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Crop and Economic Water Productivity of Wheat at Perennial and Non-Perennial Canals in Sindh

Muhammad Ali [1] Zain ul Abdin [2] Rafique Chandio [3] Ali Raza Zaidi [4]

Abstract: *The freshwater resources are under immense pressure to provide water and food security. New climate change projections for current and future water availability suggest that farmers and policymakers must move from traditional per-acre crop yield measurement to crop and economics water productivity. This research aimed to assess wheat-crop CWP and EWP at perennial and non-perennial canals. The Nara and Rice canals were selected, and both canals were off-take at Sukkur Barrage from Indus. Two distributaries were selected from each canal with the location of the head and tail. A survey tool was designed to collect data. In total, 431 farmers were randomly selected. The collected data was analyzed by using CWP, EWP, Vw, Cobb-Douglas production function, and DEA techniques. Results show that the tail of the Rice canal, CWP, EWP, and Vw was higher than the head. But at the head of the Nara canal, CWP, EWP, and VW were higher than at the tail. The Cobb-Douglas results show the significant impact of irrigation, fertilizer, and watercourse position on production. Further, in DEA results, the tail reaches of both canals were more efficient. Similarly, higher water-saving potential is observed at the head of both canals.*

Key Words: Crop Water Productivity, Economic Water Productivity, Food Security

Introduction

Globally, freshwater resources are under immense pressure and will become a complex and multidimensional problem if not managed properly. Approximately 70% of the global freshwater is used by the agriculture sector. The rapidly growing population is estimated to reach 9.5 billion by 2050, and the agriculture sector is facing the challenges of fulfilling the nutritional needs of this population (Bouman, 2007). In order to adequately feed over 9 billion people, the production needs to be increased by 50% for all fodder and food crops. Therefore, water consumption would increase at the same rate(Falkenmark & Rockström, 2004). Moreover, due to increased competitors, freshwater resources are becoming scarce (Rijsberman, 2006). Freshwater scarcity was identified as the most important environmental issue in the UN report "Water a Shared Responsibility" (UNESCO, 2006). A number of factors affect the availability of fresh water. These factors include the growing world population, rise of the middle class, and change in demand, coupled with climate change and industrial processes. In the 21st century, managing freshwater resources and their consumption has become the main challenge for all stakeholders. (WBCSD, 2006)

Food production is among the largest consumers of fresh water. Food production consumes up to two-thirds of all the available freshwater resources. In different parts of the globe, freshwater supplies have become scarce. Due to the conventional irrigation systems, water is being wasted largely. There is a huge potential in the agriculture sector to save water by using modern irrigation methods such as drip irrigation and sprinkler irrigation systems. According to Postel (2001), a huge quantity of water can be saved by

[1] Assistant Professor, USPCAS-W, Mehran University of Engineering and Technology, Jamshoro, Sindh, Pakistan.
[2] Research Scholar, US Pakistan Center for Advanced Studies in Water, Mehran University of Engineering and Technology, Jamshoro, Sindh, Pakistan.
[3] Professor, Department of Economics, University of Sindh, Jamshoro, Sindh, Pakistan.
[4] Assistant Professor, Department of Business Administration, GC University, Hyderabad, Sindh, Pakistan.

- **Corresponding Author:** Muhammad Ali (mali.uspcasw@faculty.muet.edu.pk)
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introducing and applying new technologies and techniques such as drip irrigation sprinklers, scheduling the water application as per the requirement of plants, and introducing crop varieties that are water-efficient. Additionally, the increased irrigation efficiency will minimize the salinization process, increase crop yields, reduce runoff, and reduce water pollution (Postel, 2001). The CWP for sweet potatoes was increased by 243 percent, and the CWP for potatoes was increased by 46 percent by using drip irrigation in India (Gleick, 2002). According to the FAO, food insecurity will be solved in developing countries by increasing crop productivity, expanding new agricultural fields, and increasing cropping intensity. Pakistan has also been facing the challenges of inefficient water use, low agricultural yields, population growth, rise in the middle class, increased poverty, rapid urbanization, industrialization, etc.

Until 1951, the country had a freshwater supply of 5260 m^3/capita/year and considered a water-rich country (Bhatti et al., 2009), but due to uncontrolled population growth, it has been dropped to 1,017 m^3/capita/year (Kochhar et al., 2015) and it is decreasing at an alarming rate. Pakistan is among the countries with the lowest crop water productivity. In spite of having the same climatic conditions, India is ahead of Pakistan in terms of crop water productivity. According to Control & Diety (2015), wheat yield per acre in Pakistan is the lowest in the world, with an average of 0.92 tons per acre, while neighboring India has 1.04 tons per acre. Other developed countries have yield per acre as follows: USA 1.2 tons, Germany 2.6, France 2.5 tons, England 3.08 tons, New Zealand 2.96 tons, Denmark 3.12 tons, the Netherlands has an average of 3.64 tons, Japan 1.6 tons.

