



Original Research

# Garlic as a Climate-Resilient Crop for Smallholder Farming Systems in Khyber District, Pakistan

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## Abstract

Garlic production has significant potential to enhance food security and income generation among smallholder farmers in Pakistan. This study evaluates the impact of improved garlic cultivation practices using certified seed on productivity in District Khyber, Khyber Pakhtunkhwa. A total of 20 beneficiary farmers were selected, and field trials were conducted during the 2024–25 growing season. The study considered three key factors: landholding size, land allocated for garlic cultivation, and farmer experience. Data were analyzed using a Completely Randomized Design (CRD), and treatment means were compared using Tukey's Honestly Significant Difference (HSD) test at a 5% probability level. The results showed that farmers with smaller landholdings (>1 acre) achieved the highest yield (8.21 t ha<sup>-1</sup>), compared to those with larger landholdings (<5 acres), who recorded the lowest yield (5.00 t ha<sup>-1</sup>). Similarly, farmers cultivating garlic on smaller, intensively managed plots (1 kanal) achieved higher yields (8.43 t ha<sup>-1</sup>) than those cultivating larger areas (6.07 t ha<sup>-1</sup>). Farmer experience also had a significant effect on productivity, with experienced farmers (≤5 years) achieving higher yields (8.10 t ha<sup>-1</sup>) than inexperienced farmers (5.00 t ha<sup>-1</sup>). The findings indicate that garlic is a climate-resilient and economically viable crop for smallholder farmers, particularly when supported with certified seed and improved agronomic practices. The study highlights the importance of targeted interventions to enhance productivity and strengthen rural livelihoods in Khyber District.

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**Statement of Sustainability:** The study was carried in remote area of a newly merged district (Khyber) previously know as Federally administered tribal areas (FATA) for attracting them to engage the community in positive agriculture practices and use these for elevating the socioeconomic conditions. The targets and clients was hard task to have them in an area already specified by the donor of the projects. The study was very successful with farmers took keen interest in garlic cultivation.

## 1. Introduction

As the agricultural and agro-industrial sectors become more consolidated and increasingly organized around intensive crop and livestock systems, productivity indicators improve significantly with community movements and farmer groups serve as important forms of collective action that contribute to rural development (Stewart, 2005). The development of sustainable production systems therefore requires a systemic perspective, regardless of the scale of production or the type of practices adopted (Solava, 2006). Agricultural production is shaped by a range of interacting factors, including climate variability, market conditions, production seasonality, and farmers' management decisions (Chia et al., 2013). Consequently, agricultural development whether considered in the short or long term is best understood through an integrated perspective that captures the complexity of productive, economic, and social processes (Ondersteijn, 2003).

According to Sahu et al. (2010), productive activity at the farm level is closely integrated with administrative and managerial control. Farmers are often responsible for day to day farm management, operational activities, and long term strategic decision-making. In their managerial role, farmers may seek to maximize current income; however, in their role as landowners, they may also aim to maximize long-term capital accumulation (Quesado et al., 2018). Rural development policies in Pakistan, particularly in the tribal districts of the northwestern region, have increasingly incorporated agriculture as a means of promoting economic empowerment through commercial agricultural production. Herrera et al. (2024) note that modern agriculture has introduced new demands on



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farmers, including the need for farms to remain economically viable and self-sustaining production units.

