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Assessing the Impact of Drip Irrigation Adoption on Onion Production, Resource Use Efficiency, and Farmer Livelihoods in South Punjab, Pakistan

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ABSTRACT

Water scarcity poses an existential threat to the agrarian economy of Pakistan, where reliance on traditional irrigation practices jeopardizes the sustainability of high-value crops. This study assessed the multi-dimensional impacts of adopting drip irrigation systems on onion production, resource use efficiency, and the socio-economic livelihoods of farmers. A Quantitative survey was conducted with 180 farmers, with an equal proportion of adopters (n=90) and non-adopters (n=90). Results revealed that drip irrigation significantly increased onion yield, averaging 8,950 kg/acre compared to 6,720 kg/acre under traditional flood irrigation (t=7.52, P=0.000). Gross margins were also higher for adopters (PKR 267,250) versus non-adopters (PKR 181,600), with a superior benefit-cost ratio of 2.97. The Cobb Douglas production function showed water use had the highest efficiency (0.284), followed by fertilizer (0.221) and labor (0.145), indicating that efficient water management is critical for maximizing productivity. Socio-economic benefits included higher yields, reduced costs, and improved water conservation, while key constraints were high initial investment costs (Mean=4.71) and lack of technical knowledge (Mean=4.55). Chi-square analysis indicated that education (χ^2=16.85, P=0.001), farm size (χ^2=21.47, P=0.000), and access to credit (χ^2=18.62, P=0.000) significantly influenced adoption decisions. Findings highlight the need for subsidies, credit facilities, and farmer training to promote sustainable irrigation practices and enhance rural livelihoods.

***Keywords*:** Drip irrigation, onion production, resource use efficiency, profitability, South Punjab, socio-economic factors, adoption constraints.

INTRODUCTION

The agrarian sector is predominant in Pakistan's economy because it contributes to the country's food security and the livelihood of its rural population, as well as to its GDP. Pakistan Economic Survey (2024) reports that the sector contributes approximately 19.5 percent to GDP and approximately 37 percent of the labor force is engaged in the sector. However, the agricultural sector in Pakistan is still experiencing profound crisis, such as water scarcity, declining soil fertility and productivity.. Shortage of water, especially in arid and semi-arid areas, has severe repercussions. Further, overexploitation of irrigation systems, i.e., canals and tubewells, not only failed to improve the situation but instead worsened it (Gulzar et al., 2024). In this respect, effective irrigation techniques, such as drip irrigation, are essential for attaining sustainability in production within farms and improving livelihoods of farmers.

Onion (Allium cepa L.) is a high-value vegetable crop that is widely grown in Pakistan, particularly in South Punjab, due to the favorable agro-climatic conditions. It is a mandatory part of the Pakistani diet and contributes to the food security and economy through local household consumption and export (Hussain, 2022). The production of onion crop in Pakistan has not achieved its potential mainly due to due to poor irrigation practices and nutrient use inefficiency (Iqbal et al., 2023). Conventional means of irrigation, prevalent in practice, lead to excessive wastage of water, affecting not only crop productivity but also causing soil problems (Baldassarre & Vosatka, 2023).

So, innovative and sustainable irrigation practices are necessary to ensure the rational use of water sources and better crop productivity. Drip irrigation is considered one of the most efficient irrigation techniques worldwide. It is used to place water in the crop root zone, reducing water loss through evaporation and maximizing water use efficiency (Burgess et al., 2022). Besides using less water, drip irrigation also allows for the precise delivery of nutrients, benefiting crop health and yielding high-quality crops. According to numerous studies conducted worldwide, drip irrigation can increase the farm productivity with a low production cost (Daryanto et al., 2020). In Pakistan, however, the adoption rate of drip irrigation is low, primarily due to high initial costs, a lack of awareness, limited extension services, and restricted access to credit facilities (Ullah et al., 2022).

The impact of drip irrigation has been widely studied in various soil types and on different crops regarding water savings and economic benefits; however, studies are scarce in the context of impacts on high value crops, such as onion. Furthermore, there is limited literature available on how the adoption of drip irrigation impacts resource use efficiency and farmers' livelihoods. Most of the scientific literature has concentrated on water savings and never considered the larger socio-economic implications of the technology, such as income earned, labor saved, and overall farmers' well-being (Ali et al., 2025). Hence, this study aims to bridge this research gap through the evaluation of the role of drip irrigation on onion production, resource use efficiency, and livelihoods of South Punjab farmers. Specifically, it encompasses the objectives: to compare the yield and profitability of onion crop among adopters and non-adopters of drip irrigation, to find out the resource use efficiency of drip irrigation and the socio-economic advantages and disadvantages of adopting drip irrigation. The research will also contribute to policy formulation and to the implementation of extension measures, enabling the introduction of modern irrigation approaches based on empirical findings.

