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ASSESSING THE IMPACT OF LAND FRAGMENTATION ON CROP PRODUCTIVITY: AN EMPIRICAL STUDY IN KHYBER PAKHTUNKHWA

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ABSTRACT

Agriculture is a vital sector of Pakistan's economy, yet its growth is increasingly hindered by land fragmentation, which adversely affects agricultural productivity. This study aims to empirically assess the impact of land fragmentation on crop productivity in the rural areas of Khyber Pakhtunkhwa. Data were collected from 163 farmers, and the Simpson index was employed to quantify the degree of land fragmentation. To evaluate the impact on agricultural productivity, the multiple linear regression model was utilized. The results indicate a positive relationship between land fragmentation and crop productivity, suggesting that fragmentation may drive farmers to optimize land use and management practices. These findings underscore the need for informed land use policies that address the nuances of fragmentation to enhance agricultural outcomes. The study offers valuable insights for policymakers aiming to balance land distribution and agricultural efficiency.

Keywords: Land fragmentation, crop productivity, multiple linear regression model, Simpson index, Khyber Pakhtunkhwa.

INTRODUCTION

Land is a fundamental resource that underpins political, social, and economic development, and it is essential for human survival and ecosystem maintenance. In Khyber Pakhtunkhwa (KP), Pakistan, the patterns of land use are rapidly evolving due to changing physiographic conditions, socioeconomic factors, climate variability, and population growth (FAO, 2011). Land fragmentation, a widespread issue in many developing countries, has led to the division of large landholdings into smaller, scattered plots, resulting in inefficient land use and resource management. This fragmentation significantly impacts agricultural productivity, rural development, and food security. The changing land use patterns in KP reflect the region's socioeconomic conditions and the increasing demands of society, which in turn place pressure on the environment. As Jayne (2017) noted, a similar trend is evident in Africa, where average farm sizes are declining in densely populated smallholder areas, exacerbating the challenges of land fragmentation. The phenomenon of land fragmentation is defined as households managing multiple non-contiguous plots, either owned or rented, simultaneously. Various factors contribute to this issue, including traditional inheritance systems that subdivide land among heirs, leading to progressively smaller and more dispersed plots (Gebeyehu, 1995).

Globally, land fragmentation poses challenges such as reduced parcel sizes, irregular shapes, and scattered locations, which collectively hinder efficient agricultural production (Demetriou et al., 2013; Gonzalez et al., 2007). In South Asia, where land is a primary source of livelihood for the majority, the ties between land and people's lives are strong, influencing their goals, prosperity, and social standing (Akintayo and Lawal, 2016). However, the number of landowners is declining, and the average landholding size has decreased significantly over the years (FAO, 2001; CIRDAP, 1987). In KP, Pakistan, the average landholding per individual has shrunk from 0.10 hectares in 1980 to 0.06 hectares, highlighting the ongoing challenge of land fragmentation. While the prevailing post-World War II belief was that smaller landholdings limit productivity due to scale-related inefficiencies, more recent studies, particularly from India, have shown a positive correlation between smaller landholding sizes and productivity (Ram et al., 1999). This shift is partly due to the adoption of size-neutral technologies like improved seeds and fertilizers, which have mitigated the inverse relationship between land size and output. Small farms, by utilizing family labor and managing land intensively, can achieve significant productivity levels despite the lack of economies of scale seen in larger farms (Ellis, 1989).

In the context of KP, Pakistan, where agricultural productivity is a cornerstone of economic development, land fragmentation poses a significant barrier to enhancing agricultural output. The availability of land, labor, and technology are critical determinants of productivity, and the breakup of land into smaller, dispersed parcels has emerged as a major obstacle. This study aims to empirically assess the impact of land fragmentation on crop productivity in KP, with the goal of identifying strategies to improve agricultural performance and contribute to the region's economic growth and development.

Literature Review

Land fragmentation, a prevalent issue in many developing countries, has been extensively studied for its impact on agricultural productivity. This review explores various studies that have examined the effects of land fragmentation on crop productivity, particularly in different global contexts.

