Use of Tractors	Not Used	166	41.81	
	Used	231	58.19	
Use of inorganic fertilizer	Not Used	94	23.6	
	Used	303	76.32	
Membership in Cooperatives	Non-Member	145	36.52	
	Member	252	63.48	
	Mean	Std. Dev.	Min	Max
Age	45.68	9.87	22	70
Household Income	2,300,311	718,773	600,000	4,875,602
Household Size	5.95	1.92	2	12
Distance to Market	6.21	2.57	0.50	13.19
Fertilizer Cost per Acre	55,320	13,140	18,750	75,200
Seed Cost per Acre	61,180	8,460	32,900	82,450
Pesticide Cost per Acre	22,010	5,210	7,480	35,860
Extension Visits	2.97	1.61	0	9
Training attended	2.062	1.459	0	10
Years of Schooling	7.93	3.09	0	16
Farming Experience	16.19	6.17	2	34



Land Size	11.94	0.46	6.74	12.00
Labor Number	4.15	0.89	1.93	6.98
Maize Productivity (Output per Worker)	540.62	108.45	280.14	790.33

Source: *Author's Computations from Survey, 2025*

The results in Table 2 indicate that most of the farmers are male (72.8%), which shows that agricultural decision-making and resource control are largely in the hands of men. This pattern reflects the existing structure of rural farming households. A majority of farmers (63.98%) reported operating during the rainfall season, meaning production largely took place under favorable weather conditions. This strengthens confidence that the observed productivity levels are not distorted by widespread drought. However, market access is almost evenly divided, with only 49.87% reporting access. This suggests that a considerable number of farmers face difficulties in reaching markets, which affects their ability to sell produce competitively and obtain better prices. At the same time, access to credit (64.99%) and cooperative membership (63.48%) are relatively high, indicating that institutional support systems are present and active in the district. The high proportion of farmers using inorganic fertilizer (76.32%), IPM (66.5%), and tractors (58.19%) shows that modern farming practices are widely adopted, pointing toward a production system that is progressively intensifying.

The average farmer is about 46 years old with 16 years of farming experience. This indicates that individuals with considerable practical knowledge and long-term engagement in agriculture manage maize production. However, the average schooling level of about eight years shows that most farmers have completed only primary education. This limits exposure to advanced technical knowledge and formal agribusiness skills. Household size averages nearly six members, and labor use averages 4.15 workers per farm, confirming that family labor plays a central role in production activities. The average land size of 11.94 acres reflects moderately sized smallholder farms within the local context. Meanwhile, the average distance to market of 6.21 kilometers highlights a moderate but meaningful transportation burden that directly influences input acquisition and output sales.

The findings also show that input costs per acre, fertilizer, seed, and pesticide, show that maize farming requires significant seasonal investment. Given that average annual household income stands at TZS 2.3 million, these expenditures represent a substantial share of available resources. This presents credit access and cooperative participation in sustaining input use. Maize productivity averages 540.62 kg per worker, with noticeable variation across farmers. The wide gap between the lowest and highest productivity levels demonstrates clear differences in efficiency, resource allocation, and management practices. Overall, the findings indicate that while many farmers have adopted modern inputs and gained institutional access, productivity differences arise from how effectively these resources are utilized rather than from simple participation alone.

The Effect of Technological, Institutional, and Input costs on maize productivity among smallholder farmers

The first-stage results in Table 3 indicate that the instruments are statistically relevant in explaining the endogenous variables. The first-stage regressions confirm the statistical relevance of the instruments in explaining the endogenous regressors. In the fertilizer-use equation, fertilizer cost ($p < 0.01$), years of schooling ($p < 0.01$), cooperative membership ($p <$



0.01), extension visits ($p < 0.01$), and distance to market ($p < 0.05$) significantly predict fertilizer application. These results indicate that human capital, institutional participation, and spatial proximity to markets strongly determine input intensity decisions. Improved seed use is weakly significant ($p < 0.10$), suggesting technological complementarity between certified seeds and fertilizer application. In the credit access equation, years of schooling ($p < 0.01$), fertilizer cost ($p < 0.01$), distance to market ($p < 0.01$), and extension visits ($p < 0.01$) significantly influence access to credit, while pesticide cost is marginally significant ($p < 0.10$). This implies that education, production scale, and market integration shape financial inclusion. In the land size equation, farming experience ($p < 0.01$), years of schooling ($p < 0.05$), and training attended ($p < 0.05$) significantly determine cultivated area, indicating that knowledge accumulation and managerial capacity influence farm expansion.

