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Economic Evaluation of Different Irrigation Systems for Wheat Production in Rechna Doab, Pakistan

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ABSTRACT

Water productivity (WP) is reported lower in Pakistan when compared to the rest of the world. This paper investigates the factors responsible for low water productivity and demonstrates various irrigation techniques farmers could use for its improvement. A comprehensive questionnaire was designed, and 230 farmers were interviewed in a cotton-wheat area (Samundri-site I), a mixed crop area (Chiniot-site II), and a rice-wheat area (Hafizabad-site III) in Rechna Doab, Punjab, Pakistan. This survey found that the majority of farmers expressed major concerns about shortages of canal water, energy, and fertilizer. These issues were the main factors affecting their land and water productivity. Field experiments were conducted at the above mentioned sites. The results indicated that drip irrigation was the most efficient irrigation technique, which produced a maximum WP of 2.26 kg m^{-3} for wheat. Drip irrigation was 98% efficient, and water savings were 40% better when compared with that under conventional irrigation. The perforated pipe irrigation technique also resulted in relatively better WP averaging 1.51 kg m^{-3} and averaged 77% efficiency with water savings of 18%. Gross margin for the drip irrigation system was found to be higher than for perforated pipe in the same area (with margins of Rs. 36,832.84 in the first year). Drip irrigation also shows a benefit cost ratio (BCR) of 1.69 at a 4% discount rate (close to real interest rate) and an internal rate of return (IRR) of 36% in district Faisalabad for its 10-year useful life. For perforated pipe irrigation, gross margins were also higher than the conventional irrigation method in the first year of production in all districts. For the entire useful life of perforated pipe (three years), the BCR ranged from 1.88 to 2.39 at a 4% discount rate depending on site conditions, and was found to be profitable at all discount rates in all the districts. The IRRs for perforated pipe were 187%, 277%, and 197% in districts Faisalabad (Samundri site), Chiniot, and Hafizabad, respectively. These findings suggest that flexible irrigation techniques, in response to crop water requirements, can improve land and water productivity.

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

INTRODUCTION

Pakistan is primarily an agricultural country, and its agricultural production depends on adequate availability of irrigation water supplies, as it lies in the arid to semi-arid region. The average annual rainfall varies from 328mm in southern parts of the country to more than 2,000mm in the northern mountainous areas. Because of this, the country has built the largest contiguous irrigation system comprising three reservoirs (Mangla, Tarbela, and Chashma), 23 barrages/head works, 12 inter-river link canals, and 45 canal commands, extending over 60,800km and providing water to over 140,000 watercourses (GOP, 2013). The canal commanded irrigated area is about 16 million hectares (Mha) in addition to about 4 Mha of rain fed areas. The major sources of irrigation water are river supplies, with 70% of their water coming from melting glaciers and 30% from monsoon rainfalls. These river supplies are seasonal and vary from less than 100 million acre-feet (MAF) during dry years to more than 150 MAF during heavy rainfall and flood seasons. Irrigation water is diverted from rivers to canals and reaches the fields through gravity. Although it is a marvelous gravity flow system, which does not require any additional energy for its flows, its irrigation efficiency is very low, about 40%, due to water losses during its operational and application phases (Hussain *et al*., 2011). These water losses occur during conveyance from head works, on rivers, to the fields through the canal networks and also from the irrigated fields. In order to improve irrigation efficiency, there is the need to monitor and minimize these losses using efficient and innovative methods.

There are a number of irrigation methods which have the potential to apply water efficiently. However, each method works best under specific farming conditions. For example, sprinkler irrigation is mostly suitable under undulating terrain where it is otherwise difficult to apply irrigation water through gravity. Similarly, drip irrigation is highly suitable for point application of irrigation water especially for orchards (Bakhsh *et al*., 1994). Both sprinkler and drip are considered as pressurized, high efficiency irrigation systems. In Punjab, Pakistan, in the irrigated canal command areas, cultivated land is mostly flat and fields are leveled. Farmers grow mostly row crops and apply irrigation water in the form of flooding. Recently, the situation has begun to change. Irrigation water is becoming scarce as water availability in Pakistan has approached about 1000 m^3/capita, categorizing the country as a water deficit country. Moreover, projections show that with the current pace of population growth, water availability will reach 915 m^3/capita in 2020 (GOP, 2011). Under these circumstances, farmers need to apply irrigation water efficiently to increase water productivity, which has been reported to be as low as 0.1 kg m^{-3} of water (GOP, 2012).