Ali et al., (2023) investigated the impact of land fragmentation on rice production in northern Bangladesh, using primary data from 193 farm households in Mymensingh and Dinajpur districts. Employing perception indices, fragmentation indices, Simpson indices, and multiple linear regression models, the study concluded that land fragmentation negatively affects rice productivity. Similarly, Nguyen et al. (1996) examined the economic cost of land fragmentation on crop productivity in China using household survey data. They found that larger land consolidation could reduce production costs and suggested that policy should facilitate easier land transactions and better rural credit and grain markets.

Zhou et al. (2024) explored the effect of land fragmentation on technical efficiency in Southern China, using data from 305 villages across 12 provinces. The study found a negative linear relationship between part-time farming and land fragmentation, while crop diversification positively influenced technical efficiency. Wan and Cheng (2001) highlighted land fragmentation as a primary issue in rural land management, particularly in developing countries, showing that fragmentation reduces productivity due to increased costs and operational inefficiencies.

Studies in Vietnam (Wan & Cheng, 2001) and Nigeria (Ulunma et al., 2012) further underscore the detrimental effects of land fragmentation on productivity. Regression analysis using Vietnam Household Living Standard Survey data revealed a limited relationship between productivity and fragmentation, while a study in Nigeria utilizing the Janusezwski index found that land fragmentation reduces the productivity of arable crops. The increased labor and fertilizer requirements due to fragmented land contribute to higher production costs and lower productivity.

Gavgani et al. (2023) examined the impact of land fragmentation on crop yield and profitability in Jiroft, finding that increased fragmentation decreases productivity. Similarly, Rakhshanda et al. (2020) identified land fragmentation as a barrier to agricultural mechanization and technological advancement, leading to lower productivity and profitability in agriculture. Swai (2016) noted the negative implications of land fragmentation for farm households' welfare and national development.

Latruffe et al. (2014) proposed that land fragmentation could sometimes positively affect agricultural performance by optimizing cropping patterns and diversifying land quality. However, this benefit is context-dependent and often overshadowed by the logistical challenges posed by fragmented land. Khanal and Dhakal (2018) and Wickramaarachchi (2016) highlighted similar issues in Nepal and Sri Lanka, where fragmented land reduced productivity due to increased transportation and labor costs.

The literature presents conflicting evidence regarding the impact of land fragmentation on productivity. For instance, some studies like those by Wu et al. (2005) found no significant effect of land fragmentation on output, while others, such as Wan and Cheng (2001), demonstrated a clear negative impact. Kadigi (2016) summarized these opposing views, noting that some researchers see fragmentation as beneficial for risk diversification and crop variety, whereas others view it as detrimental due to increased inefficiencies.

Balogun et al. (2017) noted that in some contexts, like those observed in Nigeria, fragmentation could lead to better land management through more intensive farming practices, thus challenging the assumption that smaller plots always limit productivity. Looga and Jürgenson (2018) found a U-shaped relationship between farm productivity and land fragmentation, suggesting that while larger farms may benefit from spreading productive areas, smaller farms with fewer plots often face reduced efficiency.

Despite extensive global research, empirical evidence on the effects of land fragmentation on crop productivity in Khyber Pakhtunkhwa (KP), Pakistan, remains limited. Most studies in South Asia have focused on countries like India and Nepal, with little attention to the specific dynamics of land fragmentation in KP's Buner and Charsadda districts. This study aims to fill this gap by investigating the specific mechanisms through which land fragmentation affects crop productivity in KP, thereby providing insights for developing strategies to mitigate these impacts and enhance agricultural productivity in the region.