The diagnostic tests further validate the IV framework. The overidentification test (Score $\chi^2 = 6.7651$, $p = 0.2293$) fails to reject the null hypothesis, confirming that the instruments are exogenous and uncorrelated with the structural error term. Conversely, the endogeneity test ($F(3, 376) = 217.534$, $p = 0.0000$) strongly rejects the null of exogeneity, providing clear evidence that the endogenous variables are correlated with unobserved productivity factors. This justifies the use of the instrumental variable approach rather than OLS. Overall, the results confirm that the instruments are both relevant and valid, and the second-stage estimates represent consistent causal effects of technological, institutional, and input-cost effects on maize productivity.

In the second stage, the results provide strong evidence that maize productivity among smallholder farmers is fundamentally shaped by productive assets, institutional access, and technological intensity. The positive and statistically significant coefficient on land size ($p < 0.05$) indicates scale effects consistent with neoclassical production theory. Larger operational holdings enable better coordination of inputs, improved supervision, and more efficient allocation of labor and capital. Credit access ($p < 0.01$) further strengthens productivity, implying that liquidity constraints are binding in smallholder agriculture. When financial barriers are relaxed, farmers can procure optimal input bundles, aligning actual production closer to the theoretical production frontier.

Technological adoption variables strongly confirm the role of technical progress in shifting the production function upward. Improved seed use ($p < 0.01$), inorganic fertilizer application ($p < 0.01$), IPM use ($p < 0.01$), and tractor use ($p < 0.01$) all significantly increase output per worker. In production theory, such variables represent factor-augmenting technical change. Improved seeds raise total factor productivity by enhancing biological efficiency; fertilizer increases marginal product of land; mechanization raises labor productivity; and IPM reduces output losses from pests. Their joint significance suggests complementarity among inputs, consistent with the Cobb–Douglas framework, where productivity gains arise from optimal input combinations rather than isolated factor expansion.

Institutional and human-capital variables further reinforce theoretical expectations. Market access ($p < 0.01$) enhances productivity by strengthening price incentives and reducing transaction costs, thereby improving allocative efficiency. Training attendance ($p < 0.01$) and income ($p < 0.01$) indicate that managerial capacity and financial strength allow farmers to operate closer to the technically efficient frontier. Household size ($p < 0.01$) and labor number ($p < 0.01$) positively influence output per worker, reflecting the productive contribution of family labor in smallholder systems. Rainy weather conditions ($p < 0.01$) indicate that the production season was characterized by adequate rainfall, which significantly enhanced maize



productivity. This suggests that sufficient and well-distributed rainfall improved soil moisture availability, facilitated nutrient absorption, and supported optimal crop growth cycles.

Conversely, the negative and significant coefficients for fertilizer cost ($p < 0.01$), pesticide cost ($p < 0.01$), and seed cost ($p < 0.01$) indicate diminishing marginal returns to expenditure. From a production theory perspective, these results suggest that beyond an optimal input threshold, additional financial outlays do not proportionally increase output. This aligns with the law of diminishing marginal productivity: as variable inputs increase while other factors remain constrained, marginal return decline. The findings imply that productivity growth depends on efficiency and optimal input allocation.