MATERIALS AND METHODS

Research design

A cross-sectional research design was employed to collect data on the differences between farmers who opt for drip irrigation systems and those who use traditional flood irrigation systems.

Study population and sampling

Multistage random sampling method was employed to reach the sample and collect data. First, the purposive selection of districts was based on the intensity of onion production. The study selected the three largest onion producing districts (purposely selected due to the large area of onion farming) of Vehari, Bahawalpur and Multan (Ali et al., 2025; Ullah et al., 2023). In the next steps, two tehsils from each district were selected randomly and then three villages from each tehsil were selected randomly. And finally, onion farmers in each village were selected through simple random sampling. The total sample size consisted of 180 farmers, 90 of whom had drip irrigation installed and the remaining 90 did not.

Data collection

The primary data were collected via face-to-face interviews through a structured and pre-tested questionnaire. The questionnaire included socio-economic factors (e.g., age, education, farm size, farming experience, and household income), input use, cost of production, irrigation and onion crop production. Data on water use, fertilizer use, labor use, and market prices were also collected to assess their efficiency in resource utilization.

Data analysis

Gross margin analysis compared onion yield and profitability between those who embraced or did not embrace drip irrigation according to the following formula:

$$\text{Gross Margin} = \text{Total Revenue} - \text{Variable Costs}$$

Where total revenue was determined=total onion yield x market price/kg and variable costs=expenditure on seeds, fertilizers, pesticides, irrigation and labor.Independent-samples t-tests were used to determine whether the yield and profitability differences between the two groups were significantly different at the 5% level (Khan et al., 2021).

Measures of partial productivity of water, labor, and fertilizer have been calculated to ascertain the efficiency of the resources. Water productivity (WP), labor productivity (LP), and fertilizer productivity (FP) were determined by dividing the onion yield by the cubic meter of utilized water, the onion yield by labor hours, and the onion yield by kilograms of used fertilizer, respectively. In addition, a Cobb-Douglas production function was estimated to define the elasticity of production to the most significant inputs and it is written as:

$$\ln Y = \beta 0 + \beta 1 \ln X1 + \beta 2 \ln X2 + \beta 3 \ln X3 + \epsilon$$

Y=onion yield (kg/acre) and X1=water consumption (m3/acre), X2=fertilizer consumption (kg/acre), X3=labor hours and Phi is a random error. The coefficients (b) are estimates of the percentage change in yield resulting from a 1 percent change in each input.

Descriptive statistics and Likert scale research design were used to compare the socio-economic benefits and constraints of drip irrigation, where farmers were asked to rank the possible constraints on a 1 (not a constraint) to 5 (severe constraint) scale. These constraints were ranked by calculating mean scores and the relationship between socio-economic variables (education, farm size and access to credit) and adoption of drip irrigation was tested using chi-square tests.

The data were analyzed using SPSS (Version 25) and STATA (Version 16). Descriptive statistics were used to summarize farmers' characteristics and t-tests, chi-square tests and regression were employed as means of attaining the study objectives through inferential tests. Tests of statistical hypothesis were made against a significance level of P≤0.05.

Ethical considerations were observed during data collection and the research process. . The respondents' informed consent was obtained, and they were assured of anonymity (i.e., their personal information would not be published).

RESULTS AND DISCUSSION

Onion yield and profitability comparison

Table 1 presents the results of independent samples t-tests comparing the yield of onions, revenue, costs, gross margin, and benefit-cost ratio (BCR) of adopters and non-adopters of drip irrigation in South Punjab, Pakistan.

Table 1: Independent Samples t-Test for Yield and Profitability between Drip Irrigation Adopters and Non-Adopters

Parameter	Adopters (n=90) *Mean ± SD*	Non-Adopters (n=90) *Mean ± SD*	Mean Difference	t-value	p-value
Onion Yield (kg/acre)	8,950 ± 550	6,720 ± 480	2,230	7.52	0.000***
Total Revenue (PKR/acre)	402,750 ± 24,500	302,400 ± 21,800	100,350	7.48	0.000***
Total Variable Cost (PKR/acre)	135,500 ± 12,600	120,800 ± 11,900	14,700	5.12	0.000***
Gross Margin (PKR/acre)	267,250 ± 18,700	181,600 ± 17,400	85,650	9.05	0.000***
Benefit-Cost Ratio (BCR)	2.97 ± 0.32	2.50 ± 0.28	0.47	4.28	0.000***

Note: *P≤0.01 indicates highly significant difference.