RESULTS AND DISCUSSION

Descriptive statistics

Several significant variables are discussed by the dataset analysis, providing a variety of insights on the sample. With a mean of 76.83 and a median of 36.00, the Total Cost (TC) shows significant fluctuation; however, a maximum of 2800.00 and a high standard deviation of 229.34 indicate the existence of outliers. The Total area (TAR) has a standard deviation of 19.35 and a range of 0.50 to 200.00, with a mean of 20.62 and a median of 18.00. With a modest standard deviation of 8.57 and a mean of 16.65 and median of 16.00.The Number of People (NOP) exhibits moderate variability. The standard deviation of the SI Index is 0.38, with an average of about 0.89 and a median of 0.99, but it varies greatly (-3 to 0.99). Education Level (EDU) ranges from 0 to 5 with a standard deviation of 1.63 and is somewhat skewed (mean 2.02, median 2.00). The age (AGE) data, which extends from 21 to 80 years old and has a standard deviation of 10.60, is actually symmetric (mean 43.65, median 42.50). With values ranging from 0 to 300, the Credit (CR) shows significant variability (mean 23.68979, median 17, standard deviation36.27679). The manage unexpected events (MUE) and fluctuations market price (FMP) show significant consistency (means of 3.27 and 3.38, medians of 3.00, standard deviations of 0.80-0.92). With values up to 10, Hour works (HW) has a somewhat higher mean (3.95) and variability (standard deviation 1.82). Extreme weather events (EWE) and Fertility of yield (FYL) both exhibit symmetric distributions (means 3.27 and 1.66, medians 3.00 and 1.00), with FYL showing notable variability (standard deviation 1.01).

Table1 Descriptive statistics

Variable	Mean	Median	Maximum	Minimum	Std. Dev.
Total cost	76.83	36	2800	6.2	229.33
Total area	20.62	18	200	0.5	19.34
Number of people	16.64	16	45	2	8.57
SI_INDEX	0.88	0.988281	0.999852	-3	0.38
Education	2.018	2	5	0	1.63
Age	43.65	42.5	80	21	10.60
Credit	23.68	17	300	0	36.27
Fluctuation of market price	3.265	3	5	1	0.92
Manage unexpected events	3.38	3	5	1	0.80
Hours work	3.95	4	10	1	1.82
Extreme weather events	3.27	3	5	1	0.87
Fertility your land	1.66	1	3	0	1.01

The Variance Inflation Factor (VIF) analysis

The variance inflation (VIF) helps to assess Multicollinearity in the regression model. Multicollinearity occurs when independent variables are highly correlated, which can distort the results of the regression analysis. A VIF value greater than 10 typically indicates high Multicollinearity.

The VIF values in this model are all much below the threshold of 10, indicating that Multicollinearity is not a major problem. The variable with the highest VIF is "tar" with a VIF of 3.63, indicating a moderate correlation with other variables. "Total Cost" also has a moderate VIF of 3.19. All other variables have VIF values close to or below 1.5, indicating low correlation among them. The mean VIF for the model is 1.58, reinforcing the conclusion that Multicollinearity is not problematic in this regression analysis. This ensures the stability and reliability of the coefficient estimates.

Table2 Multicollinearity test results of the variables used in the analysis.

Variable	VIF	1/VIF
Tar	3.63	0.275852
Total Cost	3.19	0.313779
Nop	1.59	0.630332
SIIndex	1.34	0.747835
Edu	1.24	0.808816
Age	1.22	0.822786
CR	1.18	0.84937
Fmp	1.16	0.85867
Mue	1.15	0.872312
Hw	1.13	0.887212
Ewe	1.1	0.905946
Fertility of your land	1.06	0.943498
Mean VIF	**1.58**	

Shapiro-Wilk Test for Normality

Regression model residual normality is evaluated using the Shapiro-Wilk test. The data's normal distribution is the test's null hypothesis. We infer that the data do not follow a normal distribution and reject the null hypothesis if the p-value is smaller than the selected alpha threshold, which is usually 0.05.The Shapiro-Wilk W test for normality of the residuals in the regression model yields a W statistic of 0.91702, with a corresponding z-value of 5.326 and a p-value of 0.00000. Given that the p-value is significantly less than 0.05, we reject the null hypothesis of normality. This indicates that the residuals of the regression model do not follow a normal distribution. The non-normality of residuals suggests potential issues with the model, such as the presence of outliers, heteroscedasticity, or an incorrect functional form, which might affect the validity of inference and predictions based on the model.