In Pakistan, efficient irrigation management and integrated water resource management are need of the hour. This can only be done by assessing the CWP and EWP. The assessment of CWP and EWP has remained neglected and unaddressed for a long time. The availability of water is dependent on rainfall, climate change, rapidly increasing population, glacial melt, and many other factors that make water availability highly uncertain. Therefore, policymakers need to focus more on increasing water and economic productivity to ensure water availability and food security. This study will help policymakers by providing the existing practices and CWP & EWP of wheat crops by comparing perennial and non-perennial canals in Sindh province.

Literature Review

CWP is defined as "the physical mass of product or the economic value of product calculated against gross inflows, net inflow, depleted water, process depleted water, or available water" (Brauman et al., 2013). The output produced from a unit of water is called water productivity. (Kuppannan et al., 2009) Stated that crop water productivity focuses on the techniques and methods to enhance crop productivity with the same or less amount of water. In the agronomical context, the quantity or amount of organic matter produced by an organic plant divided by the amount of water is called "water use efficiency." The term "water use efficiency" was in contrast with the classic notion of "efficiency," which shows the same input units and the same output units. Therefore, the International Water Management Institute (IWMI) proposed changing the taxonomy from Water Use Efficiency to Water Productivity. There are various methods to determine and analyze water productivity depending on the context, scale, degree, and extent of the analysis (van Dam & Malik, 2003).

Dong et al. (2001) defined water productivity in three ways: first, evapotranspiration. Second is irrigation water output per unit, and third is rain plus irrigation production. In the first term, water productivity is calculated by a unit of evapotranspiration, which divides up the crop's mass of total water evaporated from the soil. In the second, water productivity is calculated. The irrigation water output per unit is the crop production divided by the irrigation flux. Third, water productivity is calculated as the production of rain plus irrigation, which is the production of water per unit of gross influx. In evapotranspiration, the productivity heavily depends on the plant behavior because it is calculated with the help of evaporated water. On the other hand, the remaining two calculation methods of water productivity include not only evapotranspiration but also water that is used for waste crops and water by other means.

EWP (Economic Water Productivity) calculates the market prices of crops by dividing them by the total water used. EWP has become a top priority in water management, especially for crops with higher water requirements, particularly in underdeveloped and developing countries with limited water and financial resources and large populations depending on the agriculture sector (Kumar & van Dam, 2013).

A study was conducted by (Khan et al., 2015) to compare the CWP of Civil and Public canals, and the results show that the average CWP under public canals for the crops of maize, sugarcane, tomato, and wheat was 1.11, 3.31, 3.61, 0.96 kg/m^3 and civil system canals CWP for same crops was 0.77, 2.36, 2.98, 0.90 kg/m^3 respectively. The public canal system had a higher average CWP of these crops as compared to the civil canal system by 40, 44, 21, and 7%, respectively, in another study conducted by Shabbir et al. (2012) to evaluate the apparent and real CWP of wheat crop. The study results revealed that the mean yield was 3,210 kg/hectare, the apparent water productivity (yield/irrigation water) was 0.43 kg/m^{3,} and real water productivity (yield/water evapotranspiration) was 1.12 kg/m^3. Another study conducted by Ahmad et al. (2004) in Punjab province, where the CWP of wheat and rice system was evaluated, shows that CWP of wheat and rice was between 0.78 to 2.03 kg/m^3 and 0.17 to 0.38 kg/m^3 respectively and EWP of wheat, rice, and wheat-rice system was between $50 to 150/1000 m^3, $5 to 51 /1000 m^3, and $26 to 76/1000 m^3 respectively.

To compare the economic efficiency of the wheat crop in different cropping systems, Koondhar et al. (2018) used the Cobb-Douglas production function. The findings of the study showed that irrigation, plow, fertilizer, and seed were the main factors in increasing the crop yield in the cotton-wheat cropping system. On the other hand, fertilizer, plow, and seed were key factors in increasing the yield of the rice-wheat cropping system. In mixed cropping systems, seed, plant protection, and plow were the main factors in increasing the yield. Due to inappropriate and inefficient irrigation strategies and poor land management techniques, the coefficient of irrigation has a negative value. Rehman et al. (2019) conducted a study on the factors responsible for the decline in agricultural productivity in Pakistan. Cobb-Douglas production function was used to analyze the impact of major factors on agricultural production. Results showed that fertilizer consumption, credit availability, and improved seed distribution have a positive impact, and poor water availability has a negative impact on the country's agricultural GDP.

In a research conducted by Malana & Malano (2006), an assessment of the benchmark of wheat productive efficiency was done in India and Pakistan by using Data Envelopment Analysis (DEA). Seed, fertilizer, and irrigation were taken as inputs. The untimely overuse of fertilizers and irrigation was identified as the main cause of lower productivity. The findings showed that DEA is an effective method to analyze and benchmark the productivity and efficiency in the agriculture sector. Inefficiencies in resource use by using DEA were studied by Shafiq & Rehman (2000) in cotton production in the Punjab province of Pakistan. Findings showed that due to mismanagement, there were a number of inefficiencies in resource distribution. However, the allocated and technical efficiencies increased with an increase in input variables in the DEA model.