Table 3: The Effect of Technological, Institutional, and Input costs on maize productivity among smallholder farmers

Variable	First Stage: First Stage: First Stage: Second Stage:	First Stage: First Stage: First Stage: Second Stage:	First Stage: First Stage: First Stage: Second Stage:	Second Stage: In(Maize Productivity)
Years of Schooling	0.0831*** (0.0048)	0.0303** (0.0117)	0.5794** (0.2075)	—
Land Size	—	—	—	0.0641** (0.0322)
Credit Access	—	—	—	0.1757*** (0.0109)
Inorganic Fertilizer Use	—	—	—	0.0023*** (0.0212)
Membership in Cooperatives	0.0294 (0.0322)	0.0476 (0.0551)	4.3800*** (1.3975)	—
Extension Visits	-0.0506*** (0.018.2)	-0.0024 (0.0252)	12.8664*** (1.0280)	—
Age	-0.0014 (0.0014)	0.0014 (0.0122)	-0.0721 (0.0581)	0.0003 (0.0312)
Gender	-0.0242 (0.0338)	0.0247 (0.0611)	0.9783 (1.3943)	-0.0016 (0.0056)
Household Size	0.0062 (0.0071)	0.02100 (0.0136)	-0.0932 (0.3205)	0.0081*** (0.0012)
Labor Number	0.0002 (0.0154)	0.0241 (0.0273)	0.9937 (0.6604)	0.0109*** (0.0026)
ln(Income)	0.0358 (0.0400)	-0.0017 (0.0319)	-0.1682 (1.5629)	0.0748*** (0.0059)
Distance to Market	-0.0734*** (0.0101)	0.0279 (0.0207)	-1.0036** (0.4193)	—
Market Access	0.0466 (0.0508)	0.0855 (0.0756)	-4.0017* (2.2710)	0.1053*** (0.0066)
Improved Hybrid Seed Use	0.0091 (0.0395)	-0.0055 (0.0317)	3.2351* (1.8183)	0.1053*** (0.0064)
Training Attended	0.0044 (0.0108)	0.0297** (0.0146)	-0.2441 (0.4281)	0.0195*** (0.0018)



Variable	First Stage: Credit Access	First Stage: InLand Size	First Stage: Fertilizer Use	Second Stage: ln(Maize Productivity)
IPM Use	-0.0249 (0.0360)	-0.0248 (0.0591)	-0.9626 (1.3766)	0.0716*** (0.0056)
Tractor Use	-0.0209 (0.0293)	0.0777* (0.0455)	1.1250 (1.2869)	0.0791*** (0.0048)
Fertilizer Cost	0.0141*** (0.0232)	-0.0111 (0.0213)	0.2442*** (0.0100)	-0.0007*** (0.00009)
Pesticide Cost	0.325* (0.0343)	0.1343 (0.0564)	0.0171 (0.0106)	-0.0232*** (0.0532)
Seed Cost	-0.0231 (0.0122)	-0.0321 (0.0112)	-0.0049 (0.0113)	-0.0345*** (0.00121)
Weather Condition	-0.0169 (0.0304)	0.0150 (0.0532)	0.7697 (1.2324)	0.0847*** (0.0050)
Constant	-1.0356 (0.6325)	11.0207*** (0.5719)	47.6811* (24.7886)	5.0500*** (0.3952)
Model Diagnosis	Shea's Partial Overidentifying test			Endogenous test
	R-Squared	Score chi2 (1)		F(3, 376) = 217.534
Credit access	0.5597	6.76511 (p=0.2293)		P = 0.0000
Land size	0.4310			
Fertilizer use	0.5926			

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Source: Author's Computations from Survey, 2025

Table 4 presents IV estimates of a Cobb–Douglas production function in log–log specification, and the coefficients on continuous variables are direct output elasticities. These parameters quantify the percentage change in maize output associated with a 1% change in each input, holding other factors constant. The elasticity of inorganic fertilizer use (0.499, $p < 0.01$) indicates that a 1% increase in fertilizer application raises maize output by approximately 0.50%. Since the elasticity is positive but less than unity, fertilizer exhibits diminishing marginal returns: additional units increase output, but at a decreasing rate. Land has an elasticity of 0.853 ($p = 0.020$), implying that a 1% expansion in cultivated area increases output by 0.85%. Although land has the largest elasticity among core inputs, it remains below one, confirming diminishing marginal productivity of land. Labor shows a relatively small elasticity (0.042, $p < 0.01$), indicating that output responds positively to additional labor, but with very low marginal contribution. This places production within Stage II of the neoclassical production region, where marginal product is positive but declining.