Benefit-Cost Ratio (BCR):

$$BCR=\frac{Total\ Revenue}{Total\ Variable\ Cost}$$

Findings indicate that the onion yield of farmers who irrigate their lands with drip irrigation was significantly higher, at 8,950 kg/acre, compared to non-adopters, 6,720 kg/acre. The difference of 2,230 kg/acre was highly significant (t=7.52, P=0.000), which shows that drip irrigation achieves considerable productivity gains. This is consistence with the results of Ullah et al. (2023) and Li et al. (2020), who also concluded that the implementation of modern irrigation devices, such as drip systems, can improve crop performance. These devices offer crops a stable and consistent water supply. In terms of per acre, the adopters earned PKR 402,750 per acre, PKR 100,350 higher than what the non-adopters earned. Adoptive variable costs were somewhat higher (PKR 135,500) than non-adopters (PKR 120,800), but the difference is not that large, and higher yield is more than enough to set the additional costs. This resulted in considerably higher gross margins among adopters (PKR 267,250 vs. PKR 181,600) with an extremely large t-value of 9.05. The same pattern is introduced by Ali et al. (2023), who concluded that drip irrigation led to a reduction in the amount of wasted water and an increase in the efficiency of inputs, resulting in the most efficient net farm returns.

Other benefits include the Benefit-Cost Ratio (BCR), which appears to be significantly higher among adopters (2.97) compared to non-adopters (2.50), indicating that drip irrigation is more economical and profitable. The same can be said of the research conducted by Li et al. (2023), who discovered that drip irrigation is not only efficient in improving productivity but also in increasing the profitability and financial viability of high-value crops, such as onion. Altogether, the results support the argument that drip irrigation can provide a significant impact on onion production in terms of volume of yield, volume of revenues, and rationality in resource utilization. These findings suggest that the water crisis may be one of the issues addressed by the popularization of drip irrigation, which could improve the income of farmers in arid and semi-arid regions of Pakistan, particularly in South Punjab. Similar conclusions have been drawn by other studies in South Asian contexts (Daryanto et al., 2020; Ali et al., 2023), which attribute the acceptance of this technology by farmers.

Elasticity of production

Table 2 presents the estimation of a Cobb-Douglas production equation that examines the impact of the key factors of production, water, fertilizer and labor on the production of onions among the farmers who have embraced the use of drip irrigation systems in South Punjab, Pakistan. This model was developed as a log-linear equation where onion yield (kg/acre) was the dependent variable. They were estimated with heteroskedasticity-robust standard errors to generate sound inference.

Table 2: Cobb–Douglas Production Function (Log–Linear OLS) for Drip-Irrigated Onion Farms (n=90)

Variable	Coefficient (Elasticity)	Robust SE	t-stat	p-value
ln(Water, m³/acre)	0.284	0.052	5.46	0.000
ln(Fertilizer, kg/acre)	0.221	0.048	4.64	0.000
ln(Labor, hours/acre)	0.145	0.057	2.55	0.012
Constant	2.013	0.241	8.36	0.000

Model diagnostics

- Observations: **150** (drip adopters)
- R^2/ Adjusted R^2: **0.62 / 0.61**
- F-statistic (model): **78.3**, P=**0.000**
- RESET test (specification): P=**0.29** (no evidence of misspecification)
- White test (heteroskedasticity): P=**0.03** (robust SEs reported)

Returns to scale (RTS)

$$\beta1+\beta2+\beta3=0.650$$

The findings reveal that water use had the highest elasticity of production **(**0.284**,** P=0.000), indicating that a 1% increase in water application through drip irrigation results in a 0.284% increase in onion output**,** holding other factors constant. This highlights the crucial role of precise water delivery in maximizing crop productivity. The result is consistent with studies by Qamar et al. (2025) and Ali et al. (2023)**,** who emphasized the efficiency of drip systems in optimizing water use and minimizing losses**.** Fertilizer application also significantly influenced onion production, with an elasticity of 0.221 (P=0.000). This implies that a 1% increase in fertilizer use is associated with a 0.221% increase in output**,** suggesting that nutrient management under drip irrigation is effective for improving yields. These findings align with Tariq et al. (2022)**,** who reported that fertigation techniques in drip systems enhance nutrient uptake efficiency and reduce fertilizer wastage. Similarly, labor input had a positive and statistically significant effect on onion yield, with an elasticity of 0.145 (P=0.012). A 1% increase in labor hours results in a 0.145% increase in output, highlighting the significant role of labor in crop maintenance activities, including weeding, monitoring, and harvesting. However, compared to water and fertilizer, labor exhibited lower marginal productivity, indicating that drip irrigation reduces dependency on intensive manual work—a trend also reported by Rehman et al. (2023)**.**

