

AN ECONOMETRIC ANALYSIS OF THE DETERMINANTS AND CONSEQUENCES OF LAND FRAGMENTATION ON CROP PRODUCTIVITY: EVIDENCE FROM DISTRICT CHARSADDA, KHYBER PAKHTUNKHWA

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DOI: <https://doi.org/10.5281/zenodo.18438460>

Keywords

Determinants and Consequences, Land fragmentation, Crop productivity, OLS regression model, Khyber Pakhtunkhwa.

Article History

Received: 06 December 2025

Accepted: 16 January 2026

Published: 31 January 2026

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Abstract

This paper presents an econometric analysis of the determinants and consequences of land fragmentation on crop productivity in District Charsadda, KP. Through multistage sampling technique a total of 95 sample farming households were selected, and primary data were collected using semi-structured questionnaires and interviews schedule method. Using descriptive statistics Simpson Index, and ordinary least squares (OLS) regression models to analyze the effects of socio-economic and institutional factors on land fragmentation and also the productivity of wheat and maize crop in the study area. The analysis highlighted that the coefficient and p-value for age was ($\beta = -0.005$, $p < 0.01$) and for education was ($\beta = -0.013$, $p < 0.01$) were negatively and significantly associated with agriculture land fragmentation, indicating that aging and higher educated sampled farmers tend to have more consolidated land. As compare, household size ($\beta = 0.018$, $p = 0.01$), for urban pressure ($\beta = 0.121$, $p < 0.05$), for inheritance law ($\beta = 0.141$, $p = 0.013$), and for tenancy status was ($\beta = 0.173$, $p = 0.048$) were positive and significant effected land fragmentation, suggesting that greater families, urban expansion, traditional inheritance systems, and insecure tenure contribute to greater land fragmentation. About crop productivity, fragmented landholding had significantly decrease wheat ($\beta = -11.997$, $p = 0.016$) and maize productivity ($\beta = -10.308$, $p < 0.05$). However, the other statistically significant factors included age and education of household head, farm size, access to agricultural credit, and access to extension services were negative associated, while labor availability was positively affected maize productivity. This study concludes that socio-economic and institutional

factors were critically impact on land fragmentation, which in turn negatively influence on crop productivity, emphasizing the need for policies targeting land consolidation, implement effective inheritance policies, efficient agriculture credit use, and enhanced extension services to improve crop productivity.

Introduction

Land fragmentation refers to the partition of a single agricultural landholding into numerous small and dispersed plots, and it is typically caused by inheritance systems, population increase, and land market forces. Fragmented holdings normally lead to inadequacies in agricultural operations, such as higher costs of production, underutilization of equipment & machineries, and constraints to mechanization. For instance, in Shaanxi Province in China's, agricultural land fragmentation has progressively increased between "2000-2020," limiting agricultural modernization and efficiency, with population growth and geography acknowledged as major drivers (Zhao and Feng, 2024). While, similar problems have been observed in forested landscapes of the Himalayan temperate region, where land fragmentation threatens environmental stability and complicates conservation and sustainable land management efforts (Mehmood et al., 2024).

Moreover, land fragmentation has been broadly linked with decreases in crop productivity, specifically in smallholder dominated farming systems. Fragmentation of plots typically results in late sowing, irregular fertilizer application and raised labor costs, all of which act to diminish yield efficiency. Tropical regions, studies throughout South Asia and Africa show that farmers with more fragmented land, have lower output per hectare because they do not coordinate farm management effectively, they do not mechanize and coordination costs may be higher as more legal holdings increases the costs of production management for the farm (Rahman and Rahman, 2009; Xue et al., 2020). Empirical evidence indicates that more fragmented land will reduce output as many agricultural technologies that are modern and sought after require specific holdings to be adopted, managed/controlled e.g., precision farming, improved irrigation systems, and mechanized harvesting (Phan et al., 2022). All those issues suggest, land fragmentation reduces crop productivity directly, by providing a less efficient overall operation to produce crop products

with more situational production restrictions. At the same time, researchers note that fragmentation can occasionally produce diverse outcomes. However farmland consolidation is habitually promoted to increase scale economies and reduce inefficiencies, it may also have unintended environmental trade-offs. For example, widespread pesticide usage and consolidation processes may exacerbate the loss of biodiversity and lead to new sustainability problems (Moretti and Benzaquen, 2024). Furthermore, land fragmented plots can encourage crop diversity, boosting flexibility and household food security in a variety of subsistence-oriented scenarios (Ntihinyurwa and de Vries, 2021). This disparity highlights the significance of creating land-specific structural plans that strike a balance between social and ecological sustainability and economic performance.