Table3 Shapiro-Wilk Test for Normality

Test	**Variable**	**Obs**	**W**	**V**	**Z**	**Prob > z**
Shapiro-Wilk	Residuals	163	0.91702	10.37	5.326	0

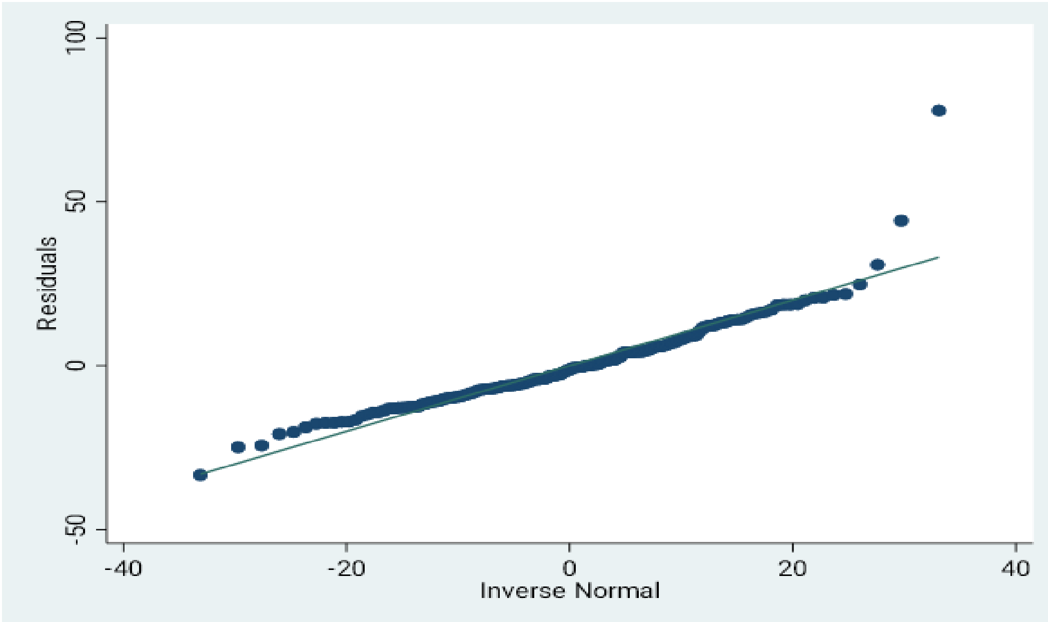

Figure 4.1: Shows Normality tests

The below scatter plot titled 'ACY vs Simpson index; represents the relationship between ACY (Average crop yield) and Simpson index (SI Index), measure of land fragmentation. The horizontal axis displays the Simpson index, while the vertical axis represents ACY values.
Option 1 show low level of land fragmentation and option 0 show high level of land fragmentation.

Most of the farmer selected option 1 because there are low level of land fragmentation and the low level land fragmentation show in graph the Average crop yield is high and 0 option is show high level land fragmentation in average crop yield is low.

