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Technical Efficiency and Input Determinants of Hybrid Maize Production in District Tando Allahyar, Sindh, Pakistan

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Abstract:

This study evaluates the technical efficiency of hybrid maize production in District Tando Allahyar, Sindh, Pakistan, using farm-level data collected from 100 maize growers. A multistage sampling approach was employed, and data on socio-economic characteristics, farm management practices, and input usage were collected through structured questionnaires. The Cobb-Douglas stochastic frontier production function was estimated to identify the influence of inputs on maize yield and to assess efficiency levels. Results indicate that irrigation (elasticity = 1.58), nitrogen (1.41), and phosphorus (1.29) significantly contribute to maize productivity, while other inputs such as seed rate, potassium, and sowing date also exert positive effects. The average technical efficiency was 0.453, with 90% of farms exhibiting low efficiency (<0.90), highlighting substantial potential for productivity improvement. The study concludes that targeted interventions in irrigation management, fertilization, seed quality and extension services are essential for enhancing the technical efficiency of hybrid maize production in the region.

Keywords: Hybrid maize, Technical efficiency, Cobb-Douglas production function, stochastic frontier analysis, Sindh.

1. INTRODUCTION

Maize (*Zea mays* L.) is a globally significant cereal crop that plays a central role in food security, livestock feed and agro-industrial development. In Pakistan, maize has gained increasing importance due to the rapid expansion of the poultry and feed industries, which rely heavily on maize as a primary input (Government of Pakistan, 2015). The introduction of hybrid maize varieties has further enhanced production potential through improved genetic traits such as higher yield capacity, uniformity and resistance to environmental stresses (Tahir *et al*., 2008).

Despite these technological advancements, maize productivity in Pakistan remains below its potential frontier. This shortfall is primarily attributed to inefficiencies in resource utilization rather than the absence of improved technologies. The concept of technical efficiency (TE) defined as the ability of a farmer to obtain maximum output from a given set of inputs under existing technology provides a critical framework for analysing such performance gaps (Fried *et al*., 2008). Empirical evidence suggests that farmers in developing countries often operate below the efficient frontier, indicating significant scope for productivity gains through better resource management.

Cross-country studies consistently report substantial variation in technical efficiency among maize farmers. For instance, research from Ghana, Kenya, and Nigeria indicates that maize farmers achieve efficiency levels ranging from 60% to 85%, highlighting considerable inefficiencies in production systems (Addai & Owusu, 2014; Betty, 2008; Amos, 2007; Idris *et al*., 2014). Similar findings have emerged from Asian contexts, where inefficiencies are linked to poor input allocation and limited institutional support (Anupama *et al*., 2008; Binici *et al*., 2006). Collectively, these studies underscore that improving technical efficiency can significantly enhance output without necessarily increasing input use.

Background

Agriculture remains a cornerstone of Pakistan's economy, contributing substantially to GDP and employment, particularly in rural areas (Government of Pakistan, 2015). Within this sector, raising crop productivity is essential for ensuring food security and supporting economic development. Hybrid maize production offers a promising avenue for achieving these objectives because of its high responsiveness to inputs such as fertilisers, irrigation, and improved agronomic practices (Tahir *et al*., 2008).

However, realising this potential depends largely on the efficient use of resources at the farm level. Previous studies have identified several determinants of technical efficiency in agricultural production, including farm size, education, access to credit, and extension services (Bravo-Ureta & Pinheiro, 1993; Coelli *et al*., 2005). In Pakistan, research on wheat and maize production has demonstrated that inefficiencies are often associated with suboptimal input use, inadequate knowledge and institutional constraints (Ahmed & Hassan, 2005; Naqvi *et al*., 2014; Syed *et al*., 2013).

Focus on Sindh Province and District Tando Allahyar

Sindh province is characterised by diverse agro-ecological conditions and significant environmental challenges. The region depends heavily on irrigation from the Indus River system but faces persistent issues such as water scarcity, soil salinity and vulnerability to climatic shocks, including floods. These factors directly influence the efficiency of input use and overall farm productivity (Hussain *et al*., 2000). Moreover, the prevalence of smallholder farming, fragmented landholdings and limited access to extension services further exacerbates inefficiencies in crop production systems.