Research Objective

- To assess and evaluate the crop water productivity and economic water productivity of wheat crops at the perennial and non-perennial canals.

Research Question

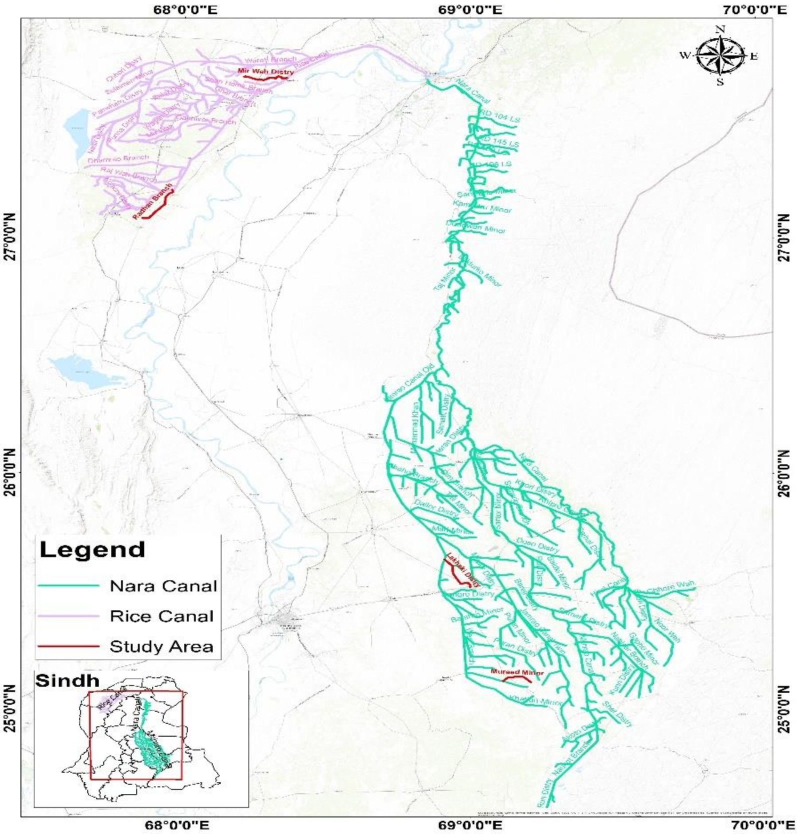
- What are the CWP and EWP of the wheat crop at the perennial and non-perennial canals under two irrigation management systems?

Methodology

Locale of the Study

Two canals from the Sindh province of Pakistan were selected, the Rice Canal and Nara Canal, which are displayed in the figure below (on the next page).

Figure 1



Description of Rice Canal

To compare the perennial and non-perennial wheat CWP, this study examined the Rice Canal as a non-perennial canal, which only flows in the Kharif season. The canal off-takes from Sukkur barrage. It provides irrigation water to rice-growing areas. The canal has 209,000 hectares of cultivable command area. Rice and wheat are dominant crops in the area. At the head of Rice Canal, the Mirwah distributary was selected as a study area. The distributary has a design discharge of 343 cusecs for a cultivable command area of 9,914 acres. At the tail, the Radhan distributary was selected. The distributary has 235.8 cusecs as design discharge for the cultivable command area of 11,538 acres.

Description of Nara Canal

In the perennial canal, this study selected the Nara Canal, which also takes off from Sukkur Barrage. The dominant crops at this canal are cotton, wheat, and sugarcane. At this canal, the head Lakhaki distributary was selected. The design discharge of this distributary is 134.19 cusecs with a 14,458 acres cultivable command area. At the tail, the Mureed distributary was selected, which has a design discharge of 197.29 cusecs and 21,864 acres of cultivable command area.

Data Analysis

Crop Water Productivity

CWP was obtained by dividing crop yield with the total volume of water applied during the entire growing period of the crop:

CWP = Y/AW (Kg/m^3) (1)

Where,
CWP = Crop Water Productivity (Kg/m^3)
Y = Crop yield (Kg/hectare)
AW = Water applied at the farm gate (m^3/hectare)

Economic Water Productivity

EWP was obtained by converting the net economic value for yield based on the market prices and dividing it by the total water applied.

$EWP = I(g) / AW\ (Rs/m^3)$ (2)
Where,
EWP = Economic Water Productivity (Rs/m^3)
I(g) =Gross Income (Rs/hectare)
AW = applied water to the field (m^3/hectare)

Valuation of Water

The Residual imputation approach is used to assess the value of irrigation water applied to different crops. This approach was used to determine the contribution of water to the value of agricultural produce.

$V_w = (TVP - \sum_{i=1}^{n} P_i Q_i)/Q_w$ (3)
Where,
Vw is the value of water
TVP is the total value of the product
Pi is the price of input i', and Qi is the quantity of input 'i' used in the production of the crop.
Qw is the amount of water used in the production of crops.

Cobb-Douglas Production Function

Cobb-Douglas's production function was used to analyze the data. Multiple linear regression was applied using SPSS software.