To improve water productivity either we have to increase the crop yields, minimize water losses, or both. In Punjab, the majority of farmers have small land holdings of less than 5 ha. These small farmers usually cannot afford expensive irrigation systems such as sprinkler and drip irrigation systems, although they certainly wish to apply irrigation water efficiently in the wake of the soaring energy prices. In Pakistan, diesel prices are quite high, and electric tube wells are subject to frequent load shedding problems. In addition to surface water, tube wells, i.e. groundwater, accounts for more than 50% of the crop water requirement. Under existing irrigation methods, tube well water takes a significant amount of time to reach the fields. Tube wells first fill the watercourses and then start irrigating the fields. Exacerbating this, often once the watercourses are filled, the electricity fails, leaving the filled watercourses to lose water in the form of seepage and other losses.

Keeping in mind these issues, there is a need to introduce cheap and innovative methods to improve water productivity and irrigation efficiency. There are efficient irrigation methods, but their economic viability has not been thoroughly evaluated. There are questions about these methods such as what are the payback periods and benefit cost ratios (BCR)? This paper investigates different irrigation techniques which can be adopted easily by the farmers and also do not require a prohibitive amount of technical knowledge. The paper then evaluates the economic viability of these methods. The following are the specific objectives of the paper:

1. Identify the causes responsible for low water productivity and suggest various retrofit measures for its improvement.
2. Conduct field experiments to demonstrate the benefits of the proposed efficient irrigation systems for improving water productivity.
3. Evaluate the economic viability and benefits to the farmers of the proposed irrigation techniques in terms of first-year Gross Margin (GM), BCR, Net Present Value (NPV), and Internal Rate of Return (IRR).

REVIEW OF RELEVANT STUDIES

A broad literature exists on water productivity and the effect of different irrigation systems and practices on productivity. Below are some select studies from the literature covering these topics from both an international perspective and the Pakistani context. Several additional references are also cited later in the paper.

Masikati *et al*. (2014) compared treatments comprising manure application (MN) and maize-mucuna rotation (MMR) against farmer practice (FP). The average values for water productivity for maize under FP, MN, and MMR interventions were 0.32 kg m^{-3}, 0.40 kg $m^{-3}$and 0.70 kg m^{-3}, respectively, and 1.34 kg $m^{-3}$for mucuna. Negative trends were shown by the crops under FP as well as MN, while positive trends were shown under MMR interventions in soil organic carbon (SOC) and total nitrogen (TN) for 30 years. Average losses for FP and MN ranged from 17 to 74 kg ha^{-1} yr^{-1} and 6-16 kg ha^{-1} yr^{-1}, respectively, and increased under MMR, ranging from 2.6 to 194 kg ha^{-1} yr^{-1} and 6 to 14 kg ha^{-1} yr^{-1}. They concluded that under nutrient depleted soil, the small landholders can use MMR interventions to increase water productivity.

Shabbir *et al*. (2012) assessed the present status of water productivity in a cotton-wheat zone and identified the factors needed to improve water productivity in district Khanewal on the Lower Bari Doab Canal command area taking off from river Ravi. Mean yield, actual, and apparent WP for the wheat crop were calculated as 3,210 kg ha^{-1}, 1.12 kg m^{-3}, and 0.43 kg m^{-3}, respectively. The corresponding values for cotton were 2,675 kg ha^{-1}, 0.22 kg m^{-3}, and 0.26 kg m^{-3}, respectively. They concluded that fertilizer, pesticide, and irrigation water increased the actual water productivity.

Srivastava *et al*. (2012) investigated the considerable savings in water by the adoption of sprinkler and drip irrigation systems in water scarce areas in India. The study explained that loss of water was eliminated in drip method cases in which water was directly trickled into the soil near the root zone of the crop, resulting in considerable water saving. The research also reported the drip irrigation method as more suitable to row crops. The results indicated 25% to 60% water savings and a 60% increase in yield from using the drip irrigation method compared with conventional surface irrigation methods.