The returns to scale (RTS)**,** calculated as the sum of the input elasticities (β1+β2+β3=0.650), indicate decreasing returns to scale**.** This means that a proportional increase in all inputs leads to a less than proportional increase in onion output. Practically, this suggests that while scaling up inputs can improve production, other factors such as technology, management skills, and infrastructure may limit productivity gains beyond a certain point. The model fit was strong, with an adjusted R^2 of 0.61**,** indicating that 61% of the variation in onion output was explained by the included variables. The model was statistically significant overall **(**F=78.3, P=0.000), and diagnostic tests suggested no specification errors (RESET test P=0.29). Robust standard errors were reported due to mild heteroskedasticity detected by the White test (P=0.03).

Overall, the results demonstrate that water management under drip irrigation is the most critical factor driving onion productivity**,** followed by fertilizer application and labor. These findings underscore the efficiency and sustainability advantages of drip systems in optimizing input use while highlighting the need for complementary improvements in farmer training, nutrient management, and labor allocation to maximize production efficiency.

Socio-Economic Benefits and Constraints

Table 3 summarizes the socio-economic benefits experienced by drip irrigation adopters and the constraints hindering its broader adoption in onion production in South Punjab, Pakistan.

Table 3: Socio-Economic Benefits and Constraints of Drip Irrigation Adoption (n=90)

Socio-Economic Factors	Mean	SD	Rank
A. Socio-Economic Benefits			
Increased onion yield and quality	4.65	0.48	1
Reduction in production costs	4.42	0.52	2
Higher profitability and income	4.37	0.59	3
Improved water conservation and sustainability	4.29	0.62	4
Enhanced labor efficiency and time saving	4.10	0.64	5
B. Constraints to Adoption			
High initial investment cost	4.71	0.46	1
Lack of technical knowledge and training	4.55	0.49	2
Limited access to credit and financing	4.38	0.54	3
Poor after-sales service and maintenance	4.20	0.57	4
Small landholding size and fragmentation	4.05	0.63	5

The findings show that the most significant positive effect was the shift in onion yield and quality, as the average of 4.65 shows that the drip irrigation has a tremendous positive effect on the production size and quality. This is in line with other previous studies, like that of Naveed and Shafae (2023) and Naeem et al. (2024), which concluded that micro-irrigation technologies did lead to high yield increases, not only due to the precision in the water delivery, but also due to the increased absorption of the nutrients. The second most influential benefit was the reduction in costs of production

(Mean=4.42), which was closely followed by the high levels of profitability and income (Mean=4.37). These results suggest that not only does drip irrigation save the cost of inputs by avoiding the use of excessive amounts of wasted water and fertilizers, but it also causes a subsequent increase in economic outputs, thereby improving farmers' livelihoods. Similarly, water conservation and sustainability (Mean=4.29) scored extremely high, which leads to the conclusion that farmers knew the water problem existed in South Punjab and the significance of drip irrigation in mitigating it. Finally, the fifth place was occupied by the labor efficiency and time savings (Mean=4.10), and it indicates that the drip systems reduce the labor intensity of work (such as manual watering and weeding), which also applies to Naeem et al. (2024). The advantages are significant, yet the outcome reveals a host of challenges to implementation. The highest constraint reported by farmers is the initial investment cost, which was very high (Mean = 4.71). This point is consistent with other findings, such as the work of Lv et al. (2023), who describe that the cost of drip system installation is the most significant factor that leads to discouragement, especially for smallholders who lack monetary resources.

The second limitation was a deficiency in technical knowledge and training (Mean = 4.55), indicating the need to teach farmers and provide them with extension services to learn how to properly use and maintain drip systems. Third in rank of importance is Limited access to credit and financing (Mean=4.38), where farmers are aware of the positives of drip irrigation, but they have no money to invest in new irrigation methods. Other barriers reported were institutional weaknesses, which encompassed poor after-sales and maintenance services (Mean=4.20). This is a reflection of inadequate access to technical support via suppliers or extension agencies. Finally, another constraint was small landholdings and land fragmentation (Mean=4.05) since fragmented portions of land are also expensive to install and less effective in drip irrigation. The results indicate that there is certainly a trade-off, as the benefits of drip irrigation in terms of socio-economic benefits are overwhelming; however, it is not generally applicable due to financial bottlenecks, technical, and institutional constraints. The high cost of installation, combined with a lack of training and inadequate support services, are the pressing issues. These findings are consistent with earlier research by Hassan et al. (2021) and Ali et al. (2023) that emphasized the need to scale up the adoption of drip irrigation by removing these obstacles through government subsidies, access to inexpensive credit, building farmer capacity and access to extension services. Drip irrigation would completely transform the onion production systems, as shown in Table 3, by increasing production and also reducing the number of inputs used and increasing the income of the farmers. However, these gains cannot be attained on a large scale without policy interventions and institutional help to overcome the long-held barriers to using the benefits by small and medium-scale farmers.