$Y = \beta_0 X_1^{\beta 1} X_2^{\beta 2} X_3^{\beta 3} X_4^{\beta 4} X_5^{\beta 5} e^{\mu}$ (4)
$\text{Ln } Y = \text{Ln } \beta_0 + \beta 1 \text{Ln } X_1 + \beta 2 \text{Ln } X_2 + \beta 3 \text{Ln } X_3 + \beta 4 \text{Ln } X_4 + \beta 5 \text{Ln } X_5 + \mu$ (5)
Where,
Y = Crop Yield in Kg per hectare (dependent variable),
β_0 = Constant term (intercept),
βi= Elasticity of production,
X_1 = Ploughing (hours/hectare),
X_2 = Seed rate (kg/hectare),
X_3 = Irrigation (m^3/hectare),
X_4 = Fertilizer (kg/hectare),
X_5 = Plant protection (litters/hectare),
μ = Error term.

The Cobb-Douglas production function is used to assess the impact of landholding and land position.

$Y = \beta_0 Z_1^{\beta 1} Z_2^{\beta 2} Z_3^{\beta 3} Z_4^{\beta 4} Z_5^{\beta 5} Z_6^{\beta 6} Z_7^{\beta 7} e^{\mu}$ (6)
$\text{Ln } Y = \text{Ln}\beta_0 + \beta 1 \text{Ln} Z_1 + \beta 2 \text{Ln} Z_2 + \beta 3 \text{Ln} Z_3 + \beta 4 \text{Ln} Z_4 + \beta 5 \text{Ln} Z_5 + \mu$ (7)
Where,
Y =Crop Yield in Kg per hectare (dependent variable),
β_0 = Constant term (intercept),
βi= Elasticity of production,
Z_1 = Landholding (acres)
Z_2 = Land under cultivation (acres),
Z_3 = Watercourse position on minor,
Z_4 = Land position on the watercourse,
Z_5 = Land under wheat cultivation,
μ = Error term.

Data Envelopment Analysis

In order to assess the efficiency of each cropping system and to identify the reason that certain farms were performing better than others in the same agro-climatic conditions, an optimization tool was used. Estimating efficiency allows us to discover the techniques and practices to enhance agricultural produce and increase agricultural water productivity. Data envelopment analysis was used to perform the efficiency technique using the input-oriented slack-based measure of efficiency model with variable returns to scale approach.

Calculating CWP and EWP through Field Data

The respondents were asked about the irrigation time applied per acre or to an acre and the total number of irrigations to the crop. Further, it was converted to per-hectare irrigation water that was applied to the crop. The irrigation department was approached for the discharge of outlets. Later, the number of irrigations applied was also determined based on the irrigation source (canal and tube well). Conversion of the canal irrigation into the volume of water was calculated by multiplying the number of irrigations (canal) by the water allowance and time of the one irrigation. For tube well irrigation, the depth of the borehole, the power of the motor used, and the size of the delivery pipe were asked of the respondents in order to calculate the discharge of the water by the tube well. This method was used as per the guidelines of FAO. The total water applied was calculated in cubic feet and then converted into cubic meters.

The average yield per acre in mounds per acre was obtained by asking the respondents to get the crop yield. Then, mound per acre was converted into kg per hectare. Similarly, as per respondents, the market price of wheat was used as a factor of Gross Income. Gross income per hectare was calculated using this data.

Ethical Consideration

Ethical consideration was the top priority of this study. Before starting every interview, it was necessary to obtain verbal consent from a respondent. Participants were informed about the study and their right to participation or non-participation, leaving any questions unanswered that they were not comfortable answering. From a confidentiality perspective, participants were given the liberty not to reveal their names or identities.

Results and Discussion

The survey participants were randomly selected from both canals with the distribution of tail and head. In total, 431 respondents were surveyed, and 204 and 207 respondents were interviewed at Rice and Nara Canal, respectively.

Water Productivity

At the head of Rice Canal, the average wheat yield was 3469.771 kg /hectare, and TWA during crop season was 3022.812 m^3/hectare. CWP was 1.148 kg/m^3. EWP and Vw were 40.742 Rs/m^3 and 19.578 Rs/m^3, respectively.

Table 1

Water productivity of wheat crop at the head of a rice canal

	Average	Standard Deviation
Yield (kg/hectare)	3469.771	494.210
Total water applied (m^3/hectare)	3022.812	1416.943
Crop water productivity (kg/m^3)	1.148	0.575
Economic water productivity (Rs/m^3)	40.742	15.634
Valuation of Water (Rs/m^3)	19.578	11.608

Source: Compiled by Authors from Collected Data

At the tail of Rice Canal, the average wheat yield was 3474.571 kg/hectare, and TWA during crop season was 1611.406 m^3/hectare. The CWP was 2.156 kg/m^3. EWP and Vw were 52.727 Rs/m^3 and 22.467 Rs/m^3, respectively.