Hashim *et al*. (2012) determined the crop water requirement and crop water productivity of different crops at the research farm in King Abdul-Aziz University, Hoda Al-Sham, Makkah region, Saudi Arabia. The water requirements for seasonal and forage crops ranged from 303 to 727.8 mm and 436.7 to 1,821.94 mm, respectively. The summer season crops had higher values of water productivity (1.478 kg m^{-3}) than that for forage crops (0.794 kg m^{-3}). The Okra crop had the highest water productivity at 1.724 kg m^{-3}.

Moayeri *et al*. (2011) conducted a study to estimate yield, water consumption and water productivity of maize during the 2006 and 2007 growing periods in the Karkheh River Basin in Iran. The average yield of maize was 4,844 kg ha^{-1}. They also estimated rain and irrigation (I+R) water productivity, water application efficiency, and maize crop water productivity as, 0.38 kg m^{-3}, 38.6%, and 1.01 kg m^{-3}, respectively. The results of this study showed that the major reasons for low water productivity were the lack of farmer's knowledge about irrigation, plant nutrient insufficiencies, and poor management practices.

Ashraf *et al*. (2010) also conducted a study to evaluate the existing water productivity in Lower Bari Doab Canal command area. The average yields, for wheat, rice, sugarcane, and spring maize at Jandraka distributary, were found as 2,884, 2,606, 49,912, and 6,443 kg ha^{-1}, respectively, whereas the average water productivities were 0.73, 0.08, 2.01 and 0.54 kg m^{-3}, respectively. At the 15-L distributary, the average yield for wheat, cotton, sugarcane, and spring maize were determined as 3,096, 2,056, 49,400, and 8,854 kg ha^{-1}, respectively, whereas water productivities were 0.65, 0.33, 1.08, and 0.80 kg m^{-3}, respectively. Except for maize, the gap between average and potential yields was more than 50%, and the gap between average and potential water productivity was above 70% for both the distributaries.

Dilbagh *et al*. (2010) conducted field experiments to evaluate the effect of different irrigation methods on the yield of seed cotton. The study found that the drip irrigation method significantly increased seed cotton yield over furrow irrigation. A maximum water use efficiency of 7.9 kg ha^{-1} mm^{-1} and water savings of about 54% were recorded under the drip irrigation system as compared to that under the furrow irrigation system.

Ghamarnia *et al*. (2010) examined the effects of different drip and furrow irrigation treatments on water use efficiency in the west of Iran. The results indicated the amount of water usage in furrow irrigation systems was about 1.8 times higher than that under surface drip irrigation systems. They also found that the grain yields, with the help of drip sets, were 188 kg/ha more than that under furrow. The water use efficiency of the drip irrigation system (1.39 kg ha^{-1} mm^{-1}) was also higher than that under the conventional furrow irrigation system (0.492 kg ha^{-1} mm^{-1}).

Ashfaq *et al*. (2009) quantified the impact of ground water on wheat production in district Jhang, Punjab, Pakistan. The results showed that tube well irrigation accounted for 19% of the total cost of production for wheat crops. The findings of the study suggested certain guidelines for policy makers to formulate policies that could promote wheat production through efficient use of groundwater.

Bakhsh *et al*. (2008) conducted a study at NIAB, Faisalabad to compare the effects of 15% (D_{15}) and 30% (D_{30}) deficit irrigation on water use efficiency of cotton in comparison to no deficit (D_0) irrigation using a drip irrigation system. All three treatments of D_0, D_{15}, and D_{30} were applied with twelve irrigations. Total applied water was 507, 444, and 381 mm, respectively. The cotton yield was measured in the field using a top loading balance. The D_0, D_{15}, and D_{30} produced yields of 3,112, 2,862, and 2,078 kg ha^{-1}, respectively. The water use efficiency of D_0, D_{15}, and D_{30} were 0.56, 0.58, and 0.49 kg m^{-3}, respectively. The D_{15} treatment resulted in better water use efficiency and showed the potential to improve efficiency in water stressed areas.

Narayanamoorthy (2008) investigated the impact of drip irrigation systems on cotton and the potential economic benefits to the farming communities in three case studies. The study found a 50% reduction in irrigation cost by using drip irrigation. The author also reported a 45% water savings as compared to the conventional irrigation practice. The study also estimated 114% higher productivity than that under conventional irrigated.