Global agricultural land fragmentation has become a major problem for farming systems worldwide, especially in regions with high population densities, rapid urbanization, and inheritance-based land fragmentation patterns. Around Asia, sub-Saharan Africa, and some parts of Eastern Europe, smallholder farmers face reducing and scattered plots that decrease the efficiency of land use and pose major difficulties for mechanization, irrigation, and the adoption of modern technologies (Van Dijk et al., 2021). However, the recent studies emphasize that land fragmentation not only undermines agricultural efficiency but also contributes to increase costs of production, fragile market integration, and lower rural incomes, thereby worsening food security concerns at both local and worldwide levels (Wu et al., 2023). Additionally, the worldwide scenario shows that while some developed countries have countered this trend through land consolidation programs, in various developing countries land fragmentation is increasing due to increasing population growth, rural housing development, and inheritance land subdivision (Demetriou, 2013). At the worldwide level, therefore, land fragmentation is not a single issue with a single remedy: its prevalence and effects depend on

institutional arrangements (land rights and transferability), farm structure, access to mechanized or shared services, and non-farm livelihood opportunities.

The farming consequences of land fragmentation are multidimensional and context dependent, but a clear body of current work relations land fragmentation to reduced mechanical and labor efficiency, higher per-unit costs of production, and obstacles to technology adoption in various situations. Experimental studies using farm-level and landscape data show that land fragmentation can prevent modernization, increase travel and operation time between plots, and discourage adoption of mechanized and precision technologies effects that usually translate into lower efficiency and, in several cases, lower produces or higher input intensity (Chi et al., 2022; Zhou et al., 2024). Connected investigation also highlights indirect ecological and agronomic effects: fragmented holdings may encourage crop diversification that can improve household resilience, yet they can also lead to higher chemical-input use when mechanization is inadequate (Chi et al., 2022). Besides, bio-economic modelling recommends that hostile consolidation strategies intended to increase scale and productivity can, under business-as-usual conditions, accelerate pesticide-intensification and biodiversity loss, except consolidation is coupled with environmental protections and careful pesticide management (Moretti and Benzaquen, 2024). Taken together, the recent works consequently highlights that effective policy must be multifunctional promoting suitable consolidation or collaboration that increases working scale and mechanization access, while protection ecological outcomes and protecting smallholder livelihoods through context-sensitive measures such as land-service markets, cooperative machinery hiring, ICT extension, and targeted social support (Hao et al., 2023; Zhou et al., 2024).

Land Fragmentation in Pakistan with a Focus on Khyber Pakhtunkhwa

Land fragmentation in Pakistan has increased over recent decades as a result of population growth, inheritance norms, rural housing development, and land market burdens, creating a landscape conquered by small, dispersed holdings that dare modern farming practice. Countrywide and district level studies document increasing parcelization and reducing

average farm size, predominantly in Punjab and Khyber Pakhtunkhwa, where per-capita cultivated land is low and the law of inheritance commonly distributes land holdings into ever smaller plots (Kousar et al., 2020). Geospatial examines in Peshawar indicated that land fragmentation increased significantly between 1990-2020 in sampled villages, driven mostly by inheritance-law and urban encroachment, a pattern that shrinks adjacent arable area and complicates land-use planning and mechanization (Naz, et. al., 2023). These important advances have a significant effect on rural living because they limit the scale of economies required to increase agricultural production and market orientation, increase labor and operating costs, and decrease the efficient use of technology. The observed proof from Pakistani studies on how land fragmentation converts into agronomic outcomes is mixed but tends toward negative effects on crop yield and effectiveness when fragmentation is severe and support services are fragile. A farm-level study in Punjab initiate that higher Simpson-index land fragmentation was related with lower crop efficiency and reduced adoption of modern machineries, implying that fragmented farms face higher labor and costs of coordination and are fewer able to benefit from mechanization or enhanced management (Kousar et al., 2020). Similar field surveys in Khyber Pakhtunkhwa report that land fragmentation usually increases unit costs of production and discourages investment in capital-intensive practices, although some studies note short-term adaptive responses (such as strengthened management of small plots) that can provisionally offset losses (Khan & Shah, 2024).