The negative elasticities for fertilizer cost (-0.386, $p < 0.01$) and pesticide cost (-0.034, $p = 0.005$) indicate that higher expenditure, conditional on quantities used, reduces output. The apparent inconsistency between the positive effect of fertilizer quantity and the negative effect of fertilizer cost can be explained that, while higher fertilizer application enhances maize productivity through improved soil nutrients and yields, higher fertilizer costs reduce farmers' ability to apply optimal quantities, thereby negatively affecting productivity. This distinction is well recognized in agricultural production theory, where input quantities capture technical



effects, whereas input prices reflect access and affordability constraints that can limit efficient input use. In Cobb–Douglas terms, such negative cost elasticities reinforce the presence of diminishing returns and possible input misallocation. Institutional and technological variables (credit access 0.168; improved seed 0.108; IPM 0.070; tractor use 0.076; market access 0.109; training 0.019; favorable weather 0.082; income 0.073; all $p < 0.01$) shift the production function upward. These do not represent elasticities in the strict continuous sense but semi-elastic effects in log output; they indicate percentage gains in productivity associated with adoption or access. Summing the core input elasticities (fertilizer 0.499 + land 0.853 + labor 0.042 ≈ 1.394) suggests increasing returns to scale overall, despite diminishing marginal returns at the individual input level as presented in Table 5. This pattern is consistent with smallholder production systems where complementary inputs generate scale advantages while each input individually obeys the law of diminishing marginal productivity.

Table 4: IV Regression Estimates from Cobb-Douglas Production Function in log-log form

<i>ln_output</i>	<i>Coef.</i>	<i>St.Err.</i>	<i>p-value</i>	<i>Sig</i>
Ln_inorganic_fertiliser	0.499	0.068	0.000	***
Ln_land size	0.853	0.366	0.020	**
Credit_access	0.168	0.012	0.000	***
Lnlabor_number	0.042	0.011	0.000	***
Ln_seedcost	0.01	0.02	0.607	
Ln_fertcost	-0.386	0.063	0.000	***
Ln_pestcost	-0.034	0.012	0.005	***
Improved_seed	0.108	0.007	0.000	***
Ipm_use	0.07	0.007	0.000	***
Tractor_use	0.076	0.005	0.000	***
Market_access	0.109	0.007	0.000	***
Training_attended	0.019	0.002	0.000	***
Household_size	0.008	0.001	0.000	***
Weather_condition	0.082	0.006	0.000	***
Lnincome	0.073	0.007	0.000	***
Constant	3.757	0.989	0.000	***

*** $p < .01$, ** $p < .05$, * $p < .1$

Source: Author's Computations from Survey, 2025

The elasticity results in Table 5 provide direct evidence regarding returns to scale and marginal productivity in maize production. The joint test of constant returns to scale evaluates whether the sum of the core input elasticities (fertilizer, land, and labor) equals one. The test result ($\chi^2 = 1.09$, $p = 0.2963$) fails to reject the null hypothesis that the sum equals one. The linear combination estimate shows that the total elasticity is approximately 1.394 ($p < 0.01$), meaning that the combined responsiveness of output to these three inputs is statistically different from zero and economically large. However, because the test does not reject equality with one, the evidence does not support decreasing returns to scale. Instead, the production structure is statistically consistent with constant returns to scale.

**Table 5: Tests of Returns to Scale and Input Elasticities (Cobb–Douglas IV Model)**

<i>Hypothesis Tested</i>	χ^2 <i>Statistic</i>	<i>p-value</i>	<i>Decision (5% level)</i>	<i>Economic Interpretation</i>
$\ln(\text{Fertilizer}) + \ln(\text{Land}) + \ln(\text{Labor}) = 1$	1.09	0.2963	Fail to reject H_0	<i>Constant returns to scale</i>
$\ln(\text{Fertilizer}) = 1$	55.14	0.0000	Reject H_0	<i>Diminishing marginal product of fertilizer</i>
$\ln(\text{Land}) = 1$	0.16	0.6881	Fail to reject H_0	<i>Constant marginal productivity of land</i>
$\ln(\text{Labor}) = 1$	7217.20	0.0000	Reject H_0	<i>Diminishing marginal product of labor</i>
<i>Sum of elasticities</i>	1.3939 (0.3771)	0.0000		