In many rural areas of Khyber Pakhtunkhwa, Pakistan, where small scale agriculture predominates, the timely availability of agricultural resources such as extension literature, quality seed, fertilizers, and irrigation has a significant impact on resource allocation, productivity, and the formation of farmer groups for commercial crop production. The growth of the garlic sector is particularly important for farmers with small landholdings, as garlic is a widely consumed culinary crop in the subcontinent and contributes to both income generation and dietary diversity. Garlic (*Allium sativum* L.) is one of the most important bulb crops after onion and is widely used for culinary and medicinal purposes (Srivastava et al., 2005). In Pakistan, however, garlic production remains insufficient to meet domestic demand. Average garlic yields are relatively low due to several constraints, including fluctuating output prices, inadequate storage facilities, temperature extremes, limited land allocation, lack of certified quality seed, soil nutrient deficiencies, and the high cost of agricultural inputs. These factors collectively limit garlic productivity in Pakistan. In 2024, garlic production packages were distributed to 20 selected male participants in collaboration with NIDA Pakistan and financed by Welthungerhilfe. This intervention was implemented under a broader project aimed at establishing and supporting small commercial agriculture-based food businesses, from production to marketing, while also strengthening smallholder garlic farming systems.

The primary objectives of this intervention were to support small farms in garlic production, enhance farmers' technical skills through targeted training and resource provision, and promote the adoption of improved cultivation practices. The initiative also aimed to integrate farmers into agricultural value chains by facilitating linkages with local markets, thereby improving market access and profitability. In addition, the project sought to increase garlic production capacity to meet high market demand, promote environmentally sustainable farming practices, develop marketing strategies to improve the visibility and competitiveness of locally produced garlic, and strengthen collaboration among farmers through the sharing of resources and best practices.

This article presents the preliminary results of project interventions designed to generate livelihood opportunities for local communities through the development of a garlic seed industry and to increase farmers' income through enhanced bulb production using disease free certified seed in District Khyber, Khyber Pakhtunkhwa, Pakistan. Despite the importance of garlic as a high-value crop, limited empirical evidence exists on its performance under smallholder farming conditions in Khyber District. In particular, the role of farm size, land allocation, and farmer experience in influencing garlic productivity remains underexplored. Therefore, this study aims to evaluate the impact of improved garlic cultivation practices using certified seed on yield performance among smallholder farmers in District Khyber, Pakistan.

## 2. Materials and Methods

### 2.1. Geographical Location of Study Area

The study was conducted in ten village councils of Khyber District during the 2024–25 growing season. A total of 20 garlic seed beneficiary farmers were selected from the beneficiary list in October 2024 through a community-based organization (CBO), based on criteria developed by the project team. The selection criteria included:

### 2.2. Data Collection and Analysis

In 2025, twenty beneficiary farmers from District Khyber, Pakistan, were selected under the project. They were provided with improved garlic bulbs (24 kg per kanal), agricultural inputs (10 kg each of Urea, DAP, and SOP per farmer), farm tools and implements (including a digger, spade, and khurpa), and technical training for skill development. An orientation session was conducted on the day of input distribution at the Agriculture Farm Service Center.

Practical demonstrations were delivered by technical agriculture experts, covering modern and improved cultivation practices from sowing to harvesting. Following the provision of inputs and training, field follow ups were conducted during the harvesting season to gather feedback and collect yield data from farmers.

The experiment was analyzed using a Completely Randomized Design (CRD), considering three independent factors: (i) landholding size (<5 acres, 1–5 acres, and >1 acre), (ii) land area under garlic cultivation ( $\leq 2$  kanals, 1–2 kanals, and 1 kanal), and (iii) garlic farming experience (no experience, 1–3 years, and  $\leq 5$  years). Data were subjected to analysis of variance (ANOVA), and treatment means were compared using Tukey's Honestly Significant Difference (HSD) test at a 5% probability level.

## 3. Results and Discussion

### 3.1. Effect of Land Holding on Garlic Yield

The results clearly indicate that farmers with larger landholdings obtained comparatively lower garlic yields, whereas those with smaller landholdings achieved higher productivity (Table 1). Farmers owning less than 1 acre recorded the highest yield, while those with more than 5 acres showed the lowest performance. This inverse relationship between farm size and productivity can be explained through economic efficiency and resource allocation behavior. Small landholders are generally more dependent on limited land for their livelihood, which creates stronger incentives for intensive cultivation, closer crop monitoring, and optimal



use of inputs. As a result, they tend to allocate labor, time, and farm inputs more efficiently per unit area, leading to higher yield per acre.