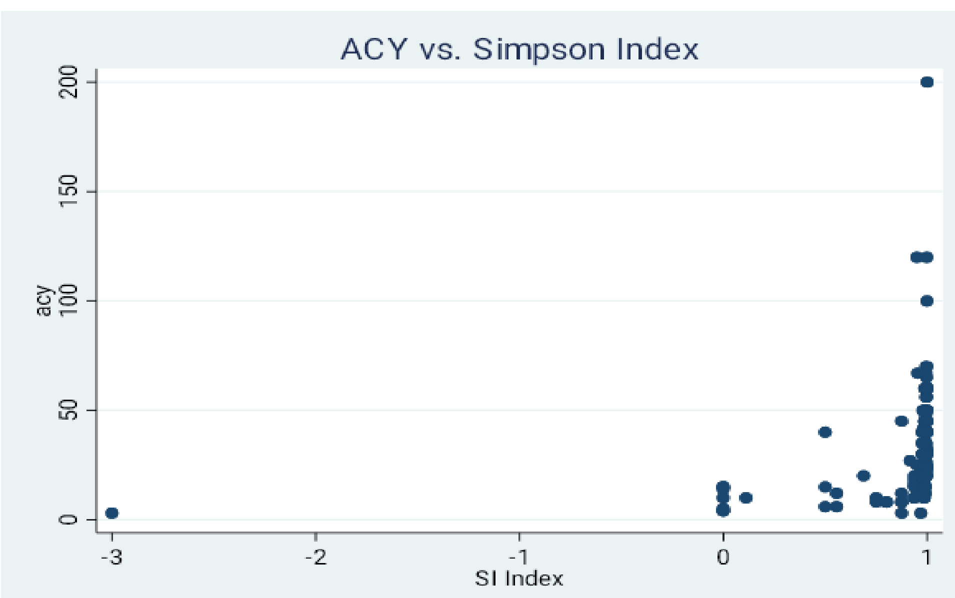

Figure: Relationship between Average crop yield and Simpson index

Breusch-pagan/cook-Weisberg test for heteroscedasticity

The Breusch-Pagan / Cook-Weisberg test is used to detect the presence of heteroscedasticity in the residuals of a regression model. The null hypothesis for this test is that the variance of the residuals is constant (homoscedasticity).

The heteroscedasticity test results for Breusch-Pagan/Cook-Weisberg show a chi-squared value of 7.55 with a p-value of 0.0060. As the p-value is below the widely accepted significance level of 0.05, the null hypothesis of constant variance is rejected.

This indicates the presence of heteroscedasticity in the residuals of the regression model. Heteroscedasticity suggests that the variability of the residuals is not constant across all levels of the fitted values of the dependent variable (acy), which can affect the efficiency and reliability of the estimated coefficients. Addressing heteroscedasticity, by using robust standard errors, is crucial to obtain valid statistical inferences.

Table4 Breusch-pagan/cook-Weisberg test for heteroscedasticity

Test	Statistic	Value	p-value
Breusch-Pagan	chi2(1)	7.55	0.006

Pairwise scatter plot matrix

A pairwise scatter plot matrix, also known as a splom (scatter plot matrix), is a graphical representation of data that displays the relationship between multiple variables in a matrix format.

Scatter plot matrix is Used for

- Explore relationships between multiple continuous variables
- Identify patterns, correlations, and outliers
- Visualize high-dimensional data in a lower-dimensional space

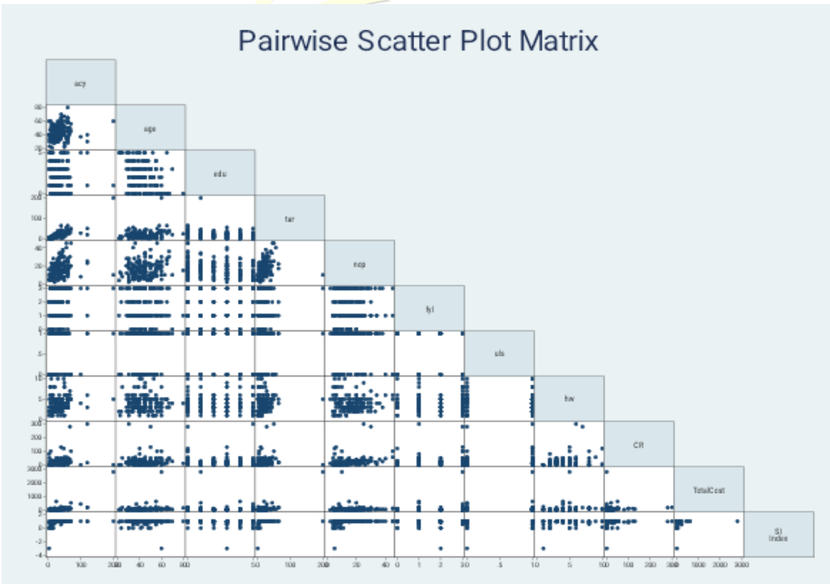

Figure2 Pairwise Scatter plot matrix

Robust regression

Table5 Robust regression results

Variable	Coef.	Std. Err.	T	p-value	95% Conf. Interval
Age	0.085	0.112	0.76	0.448	-0.136
Edu	0.918	0.745	1.23	0.219	-0.553
Tar	0.812	0.131	6.21	0	0.554
Nop	-0.007	0.158	-0.05	0.963	-0.319

Fyl	2.522	1.085	2.32	0.021	0.378
Hw	-0.031	0.588	-0.05	0.957	-1.194
Fmp	0.81	1.384	0.59	0.559	-1.925
Ewe	-0.175	1.465	-0.12	0.905	-3.069
Mue	-3.858	1.961	-1.97	0.051	-7.733
SIIndex	7.354	2.263	3.25	0.001	2.882
Total Cost	0.012	0.011	1.09	0.277	-0.009
CR	0.114	0.035	3.3	0.001	0.046
Cons	9.5	8.975	1.06	0.292	-8.234

The regression analysis results provide insights into the factors influencing agricultural crop yield (ACY). Here are the interpretations of the coefficients and their statistical significance:

Age: The coefficient for Age (0.085) is positive but not statistically significant (p = 0.448), indicating that age has no significant impact on ACY within the sample.