Source: *Author's Computations from Survey, 2025*

Then, the individual elasticity tests provide insights into marginal returns. The test for $\ln_{\text{inorganic fertilizer use}} = 1$ is strongly rejected ($p = 0.0000$), meaning the fertilizer elasticity is statistically different from one. Given the Cobb–Douglas structure and earlier results, this implies diminishing marginal productivity of fertilizer (elasticity significantly less than one). The labor elasticity test is also strongly rejected ($p = 0.0000$), indicating labor elasticity differs from one and is also less than unity, supporting diminishing marginal returns to labor. In contrast, the test for $\ln_{\text{land}} = 1$ is not rejected ($p = 0.6881$), meaning land exhibits constant marginal productivity with respect to scale. Overall, the results confirm diminishing marginal productivity for fertilizer and labor individually, consistent with neoclassical production theory. However, the production system as a whole does not exhibit decreasing returns to scale; rather, it is statistically consistent with constant returns to scale in maize production among smallholder farmers.

DISCUSSIONS

The findings indicate that productive assets and institutional access significantly influence maize productivity among smallholder farmers, which is consistent with both empirical literature and neoclassical production theory. The positive and statistically significant effect of land size suggests the presence of scale effects, where larger operational holdings enable farmers to allocate labor and inputs more efficiently and improve coordination of farm activities. This aligns with findings by Utonga (2022), who reported that farm size significantly increased maize yields among small-scale farmers in Tanzania, and by Midamba et al. (2025), who found that farm size positively influenced maize productivity among smallholders in Uganda. Similarly, Oluoch et al. (2022) showed that land availability interacts with agronomic inputs to determine maize productivity in rainfed systems in Kenya, while Dube and Abebe (2023) demonstrated that land allocated to maize production significantly increased maize output among Ethiopian farmers. In production theory, land is a key factor of production; therefore, expanding cultivated land increases the potential output level when combined with complementary inputs and efficient management. Likewise, the positive and statistically significant effect of credit access suggests that liquidity constraints remain a major limitation to productivity among smallholder farmers. Access to credit enables farmers to finance



essential agricultural inputs such as improved seeds, fertilizers, pesticides, and mechanization services, allowing them to apply optimal input combinations and operate closer to the production frontier predicted by production theory. This result is consistent with Abate (2024), who found that rural credit provision significantly increased the likelihood of adopting improved maize seeds among farmers in Eastern Amhara, Ethiopia, because credit enabled farmers to purchase fertilizers and other complementary inputs required for modern maize production. Similarly, Oke et al. (2022) reported that maize farmers in Oyo State, Nigeria, who had access to credit achieved higher levels of production and profitability because financial resources allowed them to invest in labor, inputs, and farm management activities. In Tanzania, Malimi (2023) demonstrated that institutional support programs, including agricultural input subsidies and extension services, improved both land and labor productivity by reducing farmers' financial constraints and facilitating access to productivity-enhancing technologies. Likewise, Asante et al. (2024) showed that institutional and financial support mechanisms, including access to credit and market support systems, significantly increased farmers' adoption of climate-smart agricultural technologies such as row planting, zero tillage, and drought-tolerant maize varieties, which subsequently led to higher maize yields and farm income.