District Charsadda (Khyber Pakhtunkhwa) is suffering increasing pressure on farming land from population growth, housing expansion, and new commercial activities, which together encourage the subdivision of land holdings and the scattering of plots. Recent planning documents for Charsadda note increase speed peri-urban sprawl and competing land uses, and lay out zoning and growth-management responses to protect farming land while accommodating urban and industrial development. The proposed financial initiatives and transport linkages for Charsadda and the possible increase in land values around the urban fringe and parcelization (unless controlled by land use regulations and cadastral record keeping being guided) is similar to a scenario-mapping exercise (Urban Policy

Unit, 2024). More concretely, such an exercise enables the prediction of dispersed, smaller units of agricultural consolidation which will complicate access to fields, irrigation, and improvements to coordinated land plans. The productivity implications in Charsadda are consistent with the considerable evidence from Khyber Pakhtunkhwa (KP). In areas with inadequate service markets and extension assistance, land fragmentation can lower technical expertise, discourage mechanisation, and increase operating and travel expenses between plots. However, an empirical analysis using the Simpson index reveals that in certain localities, farmers respond to land fragmentation with more intensive plot management, which can partially offset losses and even associate with higher measured output, though such gains may be expensive and difficult to scale (Khan and Shah, 2024).

Problem Statement and Justification

Land fragmentation in many developing countries is seen as a major basic problem in agriculture. Former studies conducted in countries like, Ethiopia, India, and China have revealed that fragmented land plots shrink effectiveness, increase cost of production, bounds mechanization, and eventually lower crop productions (Manjunatha et al., 2020; Demetriou, 2021; Wu et al., 2023). Study in parts of Khyber Pakhtunkhwa and Punjab, Pakistan, also confirms that inheritance-law designs, increasing population growth, and land-use change are significant drivers of land fragmentation, with severe implications for farming productivity and rural incomes. However, most of these studies have remained local or generalized, with very inadequate evidence specially focused on District Charsadda. Charsadda District represents a single case where increase population growth, cultural inheritance practices, fast and increasing demand for non-agricultural land uses have strengthened farmland subdivision. Although its importance as an agrarian hub, a slight experimental research work has been done to identify the determinants and consequences of land fragmentation and its direct effect on crop efficiency. Addressing this research gap is important because Charsadda's rural households mostly heavily depend on agriculture for their livelihood and food security. By examine the socio-economic and structural drivers of land fragmentation, as well as quantifying its effects on crop productivity, the current study will

provide evidence-based perceptions for officials, planners, and extension workers. The conclusions will contribute to designing policies for land consolidation, cooperative farming, and sustainable agricultural development, thereby improving productivity and confirming food security in District Charsadda. The following are the main objectives of the study.

Study Objectives

- To identify and quantify the key socio-economic factors contributing to land fragmentation.
- To assess the perceived and actual influences of land fragmentation on crop productivity, with especially on wheat and maize in the study area.

Research Questions

- Which socio-economic and Institutional factors significantly determine land fragmentation?
- What is the influence of land fragmentation on wheat and maize productivity, based on perceived and actual productivity measures?

Material and Methods

Study Area and Sampling Design

This study was conducted in Charsadda district Khyber Pakhtunkhwa. Charsadda District is the western parts of Khyber Pakhtunkhwa, Pakistan. This district was mostly rural area, where majority of the household heavily depend on agriculture for their livelihood and food security. However, land fragmentation has risen as a major extensive problem, disturbing the efficiency of farming practices and the overall agriculture productivity. Issues like inheritance-laws, rapid growth of population, and inadequate landholding size have contributed to the increasing fragmentation of agricultural land. This condition has generated issues in assuming modern agricultural practices and technologies, leading to compact production and inadequacies in farm management. Therefore, Charsadda district provides an appropriate location to examine the determinants of land fragmentation and its consequences for crops productivity. A multistage sampling technique was used for selection of the sampling design for the study. In the 1st stage, Tehsil Shabqadar was chosen out of the three tehsils namely; (Charsadda, Shabqadar & Tangi) of District Charsadda. At the 2nd stage, UC Hassan Zai was selected purposively, and in the 3rd stage, two villages, namely; Katozai and Khubai, were taken as the study area while in final stage a total of 95 farming households were selected through using the

following Yamane’s formula from the total number 1933 of farming households in these two villages.