Table 1. Effect of landholding size, cultivated area, and farming experience on garlic yield ( $t\ ha^{-1}$ ) in District Khyber, Pakistan.

Variable	Treatment	Yield ( $t\ ha^{-1}$ )	CV (%)	F-value
Landholding size (acres)	<5 acres	5.00 C	1.35	17.6*
	1–5 acres	6.83 B		
	>1 acre	8.21 A		
Land cultivated (kanal)	≤2 kanal	6.07 B	1.15	13.2*
	1–2 kanal	7.16 B		
	1 kanal	8.43 A		
Farming experience (years)	No experience	5.00 B	1.40	15.6*
	1–3 years	6.94 A		
	≤5 years	8.10 A		

Means followed by the same letter within each variable are not significantly different at the 5% level according to Tukey's HSD test. CV = Coefficient of Variation. \* = Significant at  $p \leq 0.05$ .

In contrast, larger farmers often operate under more extensive production systems where supervision per unit area is weaker, labor supervision is less intensive, and resource allocation is more dispersed across multiple crops or plots. This may result in suboptimal input use efficiency, delayed agronomic operations, and reduced marginal productivity of inputs, ultimately lowering yield per unit area. From an economic perspective, this phenomenon is consistent with the principle of diminishing managerial efficiency, where the ability to closely manage production decreases as farm size increases. Moreover, smallholders tend to maximize output due to land scarcity and higher opportunity cost of underutilized land, whereas larger farmers may prioritize risk diversification and labor-saving strategies over yield maximization. Similar findings have been reported by Jehanzeb et al. (2004), while Kapronczai et al. (1991) also emphasized that small farms are often more technically and economically efficient than large farms. Landholding size significantly influences resource allocation patterns and cropping intensity decisions. Furthermore, small-scale farming systems often encourage intensive input use per unit area, resulting in higher productivity. Efficient land use is widely recognized as a key determinant of agricultural productivity and economic returns, particularly under resource constraints (Plinere and Aleksejeva, 2019; Ho and Fang, 2013). In such contexts, optimal utilization of limited land, labor, and capital becomes essential for maximizing returns. Therefore, improving management efficiency on larger farms could help bridge the observed yield gap and enhance overall production efficiency. However, the findings should be interpreted with caution due to the relatively small sample size and project-based nature of the study, which may limit broader generalization.

### 3.2. Effect of Cultivated Land Area on Garlic Yield

The amount of land allocated for garlic cultivation had a noticeable impact on the total yield obtained by growers in the study area. In most cases, approximately 1 kanal was reserved for garlic production; however, yield varied significantly among farmers despite using similar seed material and input resources. The highest yield was recorded at  $8.432\ t\ ha^{-1}$  by farmers who cultivated garlic on relatively smaller, well-managed plots (approximately 1 kanal). This was followed by farmers cultivating 1 to 2 kanals, while the lowest yield ( $6.072\ t\ ha^{-1}$ ) was observed among farmers who allocated 2 kanals or more for garlic cultivation. These results suggest that yield efficiency declines as the cultivated area for a specific crop increases beyond an optimal management capacity. One possible explanation is that farmers with larger cultivated areas tend to distribute their attention and management efforts across multiple plots or crops, leading to reduced crop-specific care. In contrast, farmers with smaller cultivated areas are able to focus more intensively on crop management practices such as timely irrigation, weeding, fertilization, and pest control, thereby achieving higher productivity per unit area.

From an economic and managerial efficiency perspective, this pattern reflects diminishing intensity of supervision and input optimization as farm operation scale increases for a single crop. Small scale, crop-focused production systems often lead to higher marginal returns due to better allocation of labor and inputs per unit land area. These findings are consistent with Silva and Gazolla (2016) and Matte et al. (2019), who reported that limited land availability for a specific crop encourages intensive management practices and results in higher productivity. Efficient use of available resources plays a critical role in enhancing crop output under such conditions. Similarly, Volk and Stern (2009) observed that yield variations in garlic are influenced by genetic potential, climatic conditions, and management practices across different environments. Overall, the results indicate that optimal land allocation, combined with intensive management practices, plays a crucial role in maximizing garlic productivity per unit area.