Table 2

Water productivity of wheat crop at the tail of rice canal

	Average	Standard Deviation
Yield (kg/hectare)	3474.571	691.894
Total water applied (m^3/hectare)	1611.406	755.703
Crop water productivity (kg/m^3)	2.156	0.785
Economic water productivity (Rs/m^3)	52.727	22.780
Valuation of Water (Rs/m^3)	22.467	15.665

Source: Compiled by Authors from Collected Data

At the head of the Nara Canal, the average wheat yield was 3475.470 kg/hectare, and TWA during crop season was 1541.634 m^3/hectare. CWP was 2.254 kg/m^3. The EWP and Vw were 64.961 Rs/m^3 and 28.709 Rs/m^3, respectively.

Table 3

Water productivity of wheat crop at the head of Nara canal

	Average	Standard Deviation
Yield (kg/hectare)	3475.470	494.210
Total water applied (m^3/hectare)	1541.634	559.220
Crop water productivity (kg/m^3)	2.254	0.900
Economic water productivity (Rs/m^3)	64.961	23.854
Valuation of Water (Rs/m^3)	28.709	16.637

Source: Compiled by Authors from Collected Data

At the tail of Rice Canal, the average wheat yield was 2965.260 kg/hectare, and TWA during crop season was 1711.667 m^3/hectare. CWP was 1.732 kg/m^3. The EWP and Vw were 51.573 Rs/m^3 and 25.497 Rs/m^3, respectively.

Table 4

Water productivity of wheat crop at the tail of Nara canal

	Average	Standard Deviation
Yield (kg/hectare)	2965.260	988.420
Total water applied (m^3/hectare)	1711.667	570.556
Crop water productivity (kg/m^3)	1.732	0.579
Economic water productivity (Rs/m^3)	51.573	19.457
Valuation of Water (Rs/m^3)	25.497	14.037

Source: Compiled by Authors from Collected Data

Cobb-Douglas Production Function

The results of wheat at the head of the Rice canal are shown in Table 5, and the 8.756 intercept reflects the natural log of predicted wheat yield when no inputs are available. By increasing the rate of plowing (land preparation) and plant protection by 1%, the coefficient results suggest that wheat output can be increased up to 0.034% and 0.066%. On the other end, results show that a 1% increase in seed rate, fertilizer, and irrigation may cause a decrease in wheat output by 0.284%, 0.068%, and 0.153%, respectively. Therefore, it can be concluded that farmers have already applied enough seed and fertilizer. Data showed that seed rate and irrigation are enough while plowing (land preparation) and plant protection are non-significant.

The value of R is 0.411, which specifies independent variables have a weak relation with the dependent variable.

Table 5

The cobb-Douglas production function of wheat at the rice canal head

Coefficients					
Model	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	Beta	Std. Error	Beta		
(Constant)	8.756	0.840		10.428	0.000***
Ploughing	0.034	0.061	0.051	0.558	0.578n.s
Seed rate	-0.284	0.133	-0.201	-2.131	0.035**
Fertilizer	-0.068	0.100	-0.065	-0.677	0.500n.s
Plant protection	0.066	0.045	0.138	1.478	0.142n.s
Irrigation	-0.153	0.048	0.303	3.187	0.002***
R			0.411		

*** = significance at 0.01; ** = significance at 0.05; * = significance at 0.1; n.s = not significant

Source: Compiled by Authors from Collected Data

Further data is shown in Table 06 about the wheat on the head of the Rice canal. The 8.304 intercept reflects the natural log of the predicted wheat yield when no inputs are available. Watercourse position on minor and land position on watercourse are significant, and both have negative coefficients, while land holding, land under cultivation, soil quality, sowing date, and land under wheat cultivation are non-significant.

The value of R is 0.635, which specifies independent variables have a moderate relation with dependent variables.

Table 6

Impact of landholding and land position on wheat production at rice canal head

Coefficients					
Model	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	Beta	Std. Error	Beta		
(Constant)	8.304	0.069		119.908	0.000***
Land Holding	-0.303	0.202	-0.932	-1.499	0.137n.s
Land under cultivation	0.318	0.212	0.947	1.502	0.136n.s
Watercourse position on minor	-0.319	0.057	-0.481	-5.617	0.000***
Land position on a watercourse	-0.115	0.059	-0.162	-1.960	0.053*
Land under wheat cultivation	0.041	0.059	0.110	0.697	0.487n.s
R			0.635		

*** = significance at 0.01; ** = significance at 0.05; * = significance at 0.1; n.s = not significant

Source: Compiled by Authors from Collected Data

The data results of wheat on the tail of the Rice Canal are shown in Table 7, and the 4.949 intercept reflects the natural log of the predicted wheat yield when no inputs are available. If the seed rate, fertilizer, plant protection, and irrigation are increased by 1%, The coefficient results show that it may increase wheat yield by 0.083%, 0.415%, 0.040%, and 0.054%, respectively. Conversely, a 1% increase in plowing (land preparation) may reduce wheat productivity by 0.218%, which means farmers are using plows more than required. The plowing (land preparation) and fertilizer are significant, while seed rate, plant protection, and irrigation are non-significant.

The value of R is 0.448, which specifies independent variables have a weak relation with dependent variables.