Uzunoz and Akcay (2006) conducted a study to determine the profitability and feasibility of fruit farms in Turkey. Three criterion, the benefit cost ratio (BCR), net present value (NPV), and internal rate of return (IRR) were used for the analysis. Different discount rates were used to calculate the BCR and NPV of the farms. BCR was also found to be positive for all of the interest rates and for all of the fruits. The results showed that NPV was positive at all the discount rates. The IRR for the fruits was also found positive. The results showed that the investment in the fruit orchards was economically feasible.

MATERIALS AND METHODS

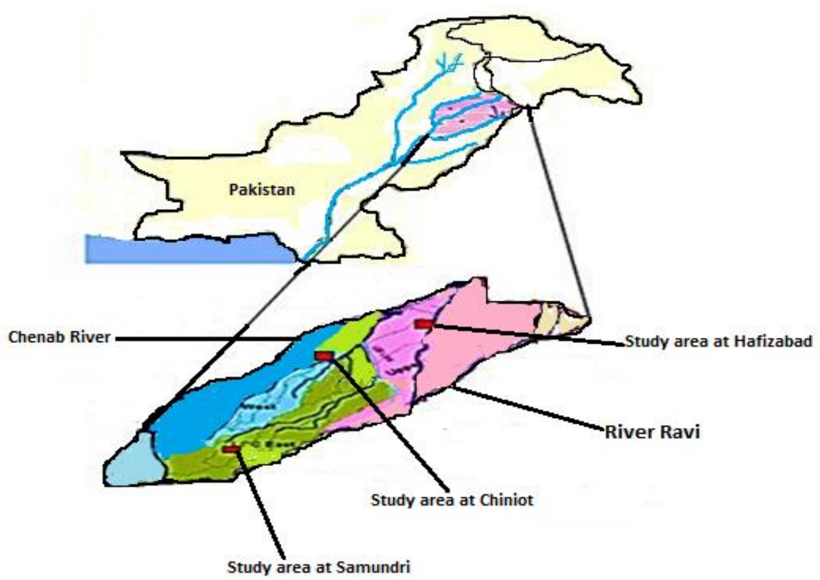
Study Area

This study was conducted at three sites in the following locations: Samundri (30.48° N, 71.52° E), Chiniot (31.72° N, 72.97° E.), and Hafizabad (32.03° N, 73.11° E.). These sites are situated in Rachna Doab—an area between the Ravi and Chenab Rivers—located in Punjab province of Pakistan, as shown in Figure 1.

To investigate soil classification and texture in the study area, soil samples were collected from each site and were sent to the Ayub Agriculture Research Institute (AARI) for analysis. The results showed that the Samundri site has clay loam soil with 34% sand, 26% silt, and 40% clay. The soil has organic matter of 0.62% with a pH ranging between 7.5 and 7.8. The Chiniot site is fertile, has alluvial soil, and can be classified as sandy loam with 78% sand, 7% silt, and 15% clay. The organic matter in the soil is 0.78% with a pH ranging between 7.8 and 7.9. The soil of the Hafizabad site is also alluvial, fertile, and classified as sandy clay loam with 57% sand, 12% silt, and 32% clay.

The study area (all sites) has diverse climates, with hot summers and cold winters. The maximum temperature in summer reaches up to 49°C, and in winter, the minimum temperature may fall near the freezing point. Summer starts from April and continues until October in the study area, and winter starts from November and continues till March. June and July are the hottest months, whereas December and January are the coldest months. Average annual rainfall at the Samundri, Chiniot, and Hafizabad sites is about 350mm, 399mm, and 790mm, respectively (ASP, 2010).

Figure 1: Map of the Study Area in Rechna Doab



During phase-I of the study, a comprehensive questionnaire was designed to determine water productivity for wheat crops at all sites and to explore the causes for low water productivity and the factors affecting it. The questionnaire was pretested in the field to identify deficiencies in the proforma as well as to incorporate various concerns of the farmers to make the questions more clear.

After developing the questionnaire, the sites were selected for primary data collection. For this, 80 farmers from Samundri, 66 from Chiniot, and 84 from Hafizabad were randomly selected from five villages in the vicinity of each site. From each village, about 13-16 farmers were interviewed and detailed information regarding their farming practices and crop yields was collected.