$$n = \frac{N}{(1+N(e)^2)} \dots\dots\dots 1.1$$

Whereas n is a sample size, N is a total number of households in the study area while, e is a precision level which is set at 10 percent (0.10). After the total sample size selection, 70 sample were taken from village Katozai and 25 from Khubai village through proportional allocation sampling technique.

Data Collection and Analytical Framework

Primary data were collected using both qualitative and quantitative approaches to gather comprehensive information on land fragmentation and its impacts. For this purpose, a semi-structured questionnaires were made to gathered information. In-depth interviews were conducted with experienced farmers, for providing qualitative insights into the historical and socio-cultural features of land fragmentation. After the collection of data, it was entered and processed using SPSS for analysis. Descriptive statistics (frequency and percentage) were used to summarize the socio-economic characteristics and institutional factors of the household. While, an Ordinary Least Squares (OLS) regression model was used to identify the determinants of land fragmentation and its consequences on wheat and maize productivity in the study area.

Econometric model

To examine the determinants of land fragmentation, the Simpson Index was used as a continuous dependent variable. The following formula equation was used to calculate the Simpson index of land fragmentation.

$$S = 1 - \sum_{i=1}^n \left(\frac{Ai}{A}\right)^2 \dots\dots\dots 1.2$$

Whereas Ai is the area of each plot and A is the total land area. The calculated Simpson Index values range “was 0 to 1”, while an Ordinary Least Squares (OLS) regression model was used to analyze the socio-economic and institutional factors of land fragmentation. The explanatory variables included in the model were Age, education of household head, household size, inheritance law, access to agriculture credit, urbanization pressure, and tenancy status. The higher Simpson Index values indicating greater land fragmentation. The general equation of Ordinary Least Square regression model is given below;

$$Y_i = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_5D_{1i} + \dots + \beta_7D_{4i} + \mu_i \dots\dots\dots 1.3$$

Whereas:

- Y_i = Dependent variable (Simpson index of land fragmentation)
- β_0 = Intercept
- $\beta_1, \beta_2, \dots, \beta_7$ = Regression coefficients to estimate
- $X_{1i}, X_{2i}, X_{3i}, D_{1i}, \dots, D_{4i}$ = Explanatory variables
- μ_i = Error term

For this current study, the specified OLS regression model is:

$$SILF_i = \beta_0 + \beta_1Age_i + \beta_2Edu_i + \beta_3HHS_i + \beta_4Inheritance_i + \beta_5UP_i + \beta_6Tenancy_i + \beta_7AC_i + \mu_i \dots 1.4$$

Whereas;

- Y_i = SILF (Simpson Index of Land Fragmentation)
- X_1 = Age (Age of household head, years)
- X_2 = Edu (Education level, years of schooling)
- X_3 = HHS (Household size, number of members)
- D_1 = Inh (Inheritance; dummy: 1 = fragmented due to inheritance, 0 = otherwise)
- D_2 = UP (Urbanization pressure; 1 = Yes, 0 = No)
- D_3 = Ten (Tenancy status; dummy: 1 = tenant/rented land, 0 = owner only)
- D_4 = AC (Access to credit; dummy: 1 = Yes, 0 = No)

To examine impact of land fragmentation on wheat and maize productivity the following specific ordinary least square regression model was used.

$$Wheat + Maize Yields = \beta_0 + \beta_1SI_i + \beta_2Age_i + \beta_3Edu_i + \beta_4FS_i + \beta_5AC_i + \beta_6Lab_i + \beta_7AE_i + \mu_i \dots 1.5$$

Whereas;

- X_1 = SI (Simpson Index of land fragmentation)
- X_2 = Age (Age of HH head)
- X_3 = Edu. (Education level, years of schooling)
- X_4 = FS (Farm size)
- D_1 = AC (Access to credit; dummy: 1 = Yes, 0 = otherwise)
- D_2 = Lab (Labor availability; dummy: 1 = Sufficient, 0 = Insufficient)
- D_3 = AE (Access to extension services; dummy: 1 = Yes, 0 = otherwise)