Table 7

The cobb-Douglas production function of wheat at rice canal tail

Coefficients					
Model	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	Beta	Std. Error	Beta		
(Constant)	4.949	1.222		4.050	0.000***
Ploughing	-0.218	0.091	-0.230	-2.386	0.019**
Seed rate	0.083	0.178	0.045	0.466	0.642 n.s
Fertilizer	0.415	0.158	0.254	2.621	0.010**
Plant protection	0.040	0.035	0.109	1.148	0.254 n.s
Irrigation	0.054	0.034	0.157	1.597	0.114 n.s
R			0.448		

*** = significance at 0.01; ** = significance at 0.05; * = significance at 0.1; n.s = not significant

Source: Compiled by Authors from Collected Data

The data results of wheat on the Rice canal's tail are shown in Table 8. The 7.990 intercept reflects the natural log of the predicted wheat yield when no inputs are available. The other remaining variables, such as landholding, land under cultivation, watercourse position on minor, land position on the watercourse, soil quality, and land under wheat cultivation, are non-significant.

The value of R is 0.203, which specifies that independent variables have a weak relationship with the dependent variable.

Table 8

Impact of landholding and land position on wheat production at rice canal tail

Coefficients					
Model	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	Beta	Std. Error	Beta		
(Constant)	7.990	0.116		68.818	0.000***
Land Holding	0.009	0.127	.0026	0.070	0.945 n.s
Land under cultivation	0.004	0.158	.0012	0.026	0.979 n.s
Watercourse position on minor	-0.098	0.080	-.0128	-1.220	0.226 n.s
Land position on a watercourse	0.063	0.093	0.074	0.674	0.502 n.s
Land under wheat cultivation	0.046	0.096	0.119	0.479	0.633 n.s
R			0.203		

*** = significance at 0.01; ** = significance at 0.05; * = significance at 0.1; n.s = not significant

Source: Compiled by Authors from Collected Data

The data results of wheat on the head of the Nara canal are shown in Table 9. The 3.784 intercept reflects the natural log of the predicted wheat yield when no inputs are available. The coefficient results show that if plowing (land preparation), seed rate, fertilizer, and plant protection are increased by 1%, wheat yield may increase by 0.088%, 0.012%, 0.461%, and 0.047%, respectively. Conversely, a 1% increase in irrigation may reduce wheat productivity by 0.143%, which means farmers are applying more water than required. The fertilizer and irrigation are significant, while plowing, seed rate and plant protection are non-significant.

The value of R is 0.499, which specifies independent variables have a moderate relation with dependent variables.

Table 9

The cobb-Douglas production function of wheat at Nara canal head

Coefficients					
Model	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	Beta	Std. Error	Beta		
(Constant)	3.784	0.800		4.728	0.000***
Ploughing	0.088	0.070	0.087	1.248	0.213n.s
Seed rate	0.012	0.139	0.006	0.086	0.931n.s
Fertilizer	0.461	0.070	0.426	6.584	0.000***
Plant protection	0.047	0.032	0.085	1.446	0.150n.s
Irrigation	-0.143	0.057	0.147	2.493	0.013**
R			0.499		

**** = significance at 0.01; ** = significance at 0.05; * = significance at 0.1; n.s = not significant*

Source: Compiled by Authors from Collected Data

Table 10 data results of wheat on the head of the Nara canal show that the 8.095 intercept reflects the natural log of the predicted wheat yield when no inputs are available. The other remaining variables, like landholding and land under cultivation, are significant; landholding had a positive coefficient, and land under cultivation had a negative coefficient, while watercourse position on minor, land position on the watercourse, soil quality, sowing date and land under wheat cultivation are non-significant.

The value of R is 0.467, which specifies independent variables have a weak relation with the dependent variable.

Table 10

Impact of Landholding and land position on wheat production at Nara canal head

Coefficients					
Model	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	Beta	Std. Error	Beta		
(Constant)	8.095	0.081		100.508	0.000***
Land Holding	-0.154	0.043	-0.700	-3.559	0.001***
Land under cultivation	0.203	0.058	0.833	3.475	0.001***
Watercourse position on minor	-0.026	0.070	-0.033	-0.372	0.710n.s
Land position on a watercourse	-0.053	0.063	-0.073	-0.841	0.403n.s
Land under wheat cultivation	0.041	0.064	0.140	0.644	0.521n.s
R			0.467		

*** = significance at 0.01; ** = significance at 0.05; * = significance at 0.1; n.s = not significant

Source: Compiled by Authors from Collected Data

Table 11 data results of wheat at Nara canal tail shows that the 0.750 intercept reflects the natural log of the predicted wheat yield when no inputs are available. Suppose plowing (land preparation), seed rate, fertilizer, plant protection, and irrigation increase by 1%. In that case, the coefficient results show that it may increase wheat production by 0.121%, 0.116%, 0.508%, 0.129%, and 0.435%, respectively. The fertilizer, plant protection, and irrigation are significant while plowing (land preparation) and seed rate are non-significant.

The value of R is 0.542, which specifies independent variables have a moderate relation with dependent variables.