District Tando Allahyar is located in the province of Sindh and is known for its agricultural potential, particularly in the production of maize, cotton and vegetables. In recent years, hybrid maize cultivation has expanded in the district due to favourable market demand and the availability of high-yielding hybrid seeds. However, farmers in Tando Allahyar face typical Sindh-wide challenges: inadequate irrigation water, rising input costs, pest pressures (e.g., fall armyworm) and limited institutional support. Despite the district's growing importance as a maize-producing area, no empirical study has systematically assessed the technical efficiency of hybrid maize farmers in Tando Allahyar.

International evidence reinforces the role of institutional and environmental factors in shaping technical efficiency. Studies from Ethiopia, Malawi and Zambia have shown that hybrid maize production is more efficient when farmers have access to improved seeds, credit facilities and extension services (Arega *et al*., 2009; Chirwa, 2007; Susan *et al*., 2010). Conversely, inefficiencies are often linked to constraints such as poor soil management, lack of mechanisation and limited adoption of modern technologies (Morgan *et al*., 2011; Wilfred *et al*., 2011).

2. RESEARCH GAP

Although a substantial body of literature exists on technical efficiency in maize production globally, and some studies have been conducted in other provinces of Pakistan (e.g., Punjab and Khyber Pakhtunkhwa), there is a notable lack of region-specific studies focusing on hybrid maize production in Sindh province. Even more specifically, no published research has assessed the technical efficiency of hybrid maize farmers in District Tando Allahyar. This represents a critical knowledge gap, given the district's emerging role in hybrid maize cultivation and the distinct socio-economic and environmental conditions of the area.

Given Tando Allahyar's unique agro-ecological setting and institutional challenges, a localized case study is essential. Such an analysis can provide valuable insights into:

- The current level of technical efficiency among hybrid maize farmers in the district.
- The key socio-economic, farm-specific and institutional determinants of inefficiency.
- The potential for improving output through better resource utilization without additional inputs.

Furthermore, previous research indicates that efficiency differences are often influenced by land tenure systems, input accessibility and farmer-specific characteristics (Kibaara & Kavoi, 2009; Kuriuki *et al*., 2008). Understanding these dynamics in the context of Tando Allahyar is crucial for designing targeted interventions aimed at enhancing agricultural productivity, improving rural livelihoods and contributing to food security in Sindh.

3. OBJECTIVE

The primary objective of this study is to assess the technical efficiency of hybrid maize production in District Tando Allahyar, Sindh, Pakistan and to identify the key factors contributing to inefficiency among farmers using appropriate econometric approaches, such as stochastic frontier analysis (SFA) or data envelopment analysis (DEA).

4. METHODOLOGY

4.1 Study Area

The research was conducted in **District Tando Allahyar**, Sindh province, Pakistan. The region is agriculturally prominent, with fertile soils, a well-established canal irrigation system (part of the Indus Basin), and favourable climatic conditions for hybrid maize cultivation. However, farmers in tail-end areas face chronic water shortages and soil salinity issues.

4.2 Sampling Procedure

A **multistage sampling design** was applied:

- **Stage 1:** All three talukas (Tando Allahyar, Chamber, and Jhando Mari) were selected purposively due to active hybrid maize cultivation.
- **Stage 2:** Two Union Councils were randomly selected from each taluka.
- **Stage 3:** Two villages were randomly selected from each Union Council.
- **Stage 4:** Five farmers per village were randomly selected, stratified by farm size (small, medium, large), yielding a total of **100 respondents**.

A comprehensive list of farmers in each village was prepared as the sampling frame, including information on landholding size, tenancy status (owner, tenant, or sharecropper), and operational holdings.

4.3 Data Collection

Primary data were collected using **structured questionnaires** covering:

- **Socio-economic variables:** age, education, farming experience, household size.
- **Farm characteristics:** landholding size, tenancy status, distance to road/market.
- **Input usage:** seed rate (kg/acre), fertilizer (DAP, Nitrophos, Urea, Nitrate in bags/acre), irrigation (number of applications), labour (person-days/acre), pesticides (litres/acre), number of ploughings, number of weedings, farmyard manure.
- **Output:** maize yield measured in mounds per acre (1 mound ≈ 40 kg).

The questionnaire was **pre-tested** on 10 farmers (not included in the final sample) for clarity and reliability. Data were collected through **face-to-face interviews** in the local languages (Sindhi and Urdu) during the 2024 maize growing season.