Results and Discussion

Descriptive Statistics

The table 1 showed the demographic and institutional factors descriptive statistics included in the analysis. The table results highlighted that average age of the household head was 56 years, with minimum age was 21 and maximum 76 years, indicating that middle to

older aged individuals' were mostly managed by agriculture activities. The findings also showed that the average level of education of the household head was 8 years representing that most of the household heads have completed primary to middle level of education, while a smaller percentage have completed higher level of education or have no formal education. The results illustrated that averaged household had 9 members, with minimum 2 members and maximum of 25. The results showed that 66% of households were subject to inheritance legislation with regard to institutional and background characteristics,

highlighting the significant influence that inheritance practices play in land subdivision. Urban pressure almost affected 51% of the sampled households' farmland and 54% of the households operated under tenancy arrangements, while 47% had access to agriculture credit facilities, suggesting that moderate levels of tenure security and financial access in the study area. The overall table results indicated a comprehensive profile of the institutional, and socio-economic characteristics of the sampled households, which serve as critical explanatory variables in the subsequent econometric analysis.

Table 1. Descriptive statistics of household-level socio-economic variables

Variables	N	Min.	Max.	Mean	Std. Deviation
Age of the household head	95	21	76	56.00	13.586
Education of the household head	95	0	18	8.00	6.646
Household size	95	2	25	9.00	4.922
Inheritance law	95	0	1	.66	.475
Urban pressure	95	0	1	.51	.503
Tenancy status	95	0	1	.54	.501
Access to credit	95	0	1	.47	.502

Effects of Household Socio-Economic and Institutional Factors on Land Fragmentation

The OLS regression model was estimated to analyze the effect of household socio-economic and institutional variables on land fragmentation. The regression model showed a good explanatory power, with an R² value of 54.4%, indicating that more than half of the variation was explained by the explanatory variables in land fragmentation which is included in the model. The F-statistic (14.858) and its corresponding p-value (.000) were statistically significant at the 1% level of significance, confirming the overall goodness of fit and reliability of the estimated model. The model incorporated key household and institutional characteristics, including a socio-economic and institutional variables such as the age and education of the household head, household size, inheritance law, urban pressure, tenancy status, and access to credit. While the associated t-values and p-values revealed their statistical significance, the evaluated regression coefficients presented insights into the direction and strength of these associations. The findings of table 2 demonstrated a statistically significant negative correlation between land fragmentation and the age of the household head. The coefficient value for age was ($\beta = -0.005$), and p-value was (.006) which is <0.01, indicating that if one year

increase in the age of the household head, eventually declined land fragmentation by 0.005 units. Because older farmers tend to manage more consolidated landholdings. This reveals that more farming experience and long-term planning contribute to lower land subdivision. Similarly, education of the household head was negatively and statistically highly significant association with land fragmentation. The regression coefficient for education was ($\beta = -0.013$), and p-value was (0.001) which is < 0.01, suggesting that if one year increase in education, land fragmentation decreases by 0.013 units, representing that educated household heads are more likely to know the economic inefficiencies associated with fragmented landholding and adopt better land management and inheritance strategies. This study findings align with Duangbootsee (2024), they specified that older and more educated household heads tend to have less fragmented landholdings, as their farming experience and education contribute to better land consolidation in rural areas. In contrast, household size had a positive and statistically highly significant association with land fragmentation with coefficient value was ($\beta = 0.018$), and p-value was (0.001) which is <0.05. This results underscored that if a one member of household increase, land fragmentation increased by 0.018 units, reflecting