Education (Edu): The coefficient for Education (0.918) is positive but not statistically significant (p = 0.219), suggesting that higher education levels might improve ACY, but this effect is not statistically confirmed.

Total area (Tar): The coefficient for Target (0.812) is highly significant (p < 0.001), implying that achieving specific targets strongly correlates with increased ACY.

Number of People (Nop): The coefficient for Nop (-0.007) is negative and not significant (p = 0.963), indicating no substantial effect of the number of plots on ACY.

Fertility your land (Fyl): The coefficient for Fyl (2.522) is positive and significant (p = 0.021), indicating that more years of farming experience significantly increase ACY.

Hours Worked (HW): The coefficient for HW (-0.031) is negative and not significant (p = 0.957), suggesting no significant impact of hours worked on ACY.

Fluctuation market price (Fmp): The coefficient for Fmp (0.81) is positive but not significant (p = 0.559), indicating no substantial effect on ACY.

Extreme weather events (Ewe): The coefficient for Ewe (-0.175) is negative and not significant (p = 0.905), showing no significant impact on ACY.

Manage unexpected events (Mue): The coefficient for Mue (-3.858) is negative and marginally significant (p = 0.051), suggesting that inefficient use of mechanization may reduce ACY.

Simpson Index (SIIndex): The coefficient for SI-Index (7.354) is highly significant (p = 0.001), indicating a strong positive relationship between land fragmentation and ACY.

Total Cost: The coefficient for Total Cost (0.012) is positive but not significant (p = 0.277), suggesting no significant impact on ACY.

Credit (CR): The coefficient for CR (0.114) is highly significant (p = 0.001), indicating that access to credit significantly increases ACY.

Constant (Cons): The constant term (9.5) is not significant (p = 0.292).

In comparing this research findings in Charsada and Buner with previous literature indicating a negative impact of land fragmentation on crop productivity,

This research inconsistent with previous work they shows positive impact on crop productivity.

Reasons;

Fertilizer Management; Probably Farmers in these areas adjust fertilizer application to the unique requirements of small plots, in contrast to larger farms where uniform treatment may result in unequal nutrient distribution or excesses. By making sure crops receive the most nutrition possible at every stage of growth, this focused strategy improves overall output and quality.

Seed types; may be Farmers in Charsada and Buner are encouraged to diversify their crop choices and seed kinds by the fragmented land ownership. This diversity makes it possible for the production of crops that are suitable to local soil conditions, climate fluctuations, and market demands, while also reducing the hazards associated with monoculture. Through careful selection and adaptation of seed varieties, farmers may utilize the distinct features of individual plots to optimize productivity and adaptability to outside influences. Probably they use hybrid seed they also increase productivity.

Irrigation system; may be these regions' close connection to water sources makes it easier for farmers to implement effective irrigation techniques. For smaller plots, farmers can use drip irrigation or localized watering systems, which save water while still providing enough moisture for crops. Effective water management is a major factor in crop health and productivity, particularly in times of drought or variable rainfall.

Analysis of Cauchy membership function

Summary Statistics

The Mean **is** 0.032 and the standard deviation is 0.136.

Interpretation of Variability

The mean value near 0 suggests high variability in farm productivity. This indicates significant differences among farms, with some having very low productivity and others being more productive. Factors contributing to this variability may include soil fertility, climatic changes, technological advancements, and financial challenges.

CONCLUSION

Land is a crucial component of agricultural development, serving as a primary source of minerals, agricultural inputs, and other essential products. In recent decades, land fragmentation has increased, characterized by the presence of multiple plots owned by the same farmer but located in different places. This phenomenon involves several factors, including the number of fragmented plots, plot size, topography, distance between plots and farm buildings, and the overall distribution of plots. Land fragmentation is a significant concern in developing countries like Pakistan, where there is also an unequal distribution of arable land. Such fragmentation and uneven distribution can negatively impact agricultural productivity and profitability.