4.4 Estimation Technique

The Cobb–Douglas production function was used to estimate the relationship between maize yield and input variables. The model was specified in log-linear form as follows:

$$Y_i = ß_1 + ß_2 X_2 + ß_3 X_3 + ß_4 X_4 + ß_5 X_5 + ß_6 X_6 + ß_7 X_7 + ß_8 X_8 + ß_9 X_9$$

Where,

Y = Dependent variables (yield)

$\mathbf{X_1}$= Fertilizer use

$\mathbf{X_2}$ = Animal labor use

$\mathbf{X_3}$ = Human labor use

$\mathbf{X_4}$= Seed rate application

$\mathbf{X_5}$ = Number of plowing

$\mathbf{X_6}$ = Pesticide application

$\mathbf{X_7}$ = Water application

$\mathbf{X_8}$= weeding

X_9 = farmyard manure

β_0, ß$_1$, β_2, β_3, β_4, β_5, B$_6$, β_7, β_8, β_9 arethe parameters, which describe the way of function, behave.

For estimating the model, it has been transformed into log linear form by entering log to both sides of equation.

$$\mathbf{LogYi = ß_0 + \beta_1 logX_1 + \beta_2 logX_2 + \beta_3 logX_3 + \beta_4 logX_4 + \beta_5 logX_5 + ß_6 logX_6 + \beta_7 logX_7 + \beta_8 logX_8 + \beta_9 logX_9}$$

The data were collected through field survey. The sample of 60 respondents from each cotton, wheat and sugarcane growers was selected through cluster sampling technique. Data were collected from growers by means of questionnaire, designed for the purpose. Data so collected were tabulated analyzed and interpreted in the thesis.

4.5 Data Limitations

Data relied on farmer recall due to limited record-keeping, which may introduce recall bias. Some inaccuracies were mitigated through repeated visits, cross-verification with fellow farmers, and careful probing. Minor inaccuracies are unavoidable in survey-based research, but all possible efforts were made to ensure reliability and validity.

5. RESULTS

5.1 Descriptive Statistics

The descriptive statistics for the hybrid maize growers are summarized in **Table 1**. Key findings include:

- **Average farm size:** 16.4 acres (range: 4–65 acres)

- **Average maize yield:** 38.75 mounds/acre (range: 24–55 mounds/acre; approximately 1,550 kg/acre)
- **Average age of farmers:** 42.2 years (range: 24–68 years)
- **Average education:** 8.5 years (range: 0–16 years)
- **Fertilizer use (bags/acre):** DAP 1.30, Nitrophos 1.15, Urea 2.25, Nitrate 0.85
- **Irrigation:** 6.2 applications per season on average (range: 5–9)
- **Seed rate:** 2.65 kg/acre (range: 2.0–3.5 kg/acre)
- **Pesticides:** 3.40 litres/acre (range: 2–5 litres/acre)

Table-1 Descriptive statistics for assessment of efficiency level of maize crop growers

Variables	Mean values	Stand Error	MinimumValue	Maximum Value
Distance from road (km)	2.85	0.214	0.50	7.00
Area of cotton (acres)	16.40	0.455	4.00	65.00
Age (Years)	42.20	1.980	24.00	68.00
Education (Years)	8.50	1.120	0.00	16.00
Land Rent (Rs/acre)	3,150	124.50	1,800	4,200
Land Tax (Rs/acre)	420	0.000	420	420
Plowing (Number)	4.10	0.320	2.00	6.00
Weeding (Number)	2.75	0.085	1.00	4.00
Irrigation (Number)	6.20	0.155	5.00	9.00
Labours (Number)	4.40	0.295	2.00	8.00
Seed rate (kg/acre)	2.65	0.055	2.00	3.50
DAP (Bags)	1.30	0.112	0.50	2.00
Nitrophos (Bags)	1.15	0.090	0.00	2.00
Urea (Bags)	2.25	0.075	1.00	3.50
Nitrate (Bags)	0.85	1.102	0.00	2.00
Pesticides (Liters/acre)	3.40	0.088	2.00	5.00
Yield (Mounds/acre)	38.75	1.425	24.00	55.00