demographic pressure on land resources and the tendency toward subdivision among family members, consistent by Aslam and Fazal (2025), they argued that, population growth and pressure are the major causes contributing to increased land fragmentation. However, landholding fragmentation was also significantly influenced by institutional factors. The results of Table 2 showed that inheritance legislation and land fragmentation were positively and statistically significantly correlated. Land fragmentation increases by 0.141 units for every unit rise in inheritance-related activities, according to the regression coefficient value for inheritance legislation ($\beta = 0.141$) and ($p = 0.013$), which is less than 0.05. This indicates that property subdivision is still largely influenced by traditional inheritance arrangements, reliable with Gatterer et al. (2024), who revealed that partible inheritance customs significantly increased agriculture land fragmentation, emphasizing inheritance patterns as a vital factor of land fragmentation. Moreover, there was a positive and statistically significant association between urban pressures with land fragmentation. The coefficient value was ($\beta = 0.121$) and p-value was (0.018), which is < 0.05 . This indicates that if urban pressure increase by one unit, land fragmentation would eventually rise by 0.121 units. This suggests that land division in peri-

urban and rural areas is accelerated by urban growth and rising land demand. This study is similar to Yuan et al. (2022), they found that farmland fragmentation was greatly increased by rapid urban growth. Furthermore, there was a statistically significant and positive correlation between land fragmentation and tenancy status. Tenancy status had a coefficient value of ($\beta = 0.173$) and a p-value of (0.048), which is less than 0.05. This suggests that by preventing long-term land consolidation, unstable or informal land tenure arrangements contribute to fragmented landholding patterns. Pierri et al., (2025) consistent with the current findings they suggested that insecure land tenure arrangements contribute to greater land fragmentation by limiting landholding consolidation. Conversely, access to credit did not show a statistically significant effect on land fragmentation ($\beta = 0.008$, $p > 0.05$), suggesting that financial access alone does not influence land subdivision decisions in the study context. The table results overall, indicate that demographic factors (age, education, household size) and institutional factors (inheritance law, urban pressure, tenancy status) play an important role in affecting land fragmentation, whereas access to credit does not have a meaningful impact.

Table 2. Effects of household socio-economic and institutional variables on land fragmentation

Explanatory variables	β	Std. Error	t-value	P-value
Age of the household head	-.005	.002	-2.833	.006***
Education of the household head	-.013	.004	-3.347	.001***
Household size	.018	.005	3.451	.001***
Inheritance law	.141	.056	2.534	.013**
Urban pressure	.121	.050	2.404	.018**
Tenancy status	.173	2.610	-2.003	.048**
Access to credit	.008	.050	.155	.877 ^{ns}
Constant	.578	.154	3.742	.000***

Number of observation = 95, $R^2 = 54.4\%$, F-value = 14.858, P-value = .000

*** = Highly significant

** = Significant

ns = Non-significant

Land Fragmentation and Socio-Economic Factors Effect on Wheat Productivity

The ordinary least squares (OLS) regression model was used to assess the impact of land fragmentation and socio-economic factors on wheat productivity. The model is statistically significant ($F = 9.997$, $p < .001$) and accounts for approximately 45% of the variation explain in wheat productivity, representing that the independent variables communally have a significant

effect on yield outcomes. The table 3 results indicated that land fragmentation had a negative and significant association with wheat productivity. The coefficient for Simpson index of land fragmentation was ($\beta = -11.997$, and $p = .016$) which is < 0.05 , indicating that if one unit increase in the Simpson Index, wheat productivity decreases by approximately 12 units, suggesting that more land fragmentation reduces efficiency and yield. This result align with Mwendwa et

al., (2024), indicated that land fragmentation was related with lower agriculture productivity, with fragmented farms showing reduced crop yields due to poor land use and management. Age of HH head had a negative and statistically highly significant effect on wheat productivity. The coefficient and p-value for age was ($\beta = -0.489$, and $p = .000$) which is $<.0.01$, reveals that if one year increase in age ultimately reduce wheat productivity by 0.49 units. Because old farmers may adopt modern technology less commonly. Tong et al., (2024) study consistent with this study, they found that aging farmers significantly decreases agricultural productivity, reflecting lower productivity among older farmers. The results showed that education of the household head was statistically significant association with lower wheat productivity ($\beta = -0.811$, $p < .001$). If one year increase in education level decreases productivity by 0.811 units, probably because more educated heads involve in off-farm employment activities or less intensive farming, consistent with findings by Bai, et al., (2023), who stated that higher human capital and off-farm engagement can decrease on-farm productivity. The regression results revealed that larger farm size was significantly associated with lower wheat productivity with farm size coefficient value was ($\beta = -0.712$, and $p = .028$) which is $<.0.05$, they indicating that if one acre increase in farm size, decreases wheat productivity by 0.71 units, due to less