This study aimed to examine the impact of land fragmentation on crop productivity and profitability in Khyber Pakhtunkhwa (KP), Pakistan. Primary data were collected from 163 farmers in rural areas of KP, using a random sampling technique. The analysis was conducted using the STATA program, employing multiple regression to assess the effects of land fragmentation. The Simpson Index was calculated to measure the degree of land fragmentation, where a value of one indicates a lower degree of fragmentation, and values closer to zero represent higher fragmentation levels. This index considered the number of plots, average plot size, and the distribution of plot sizes.

The findings revealed that land fragmentation is prevalent among farms in the study area and that higher levels of fragmentation, as indicated by the Simpson Index, hinder the adoption of new technologies and modern management practices by increasing the labor required to maintain year-round productivity. Conversely, the integration of advanced management and technology can positively influence productivity despite the challenges posed by fragmentation. The study employed the Cobb-Douglas production function and fuzzy logic models to estimate the impact of land fragmentation on crop productivity. Results suggest that addressing land fragmentation through value addition and quality improvement could enhance competitiveness in both local and international markets.

RECOMMENDATIONS

Based on the findings of this study on the impact of land fragmentation on crop productivity in Khyber Pakhtunkhwa, the following recommendations are suggested to mitigate the negative effects and improve agricultural outcomes:

1. **Promote Land Consolidation Programs:** The government and relevant agricultural bodies should introduce and promote land consolidation programs that incentivize farmers to merge smaller, fragmented plots into larger, more manageable units. This can help reduce the costs associated with fragmented farming, such as transportation and labor, and improve overall farm efficiency.

2. **Enhance Access to Agricultural Technologies:** Efforts should be made to provide farmers with easier access to modern agricultural technologies, including mechanization tools and advanced irrigation systems. Providing subsidies or low-interest loans for purchasing such technologies can help farmers overcome the challenges of land fragmentation and enhance productivity.

3. **Implement Land Reforms and Policies:** Policymakers should consider implementing land reforms that address the unequal distribution of arable land and promote equitable access for small-scale farmers. Establishing clear land ownership rights and simplifying the process for land transactions can facilitate the consolidation of fragmented plots.

4. **Develop Infrastructure to Support Agriculture:** Investment in rural infrastructure, such as roads and storage facilities, can reduce the logistical challenges posed by land fragmentation. Improved infrastructure will help lower transportation costs and time, allowing farmers to better manage fragmented plots and increase their market access.

5. **Provide Training and Extension Services:** Agricultural extension services should be strengthened to provide training to farmers on best practices for managing fragmented land. Topics such as crop diversification, efficient use of resources, and innovative farming techniques can help farmers optimize productivity even on fragmented plots.

6. **Encourage Cooperative Farming Models:** Promoting cooperative farming models where farmers pool resources, share equipment, and jointly manage fragmented plots can help mitigate the disadvantages of land fragmentation. Cooperatives can improve economies of scale, reduce input costs, and increase bargaining power for small farmers.

7. **Foster Research and Development:** Continued research on the impact of land fragmentation specific to regions like Khyber Pakhtunkhwa should be supported. Research initiatives should focus on identifying local solutions, innovative farming methods, and the development of crops that are better suited to fragmented lands.

8. **Strengthen Land Use Planning:** Developing a comprehensive land use planning framework that incorporates strategies for reducing fragmentation can help optimize agricultural land use. This planning should involve all stakeholders, including local communities, government agencies, and agricultural experts, to create sustainable land management practices.

9. **Encourage Crop Diversification:** Farmers should be encouraged to diversify their crop production to reduce risks associated with monocropping on fragmented plots. Crop diversification can lead to better utilization of varied soil conditions and microclimates across different plots, potentially increasing overall farm productivity.

10. **Implement Monitoring and Evaluation Mechanisms:** Establishing monitoring and evaluation mechanisms to assess the impact of implemented policies and programs related to land fragmentation will ensure that strategies remain effective and adaptable to changing agricultural needs.

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