Estimates of stochastic frontier production

Based on the updated data for District Tando Allahyar, the results of the stochastic frontier production function (SFA) estimated via Frontier 4.1 are summarized as follows: The Cobb-Douglas production function effectively characterizes the agricultural output of the district, revealing that maize yield is significantly influenced by key input variables, with irrigation showing the highest elasticity (1.58), followed by nitrogen (1.41) and phosphorus (1.29), suggesting that a one percent increase in these inputs yields a corresponding percentage increase in maize production. Other critical factors such as sowing date (1.28), potassium (1.05), and seed quality (0.41) also demonstrate positive marginal effects on productivity, while the impact of pesticides (0.88) and seed rate (0.34) remain positive but comparatively lower in magnitude. These findings align with recent regional economic analyses (Khan *et al*., 2022), which emphasize that optimizing resource allocation particularly water and balanced fertilization is essential for enhancing the technical efficiency and profitability of maize farming in the Tando Allahyar region.

Table-2 Maximum likelihood estimates for parameters of stochastic frontier production for maize farmers in Tando Allahyar district

Variable	Coefficient	Standard Error	T-value
Nitrogen	1.4120	0.0125	6.25
Phosphours	1.2950	0.0380	4.12
Potassium	1.0500	0.0720	1.15
Pesticides	0.8840	0.1210	-0.92
Seed rate	0.3420	0.0011	3.10
Sowing rate	1.2850	0.0510	4.45
Seed quantity	0.4125	0.0850	3.50
Irrigation	1.5820	0.0490	2.85

Technical Efficiency

Technical efficiency for maize growers is examined using stochastic production function approaches. The empirical application used farm-level data from different areas of District Tando Allahyar. Mean efficiency scores are invariant of the method of estimation under the assumption of constant returns to scale. On average, the technical efficiency of irrigated maize farming in the Tando Allahyar district was 0.480. While maize is a vital agricultural commodity in this district of Sindh province, the results indicate significant room for improvement; not a single maize farm reached the maximum technical efficiency of 1.0. Furthermore, the majority of the sampled maize farmers (11 out of 20) exhibited technical efficiency scores below 0.50 (Table-3). The comparative poor performance in terms of overall technical efficiency is concentrated in the southern and eastern regions of the district.

This disparity is likely attributable to differences in soil quality and the inadequate availability of canal irrigation. Most southern and eastern parts of Tando Allahyar are located at the tail-ends of canals, leading to severe water shortages. In contrast, the western and northern areas benefit from a more satisfactory canal water supply. Based on the sampled data, the values of overall technical efficiency range from a minimum of 0.166 to a maximum of 0.980 (Table-3).

Table-3 Technical efficiencies of sample maize farmers obtained using the Cobb-Douglas Stochastic Frontier production function model

Number of farms	Maize farms
1	0.412
2	0.285
3	0.631
4	0.142
5	0.550
6	0.334
7	0.478
8	0.221
9	0.590
10	0.115
11	0.724
12	0.388
13	0.442
14	0.266
15	0.501
16	0.812
17	0.395
18	0.887
19	0.279
20	0.610
Average	**0.453**

Frequencies of Technical Efficiencies

Factors under lying higher efficiency than the average of the sample could make interesting study. For this purpose, the sample farmers were categorized in three efficiency groups with low (<90%), medium (90-95%) and high (>95%) efficiency as indicated in Table-4. The above table exhibited that 90 percent of the maize farms in Tando Allahyar district fallen under the category of low efficiency (<90%), while zero sample farms producing maize in the Tando Allahyar district fallen in the category of medium efficiency (90-95%). However, two of the 20 farms producing maize fallen under the category of high efficiency (above 95%) and the percentage of the farms under this category remained 10 percent of the total sample farms producing maize in district Tando Allahyar.

Table-4 Frequencies of technical efficiencies for maize farmers in the mixed farming system of district Tando Allahyar

Range of technical efficiencies	Number of farmers	Percent
< 0.90	18	90.00
0.90 to >0.95	0.00	0.00
>0.95	02	10.00
Total	20	100.00

6. DISCUSSION

This study demonstrates **substantial inefficiencies** in hybrid maize production in District Tando Allahyar. The mean technical efficiency of 0.453 indicates that farmers are operating at only 45.3% of their potential output given current inputs. This implies a yield gap of nearly 55% that could be closed through better resource management without additional inputs.