intensive management on larger farms, align with Sheng et al., (2019), who urged that productivity per unit of land tends to drop as farm size increases. Access to agricultural credit was statistically significant association with lower wheat productivity ($\beta = -9.048$, $p = .002$). If a one unit increase in credit decline productivity by approximately 9 units, indicating that it may not always be used efficiently for wheat production, consistent with study of Nyirongo (2025), who stated that poor credit management and frequent use of loans for non-farm purposes limited the expected gains in farm productivity. Labour availability had no statistically significant effect on wheat productivity ($\beta = 0.987$, $p = .786$). The results highlighted that access to extension services had a significant and negative association with wheat productivity. The coefficient value for extension service was ($\beta = -6.970$), and p-value was (.013) which is $<.0.05$, suggesting that if a one unit increase in access to extension service wheat production decreases by around 6.97 units, possibly due to inefficiencies in service delivery or directing of farmers with production issues. These results are reliable with Aremu et al. (2025), who stated that publicly funded extension services in Nigeria were related to both unanticipated negative consequences and modest productivity enhancements.

Table 3. Effects of Land Fragmentation and Socio-Economic Factors on Wheat Productivity

Explanatory variables	β	Std. Error	t-value	P-value
Simpson Index of land fragmentation	-11.997	4.905	-2.446	.016**
Age of the household head	-.489	.102	-4.812	.000***
Education of the household head	-.811	.199	-4.072	.000***
Farm size	-.712	.320	-2.228	.028**
Access to agriculture credit	-9.048	2.813	-3.216	.002***
Labour availability	.987	3.625	.272	.786 ^{ns}
Access to extension services	-6.970	2.746	-2.539	.013**
Constant	254.216	7.806	32.569	.000***

Number of observation = 95, $R^2 = 44.6\%$, F-value = 9.997, P-value = .000

*** = Highly significant

** = Significant

ns = Non-significant

Factors Influencing on Maize Productivity

Table 4 presented the OLS regression estimation, examining the effects of land fragmentation and the selected socio-economic and institutional factors on maize productivity. The value of R^2 of 55.7% in model shown a good explanatory power, representing that more than half of the variation was explained by the included explanatory variables in maize productivity. The model's overall goodness of fit was confirmed by the F-statistic (15.612) and associated p-value (.000), which were statistically significant at 1% level of significance. While the corresponding p-values established the statistical significance of the relations between the independent variables and maize productivity. The calculated regression coefficients shed light on the direction and strength of those relationships. The following section interprets these results, highlighting how a one-unit increase in each explanatory variable affects maize productivity, along with relevant support from previous empirical studies. The table 4 findings exhibited negative and a statistically significant correlation between the Simpson Index of land fragmentation and maize productivity. If one-unit increase in land fragmentation decreases maize productivity by 10.31 units, according to the Simpson Index of land fragmentation regression coefficient value ($\beta = -10.308$, $p < 0.05$) when all other variables are held constant. This findings indicated that increasing land fragmentation had a negative impact on maize productivity because it makes management more challenging and rises input costs. This result is align with a study by Aslam and Fazal (2025), they found that land fragmentation making farm management more difficult and raising costs, resulting lower agricultural output. The production of maize was

negatively and statistically significantly impacted by the age of the head of the family. The regression coefficient for age was ($\beta = -0.500$, $p < 0.01$), indicating a 0.50 unit decrease in maize yield for every year increase of age. This study showed that productivity declines with farmer age, most likely as a result of diminished physical capacity or a slower adoption of contemporary farming techniques. This result similar with study of Su et al., (2024), they suggested that aging farmers tends to have lower agricultural productivity because older farmers are less likely to adopt new technologies and face physical constraints in farm operations. Similarly, education of the household head was negatively and statistically significant relationship with maize productivity. The coefficient value was ($\beta = -0.880$, $p < 0.01$), indicating that if one year increase in level of education, decline in maize productivity by 0.88 units. This implies that educated household heads tend to engage more in off-farm activities, thereby reducing attention to farm management. This study result also similar with Chang et al., (2022) study, the suggested that higher education can lead household heads to involve more in off-farm activities and decrease their on-farm labor input, potentially lowering farming output. The table 4 results also indicated that Farm size had a negative and statistical significant effect ($\beta = -0.758$, $p < 0.01$), implying that a one unit increase in farm size, decrease in maize productivity by 0.76 units. This results shows that larger farm sizes may experience inefficiencies in input management or labor supervision under prevailing conditions. This results same like with Aragon et al., (2022) study, they indicated that farm productivity can decline as farm size increases, predominantly when measured at the yield level, due to difficulties in farm organization and resource