Table 11

The cobb-Douglas production function of wheat at Nara canal tail

Coefficients					
Model	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	Beta	Std. Error	Beta		
(Constant)	0.750	2.218		0.338	$0.736^{n.s}$
Ploughing	0.121	0.154	0.066	0.789	$0.432^{n.s}$
Seed rate	0.116	0.373	0.027	0.312	$0.756^{n.s}$
Fertilizer	0.508	0.112	0.378	4.520	0.000^{***}
Plant protection	0.129	0.064	0.164	2.023	0.046^{**}
Irrigation	0.435	0.120	0.295	3.642	0.000^{***}
R			0.542		

*** = significance at 0.01; ** = significance at 0.05; * = significance at 0.1; $^{n.s}$ = not significant

Source: Compiled by Authors from Collected Data

Table 12 shows the impact of landholding and land position on wheat production at the head of Nara Canal, and the data results show that the 7.795 intercept reflects the natural log of the predicted wheat production when no inputs are available. Watercourse position on a minor scale is significant and has a negative coefficient, while land holding, land under cultivation, land position on the watercourse, soil quality, sowing date, and land under wheat cultivation are non-significant.

The value of R is 0.517, which specifies independent variables have a moderate relation with the dependent variable.

Table 12

Impact of Landholding and Land position on Wheat production at Nara Canal head

Coefficients					
Model	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	Beta	Std. Error	Beta		
(Constant)	7.795	0.158		49.252	0.000^{***}
Land Holding	-0.083	0.107	-0.168	-0.782	$0.436^{n.s}$
Land under cultivation	0.167	0.141	0.320	1.181	$0.240^{n.s}$
Watercourse position on minor	-0.512	0.138	-0.354	-3.709	0.000^{***}
Land position on a watercourse	0.016	0.116	0.012	0.136	$0.892^{n.s}$
Land under wheat cultivation	0.182	0.121	0.301	1.511	$0.134^{n.s}$
R			0.517		

**** = significance at 0.01; ** = significance at 0.05; * = significance at 0.1; $^{n.s}$ = not significant*

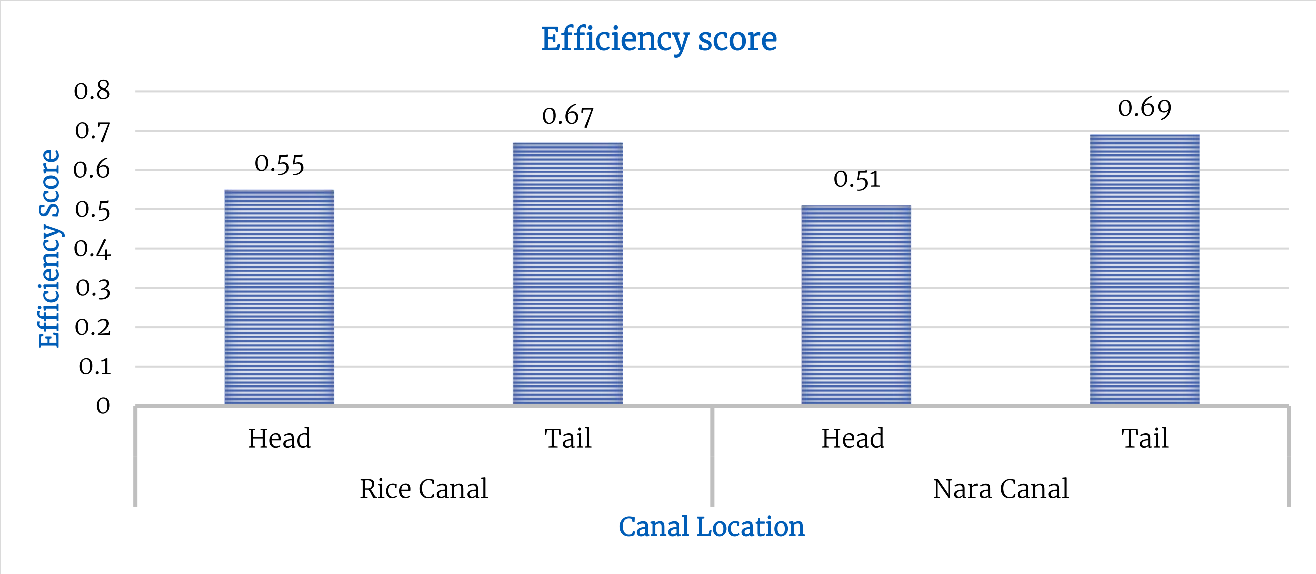
The minimum CWP was observed at the head of the Rice canal (1.148 Kg/m^3), and the maximum CWP was observed at the head of the Nara canal (2.254 Kg/m^3), which is close to Ahmed et al. (2004) study. Seed rater, plowing (land preparation), fertilizer, and irrigation were significant at the Rice Canal. On the other hand, plant protection, fertilizer, and irrigation were significant at the Nara Canal. These results are in line with the Koondhar et al. (2018) study.