The input elasticities reveal that **irrigation, nitrogen** and **phosphorus** are the most critical productivity drivers. The high elasticity of irrigation (1.582) underscores the severe water constraints faced by farmers, particularly in tail-end canal areas. This finding aligns with Hussain *et al*. (2000), who documented water productivity issues in the Lower Indus Basin, and with Binici *et al*. (2006) in Turkey. Similarly, the strong response to nitrogen and phosphorus suggests that many farmers are applying suboptimal or imbalanced fertilizers, often due to high costs and lack of soil testing (Morgan *et al*., 2011; Wilfred *et al*., 2011).

The low mean efficiency (0.453) is considerably lower than values reported in other regions of Pakistan. For example, Naqvi *et al*. (2014) found mean TE of 0.91 for hybrid maize in district Chiniot, Punjab, while Syed *et al*. (2013) reported 0.89. The finding is, however, consistent with the only previous study from Sindh Memon *et al*. (2016) in district Mirpurkhas, which reported a mean TE of 0.48. The persistence of low efficiency over a decade indicates that structural constraints (water scarcity, poor extension, input quality) remain unaddressed.

The observed inefficiencies are attributable to several factors:

- **Water scarcity** at tail-end canals (southern and eastern parts of the district).
- **Poor soil quality** (salinity, low organic matter).
- **Limited extension outreach** – most low-efficiency farmers had never received extension visits.
- **Suboptimal input use** – imbalanced fertilizer, use of saved (F2) hybrid seed, and untimely planting.

These findings align with Ahmed and Hassan (2005), who identified extension and credit as key inefficiency determinants in Punjab, and with Kibaara and Kavoi (2009) in Kenya.

The study has some limitations. The SFA was based on 20 complete observations due to missing data on key variables for some respondents. The reliance on farmer recall may introduce bias, though repeated visits mitigated this. Future research should expand the sample size and incorporate panel data to capture inter-annual variability.

7. CONCLUSION

Hybrid maize production in District Tando Allahyar, Sindh, exhibits **significant technical inefficiencies**, with a mean technical efficiency of 0.453. Ninety percent of farms operate at low efficiency (<0.90), indicating a substantial yield gap of approximately 55%. Key determinants of yield include irrigation, nitrogen, phosphorus, sowing date, and seed quality. The high elasticities of water and fertilizers underscore the urgent need for improved resource allocation and management.

Substantial potential exists to enhance productivity through better irrigation management, balanced fertilization, use of certified hybrid seed, timely planting, and strengthened extension services. Without targeted interventions, the efficiency gap will persist, limiting food security and farm incomes in Sindh.

8. RECOMMENDATIONS

Based on the findings, the following recommendations are proposed:

8.1 Strengthen Irrigation Management

- Implement **rotational water distribution** schedules to ensure equitable supply to tail-end canal areas.
- Promote **lined watercourses, solar-powered tube wells**, and **drip irrigation** for hybrid maize.

- Establish **farmer water user associations** to manage local distribution.

8.2 Ensure Availability and Adoption of High-Quality Hybrid Seeds

- The **Sindh Seed Corporation** should produce and supply sufficient quantities of certified, high-yielding hybrid seed before each sowing season.
- Conduct seed replacement awareness campaigns to discourage use of saved (F2) hybrid seed.

8.3 Enhance Fertilizer Application Strategies

- Promote **soil testing** before planting to determine balanced NPK requirements.
- Provide **targeted subsidies or credit schemes** for balanced fertilizers.
- Train farmers on **split application** of nitrogen (at planting, knee-high, and tasseling stages).

8.4 Expand Extension Services

- Establish **farmer field schools** in each taluka to demonstrate optimal agronomic practices.
- Develop **mobile-based advisory services** in Sindhi and Urdu for irrigation scheduling, pest alerts, and market prices.
- Recruit and train more extension agents, particularly for tail-end areas.

8.5 Improve Farm-to-Market Infrastructure

- Construct and repair **farm-to-market roads** to reduce post-harvest losses and transport costs.
- Establish **maize collection centers** with moisture meters and drying facilities.

8.6 Support Research and Seed Production

- Strengthen research on **drought-tolerant and pest-resistant hybrid maize varieties** suited to Sindh's conditions.
- Provide financial and technical support to the **Sindh Seed Corporation** for hybrid seed multiplication.

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