### 3.3. Experience of Farmer and Garlic Yield

Farmers' experience plays a vital role in successful crop production, particularly in high-value crops such as garlic. The results presented in Table 1 indicate that farmers with five or more years of experience in garlic cultivation achieved the highest yield



(8.098 t ha<sup>-1</sup>), followed by the farmers with 1 to 3 years experience (6.94 t ha<sup>-1</sup>) whereas the lowest yield (5.004 t ha<sup>-1</sup>) was recorded among farmers with no prior experience in garlic production. These findings clearly demonstrate that farming experience has a positive influence on garlic productivity. Experienced growers are generally more capable of making informed agronomic decisions, including timely land preparation, appropriate input application, effective pest and disease management, and proper irrigation scheduling. As a result, they are able to utilize the provided inputs more efficiently and convert them into higher crop output. In contrast, farmers with little or no experience often lack technical knowledge and practical skills related to garlic cultivation, which may lead to improper input use, delayed field operations, and suboptimal crop management. These inefficiencies ultimately result in lower yields despite the availability of similar inputs.

From an economic perspective, farming experience enhances managerial ability and reduces production inefficiencies, thereby improving the productivity of scarce agricultural resources. Experienced farmers are also better at minimizing input wastage and optimizing the marginal returns of production inputs, which contributes to higher yield performance. The present findings are supported by Hassan et al. (2023), who reported that small landholding farmers with greater agricultural experience tend to achieve better production outcomes in Khyber Pakhtunkhwa. Their study highlights that experience significantly improves the effectiveness of agricultural practices and overall farm productivity. Overall, the results suggest that farmer experience is a critical determinant of garlic yield and should be considered in agricultural development programs, particularly in training and extension services aimed at improving productivity. Garlic is considered a climate-resilient crop due to its relatively low water requirement, adaptability to diverse agro-climatic conditions, and tolerance to temperature variability. In the context of Khyber District, where climate variability poses challenges to traditional crops, garlic cultivation provides a viable alternative for stabilizing farmer income and reducing production risks.

#### 4. Conclusion

The study demonstrates that garlic cultivation using certified seed and improved agronomic practices significantly enhances productivity among smallholder farmers in District Khyber. Farmers with smaller landholdings achieved higher yields due to more intensive resource utilization and better crop management. Similarly, smaller cultivated areas and greater farming experience contributed to higher productivity levels. The findings highlight the potential of garlic as a climate-resilient and economically viable crop for smallholder farming systems. Promoting access to quality seed, technical training, and efficient resource management can further strengthen garlic production and improve rural livelihoods in the region. This publication provides evidence that localized, crop-specific interventions such as improved garlic cultivation can serve as practical entry points for transforming Pakistan's food systems into more efficient, inclusive, resilient, and sustainable systems, directly contributing to national development and food security objectives

#### Author Contributions

Conceived and designed the experiments: Maryam Samad, Shehzad Elahi, Ibrar Hussain; Performed the experiments: Maryam Samad, Nadia Samad & Shehzad Elahi; Analyzed the data: Ibrar Hussain; Contributed reagents/materials/analysis tools: Shehzad Elahi and Maryam Samad; Wrote the paper: Ibrar Hussain, Maryam Samad.

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#### Declarations

**Conflicts of Interest:** The authors hereby declare that has no conflict of interest.

**Institutional/Ethical Approval:** This study did not involve human or animal subjects, and no institutional or ethical approval was required.

**Data Availability/Sharing:** The datasets used and analysed during the current study will be made available from the corresponding author upon a reasonable request.

**Supplementary Information Availability:** Not applicable.



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