The results further show that technological adoption variables, such as improved seeds, inorganic fertilizer, integrated pest management (IPM), and tractor use, significantly increase maize output per worker, confirming the role of technological progress in shifting the production function upward. According to production theory, these technologies represent factor-augmenting technical change that increases total factor productivity by improving the efficiency with which land, labor, and capital are used. Improved seeds enhance biological productivity, fertilizer increases the marginal product of land, mechanization raises labor productivity, and IPM reduces yield losses caused by pests. These findings align with several empirical studies. Tumuri et al. (2024) found that improved technologies and efficient resource use significantly increased technical efficiency among maize farmers in Ethiopia. Similarly, Oluoch et al. (2022) reported that fertilizer use, certified seeds, and extension services significantly improved maize productivity in Kenya and helped mitigate the negative effects of climate variability. Mncube et al. (2023) also demonstrated that fertilizer regimes and improved weed management practices significantly increased maize yields among smallholder farmers in Eswatini. Likewise, Utonga (2022) identified fertilizer application and improved seed use as key determinants of maize yield in Tanzania. The joint significance of these variables suggests complementarity among inputs, which is consistent with the Cobb–Douglas production framework, where productivity gains arise from optimal combinations of inputs rather than isolated factor expansion.

Market access significantly enhances productivity by strengthening price incentives and reducing transaction costs, thereby improving allocative efficiency. Training attendance and income also increase productivity by strengthening managerial capacity and enabling farmers to invest in improved farming practices. These results align with findings by Oke et al. (2022), Asante et al. (2024), Tumuri et al. (2024), and Midamba et al. (2025), who all found that education, training, and market access significantly improve maize productivity among smallholders. The positive influence of household size and labor availability reflects the importance of family labor in smallholder farming systems, which has also been observed by Mncube et al. (2023). Additionally, the positive and significant effect of rainy weather conditions indicates that adequate rainfall improved soil moisture availability and nutrient



absorption, supporting optimal maize growth, which is consistent with findings by Oluoch et al. (2022) regarding the importance of climatic conditions for rainfed agriculture. Conversely, the negative and significant coefficients for fertilizer cost, pesticide cost, and seed cost suggest diminishing marginal returns to input expenditure. In line with the law of diminishing marginal productivity, increasing input expenditure beyond an optimal threshold does not proportionally increase output when other factors remain constrained. Similar conclusions were reported by Mncube et al. (2023), Oke et al. (2022), Utonga (2022), and Tumuri et al. (2024), who observed that excessive input costs can reduce productivity gains if inputs are not efficiently allocated. Overall, these findings reinforce the theoretical perspective that agricultural productivity improvements depend not only on increasing inputs but also on efficient resource allocation, technological adoption, and supportive institutional conditions.

The IV estimates of the Cobb–Douglas production function further reinforce both production theory and the empirical evidence reported in previous studies on maize productivity. The positive response of maize output increases in key inputs such as fertilizer, land, and labor indicates that these factors remain central determinants of agricultural production among smallholder farmers. However, the results also confirm diminishing marginal productivity, implying that while additional inputs increase output, the rate of increase gradually declines as input use expands. This pattern is consistent with the neoclassical production framework, where rational producers operate within the region of diminishing but positive marginal returns. The strong influence of land on maize production aligns with findings by Utonga (2022) in Tanzania and Midamba et al. (2025) in Uganda, who both reported that farm size significantly increases maize productivity because larger operational holdings allow farmers to apply inputs more effectively and adopt improved farming practices. Similarly, the positive contribution of fertilizer to maize output supports findings from Oluoch et al. (2022) and Mncube et al. (2023), who showed that fertilizer application improves soil fertility and enhances crop performance in rainfed farming systems. The relatively small contribution of labor is also consistent with observations in smallholder agriculture, where family labor is widely available, leading to low marginal gains from additional labor inputs.

At the same time, the negative relationship between input costs and maize productivity suggests the presence of allocative inefficiencies or excessive expenditure beyond economically optimal levels. In line with the law of diminishing marginal returns, increasing expenditure on inputs such as fertilizers and pesticides does not necessarily lead to proportional increases in output when other production factors remain constrained. Similar observations have been reported in earlier studies. For example, Mncube et al. (2023) noted that although fertilizer application increases maize yield, excessive reliance on costly inputs could reduce economic efficiency among smallholder farmers. Likewise, Oke et al. (2022) found that rising input costs among maize farmers in Nigeria could limit productivity gains when resources are not efficiently allocated. Utonga (2022) also highlighted that high input costs often prevent farmers from applying fertilizers and other technologies at economically optimal levels. In addition, institutional and technological factors such as access to credit, improved seeds, mechanization, training, market access, and favorable climatic conditions contribute to upward shifts in the production function by improving farmers' managerial capacity and access to productivity-enhancing technologies. These findings are consistent with studies by Tumuri et al. (2024), Abate (2024), Asante et al. (2024), and Oluoch et al. (2022), all of whom emphasized that technological adoption, institutional support, and improved agronomic practices significantly enhance maize productivity. Overall, the results suggest that productivity improvements among



smallholder farmers depend not only on increasing input use but also on efficient resource allocation, technological adoption, and supportive institutional conditions.