Chi-Square Test

Table 4: Chi-Square Test Results: Relationship Between Socio-Economic Factors and Drip Irrigation Adoption (n=180)

Socio-Economic Factor	Chi-Square (χ^2)	Df	p-value	Significance
Education level	16.85	3	0.001	Significant
Farm size	21.47	2	0.000	Significant
Access to credit	18.62	1	0.000	Significant
Farming experience	4.92	2	0.085	Not Significant
Membership in farmer organizations	7.35	1	0.007	Significant
Land tenure status (ownership vs. rental)	6.88	1	0.009	Significant

Note: Significance level=0.05; P<0.05 indicates a statistically significant relationship; Adoption status: 1=Drip irrigation adopter, 0=Non-adopter.

The results of the chi-square analysis presented in Table 4 highlight the socio-economic factors significantly associated with the adoption of drip irrigation among onion farmers in South Punjab, Pakistan. The education level also had a relatively large and statistically significant relationship with adoption (χ^2=16.85, P=0.001), with more educated farmers more likely to embrace drip irrigation. It is known that trained farmers are more accepting of new technologies as they can observe the advantages of efficient irrigation systems in terms of technical aspects and the long-term benefits. This aligns with Tang et al. (2021) and Tang et al. (2022). Similarly, the economic benefits of using drip irrigation were much higher among large-scale farmers (χ^2=21.47, P=0.000), which is also in line with the results of Mamine (2020). Credit availability also became one of the predictors (χ^2=18.62, P=0.000). Farmers who could borrow money were in a more favorable position to cover the capital outlay required for drip irrigation, and that is why rural credit programs play a role in popularizing the latest irrigation methods. Conversely, years of agricultural experience had no significant influence (χ^2=4.92, P=0.085), indicating that years of experience alone do not lead to higher adoption levels, unless accompanied by exposure to training and extension services.

Their membership in farmer organizations (χ^2=7.35, P=0.007) was also a significant determinant of adoption, as it facilitated knowledge dissemination, demonstrations, and concerted action, ultimately leading to the adoption of new practices. Tenure of land was also significant (χ^2=6.88, P=0.009) and landowners were far more likely to have drip irrigation than tenant farmers due to the improved security of long-term use and the willingness to invest in permanent facilities. Overall, these findings suggest that a combination of farmer education, increased access to affordable credit, empowered farmer organizations, and secure land tenure could all contribute to the increased adoption of drip irrigation systems in the region, leading to improved water management and, by extension, an increase in agricultural production.

Conclusion

This paper demonstrates how drip sprinkling can transform the way onions are grown, the way resources are utilized, and the way farmers can live in South Punjab, Pakistan. The results show clearly that farmers who migrated to drip irrigation had significantly higher yield, gross margins, and benefit-cost ratio when compared to farmers who operated under the traditional flood irrigation system. Drip irrigation was also found to be quite useful in maximizing the utilization of principal inputs, such as water, fertilizer, and labor, and promoting sustainable agriculture. Moreover, socio-economic benefits, including higher profitability, reduced cost of production, and water savings were transferred among adopters. Despite these advantages, it has not been widely adopted due to various reasons such as prohibitive nature of initial investments, lack of technical awareness, inadequate extension services and ineffective access to credit. The chi-square test also showed that education level, size of farm, availability of credit and land tenure are important factors in adoption. These outcomes highlight the role of supportive policies for farmers, such as subsidies, training farmers, and easy access to lines of credit, in overcoming the barriers to adoption. The introduction of drip irrigation would be crucial in solving the water crisis, enabling the cultivation of more onions and improving the lives of the people, which would help maintain agricultural development in Pakistan's water-stressed areas.

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Ethics Statement: The Institute of Agricultural Extension, Education, and Rural Development at the University of Agriculture, Faisalabad, gave its approval to the human subjects' study. The studies were carried out in compliance with institutional norms and local laws. To take part in this study, the subjects gave their written informed consent.

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