Data Envelopment Analysis

The efficiency scores of Rice and Nara canals are shown in Figure 1. On the Rice canal, at Mirwah (head), the efficiency score was 0.55; at Radhan (tail), the efficiency score was 0.67. On the other hand, the efficiency score at Lakhaki (head) was recorded as 0.51, and the Mureed (tail) efficiency score was 0.69 at the Nara canal. At both canals, the tail has recorded higher efficiency scores than the head of both canals, meaning tail farmers are more efficient than the head at both canals.

Figure 1

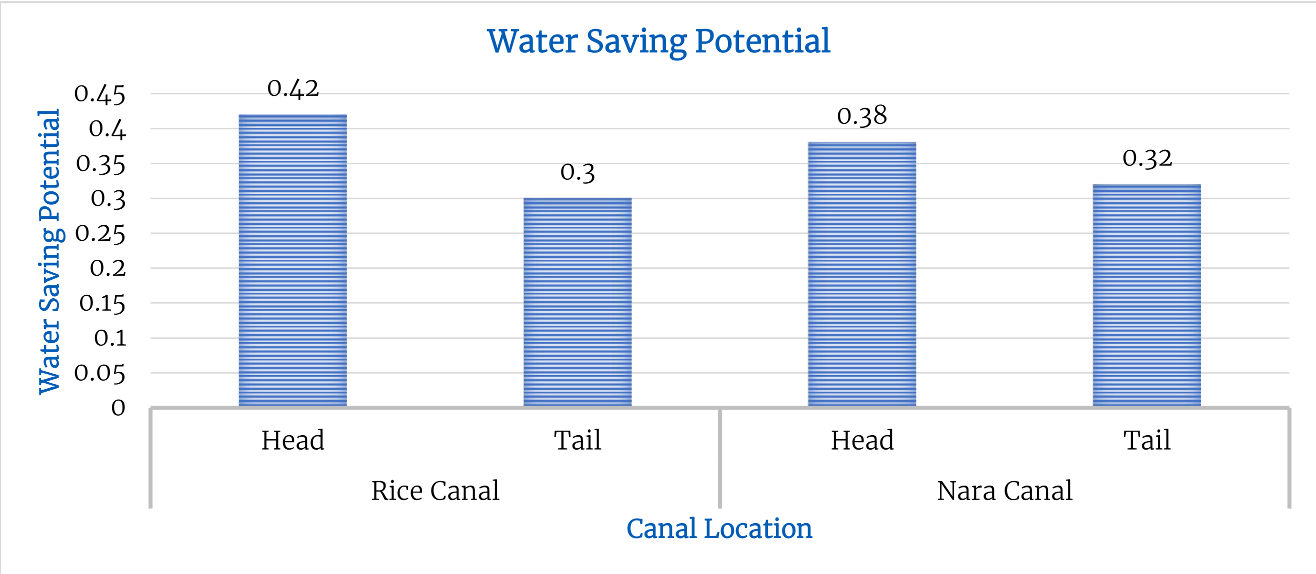
Efficiency score



The potential for water saving of both canals is shown in Figure 2. On the Rice canal, at Mirwah (head), the potential for water saving was 0.42%, and at Radhan (tail), the potential for water saving was 0.3%. On the other hand, the potential for water saving at Lakhaki (head) was recorded as 0.38%, and Mureed (tail) was 0.32% at Nara canal. At both canals, the tail has recorded less potential for water saving than the head of both canals, meaning tail farmers are more efficient than the head at both canals.

Figure 2

Water saving potential



Conclusion

The rapidly increasing population has become a significant issue, ultimately stressing food and water availability. These problems have become a danger for the whole global community. Underdeveloped and developing countries, especially Pakistan, due to the age-old infrastructure and poor water and agriculture management, are now on the brink of water scarcity and shortage of food. Scientists and researchers have been working on increasing the yield per acre and yield per unit of water. Scientists and researchers have also been working to increase crop per drop through experiments and innovative techniques.

Applying concepts of crop water productivity (CWP) and economic water productivity (EWP) is one leap forward to achieving increased crop per drop and income per water drop. The average wheat production per acre in Pakistan is low compared to the other countries in the world. Pakistan also falls behind the other South Asian countries in terms of per acre wheat productivity.

This study has assessed wheat crop CWP and EWP at perennial (Nara canal) and non-perennial (Rice canal) canals. The data collection was carried out at both types of canals with both types of locations of head and tail of canals. The study used CWP, EWP, and Vw as indicators for assessment, and to analyze the efficiency, the study used Cobb-Douglas production function and DEA.

The study areas, the heads of both canals, and the tails of the rice canal showed almost the same wheat average production. The TWA was less at the Rice Canal's tail than others. At the Nara canal head, the CWP, EWP, and Vw were higher. The Vw was observed less at the Rice Canal than at the Nara Canal. The main reason for less Vw was the fuel cost of tube wells and water lifting from the canal.

The tails of both canals were more productive and efficient than the head reaches of both canals. Comparing the tails of both canals showed that the tail of the Nara Canal was more productive than the tail of the Rice Canal. The result suggests that there is potential for water saving, especially at the head distributaries. Still, the result shows that farmers at the head of the Rice canal over-irrigated the crops more than the other farmers at both canals.

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