allocation. Access to agricultural credit had significantly and negatively relationship with maize productivity. The coefficient value for credit was ($\beta = -8.560$, and $p < 0.01$). These findings imply that credit may be misdirected to non-farm activities rather than being used for inputs that increase production. The findings were in line with Chandio et al. (2018), who indicated that farmers occasionally use agricultural loans for purposes other than farming, which lessens their influence on output results. Table 4 results indicated that maize productivity was positively and statistically significantly impacted by the labor availability. The labor availability regression coefficient and p-value were ($\beta = 7.195$, $p < 0.05$), indicating that if one labor availability increase, 7.20 unit increase in maize productivity. This findings

indicated that households with more labor resources are better equipped to manage the maize cultivation, which results in higher productivity. This findings are similar with Wani and Minja (2025), who urged that increased labor use significantly rises agricultural productivity by facilitating effective and timely farm operations. Lastly, there is a statistically significant negative correlation between access to extension services and maize productivity. The regression coefficient and p-value ($\beta = -8.334$, $p < 0.01$) suggest that the quality, targeting, and relevance of current extension services to farmers' real needs may be insufficient. These results are reliable with Maaka and Antwi (2022), who stated that various farmers believe public extension services are inadequate for raising farm productivity.

Table 4. Econometric Analysis of Factors Influencing Maize Productivity

Explanatory variables	β	Std. Error	t-value	P-value
Simpson Index of land fragmentation	-10.308	4.534	-2.273	.025**
Age of the household head	-.500	.090	-5.567	.000***
Education of the household head	-.880	.183	-4.811	.000***
Farm size	-.758	.283	-2.677	.009***
Access to agriculture credit	-8.560	2.489	-3.439	.001***
Labor availability	7.195	2.910	2.472	.015**
Access to extension services	-8.334	2.454	-3.396	.001***
Constant	253.375	6.643	38.140	.000***

Number of observation = 95, $R^2 = 55.7\%$, $F\text{-value} = 15.612$, $P\text{-value} = .000$

*** = Highly significant ** = Significant

Conclusion and Recommendations

This study concluded that both demographic and institutional determinants play a critical role in determining land fragmentation and agriculture productivity. The findings indicated that aging and more educated household head were found to maintain more consolidated landholdings, reflecting accrued farming experience and operative land management. However, increased land fragmentation was caused by larger households, traditional inheritance customs, urban pressure, and insecure tenancy status. The productivity of wheat and maize was significantly impacted by land fragmentation as well as socio-economic and institutional factors such as age, education of household head, farm size, access to agriculture credit, labor availability, and access to extension services. Increased labor availability had a favorable influence on maize productivity, but higher land fragmentation, older farmers, higher education, larger farms, ineffective credit utilization, and poorly

targeted extension services were associated to lower agriculture production. These results highlight how crucial it is to integrate structural land policies, efficient extension service programs, and efficient credit systems in order to increase production. Overall, the study's findings show practical approaches to increase crop yields and farm productivity in rural areas impacted by land fragmentation and socio-economic restrictions. In order to stop unnecessary land fragmentation, it is recommended that the government and development agencies establish efficient inheritance laws and encourage land consolidation in the study area. Farm management and resource utilization on larger and more dispersed farms can be improved by bolstering extension services with focused technical assistance and closely watched loan schemes.

Study Limitations and Future Research

The cross-sectional data used in this study is insufficient since it shows correlations at a single point

in time and is unable to demonstrate causal knowledge. Only a few institutional and socio-economic factors were examined, and the use of self-reported household data may involve recollection problems. However, other significant factors that may also have an impact on land fragmentation and agricultural output were left out, such as soil quality and market access. For a better understanding of agricultural production, longitudinal data should be used in future study along with ecological and market-related aspects.

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