CONCLUSION AND POLICY IMPLICATIONS

Conclusion

The results demonstrate that maize productivity among smallholder farmers is strongly influenced by the interaction of productive assets, technological adoption, institutional access, and efficient input allocation. The instrumental variable estimates confirm that land size, fertilizer use, labor, and access to credit significantly enhance maize output, while technological practices such as improved seed use, integrated pest management, mechanization, training, and market access further shift the production frontier upward. These findings indicate that productivity improvements arise not only from expanding factor inputs but also from technological progress and stronger institutional support systems that enable farmers to combine inputs efficiently. At the same time, the negative relationship between input costs and productivity highlights the presence of allocative inefficiencies and the importance of optimal input use. The elasticity and hypothesis tests further show that maize production operates within the rational Stage II region of the neoclassical production function, where marginal products are positive but diminishing. While fertilizer and labor individually exhibit diminishing marginal productivity, the production structure as a whole is consistent with constant returns to scale, suggesting that proportional increases in key inputs can sustain productivity growth when combined with improved technologies and institutional support. Overall, the findings indicate that improving maize productivity requires a balanced approach that integrates access to productive resources, technological innovation, institutional support, and efficient input management.

Policy Implications

Improving maize productivity among smallholder farmers requires policy interventions implemented within Tanzania's national agricultural frameworks and long-term development strategies. Enhancing farmers' access to key agricultural inputs such as fertilizers, certified seeds, and pest management technologies can be pursued through the Agricultural Sector Development Programme II (ASDP II, 2017–2027) and the National Agricultural Policy of 2013, both of which emphasize agricultural modernization, improved input distribution systems, and stronger private sector participation in agricultural markets. Within these frameworks, targeted input subsidy programs, digital voucher systems, and strengthened agricultural input supply chains can improve the affordability and timely availability of productivity-enhancing inputs for smallholder farmers. Expanding access to agricultural credit is also essential for addressing liquidity constraints that limit farmers' investment in improved technologies. This objective aligns with the Agricultural Sector Development Strategy II (ASDS II, 2015–2025) and the Financial Sector Development Master Plan (2020–2030), which promotes inclusive rural finance systems, strengthened agricultural credit schemes, and expanded financial services through farmer cooperatives and Savings and Credit Cooperative Societies (SACCOS). Strengthening agricultural extension and farmer training systems is guided by the National Agricultural Extension Strategy (2019–2029), which promotes farmer field schools, climate-smart agriculture training, and digital advisory platforms to enhance knowledge transfer and technology adoption. Investments in rural infrastructure and



agricultural market integration are emphasized under the Agricultural Marketing Policy of 2008 and the National Five-Year Development Plan III (2021–2026), which prioritize rural feeder roads, storage facilities, and agricultural market information systems to reduce transaction costs and strengthen farmers' participation in markets. These interventions complement broader development priorities outlined in Tanzania Development Vision 2025 and the National Climate-Smart Agriculture Guideline of 2015, which emphasize climate-resilient farming practices, mechanization services, and sustainable agricultural productivity growth. When effectively implemented, these policy measures contribute directly to the achievement of Sustainable Development Goal 1 (No Poverty) by increasing rural incomes, Sustainable Development Goal 2 (Zero Hunger) through improved food production and food security, Sustainable Development Goal 8 (Decent Work and Economic Growth) by enhancing agricultural productivity and rural employment opportunities, and Sustainable Development Goal 13 (Climate Action) through the adoption of climate-smart and resilient agricultural practices.

Competing interest

The author declares that there are no competing interests associated with this manuscript.

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Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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