The survey data was analyzed to determine general descriptive characteristics of the study area such as education level, age of respondents, farmers land holdings, soil fertility level, cropping pattern and intensity, crop yields, and irrigation water sources and their quality. On each site, field irrigation efficiency was calculated using the following relationship:

$$E_i = \frac{CWR}{WA} \times 100$$

where,

E_i = Field Irrigation Efficiency (%)
CWR = Crop Water Requirement (mm)
WA = Water Applied (mm)

Water savings for drip and perforated pipe irrigation were calculated by comparison against the conventional irrigation system.

Water productivity of wheat crops for each site was calculated by using the following relationship:

$$\text{Water Productivity (WP)} = \frac{\text{Crop Yield (kg/ha)}}{\text{Total volume of water applied (m}^3\text{/ha)}}$$

Crop yields were estimated from information obtained in the survey of the farmers. The total water applied was determined by multiplying number of irrigations with the discharge of tubewells plus water delivered through mogha (canal outlet) of the surveyed watercourses.

During phase-II of the study, field experiments were conducted at farmer's fields in the three sites under Randomized Complete Block Design (RCBD). Wheat was grown at each site during 2012-13. At the Samundri site, wheat was grown using conventional irrigation and two high efficiency irrigation systems (HEIS)—drip and perforated pipe irrigation. On the other sites, wheat was grown with conventional irrigation and two efficient irrigation methods—perforated pipe (which is HEIS) and open end pipe irrigation methods.

Management practices such as cultivation, planking, sowing, fertilizer application, irrigation application, and harvesting were performed at each site. The schedule of management activities performed at the Samundri site is shown in Table 1, as an example. After harvesting, wheat yield was determined at each site using a steel frame of 1 m^2 in size.

Table 1: Schedule of Management Activities at the Samundri Site

Step Number	Activities	Date
1	Pre-sowing irrigation (Rouni)	6-Nov-12
2	Cultivation with tine	18-Nov-12
3	Cultivation with Rotavator	18-Nov-12
4	Planking	19-Nov-12
5	Sowing	19-Nov-12
6	Soil sampling before sowing	17-Nov-12
7	DAP Fertilizer application @ 123.5 kg/ha	18-Dec-12
8	Urea Fertilizer application @ 123.5 kg/ha	18-Dec-12
9	1st Irrigation	18-Dec-12
10	Urea Fertilizer application @ 123.5 kg/ha	2-Feb-13
11	2nd Irrigation	2-Feb-13
12	Urea Fertilizer application @ 123.5 kg/ha	21-Mar-13
13	3rd Irrigation	21-Mar-13
14	Harvesting	1-May-13

Economic Analysis

The three irrigation techniques at the experimental sites (conventional, perforated pipe, and drip), as well as the farmer surveys (conventional irrigation), were compared on the basis of gross margins. The procedure adopted by Chaudhry *et al*. (1992) for estimating, and subsequently apportioning, the cost and returns of various budget items was used in this study. However, we adjusted it to account for the costs incurred by the investment in irrigation systems. This method does not account for the total fixed cost, only variable cost, and in our case irrigation investment costs as well. Although the perforated pipe and drip irrigation systems have longer useful lives than one season, the gross margin for one year was estimated for the purpose of illustratively comparing the three irrigation systems in the first year. The formula used to calculate the gross margins was:

Gross Margin (GM) = Total Revenue (TR) – (Total Variable Cost (TVC) + Irrigation Investment Costs)

Total variable costs include land preparation, seed, fertilizers, labor, harvesting and threshing costs, and a markup of 4 percent on variable costs.[1] Also included in total variable costs are the irrigation costs, made up of the fixed water charges (Abiana) and the variable tube well charges. This is where much of the water savings from the irrigations systems will be reflected in costs.

Irrigation investment costs include the depreciation cost and the interest charge on the depreciation for one production season for the perforated pipe and drip irrigation methods (Seckler *et al.*, 1987). The costs for drip and perforated pipe irrigation systems include high installation costs, but they also have significant useful lives. Drip irrigation in the field has a useful life of ten years (Asmon and Rothe, 2006). The useful life of perforated pipe is three years, if it is handled carefully and stored between seasons in a dry place away from direct sunlight (Enciso and Peries, 2005). Using the depreciation cost, plus an interest charge on the depreciation costs, captures the cost of one year's worth of investment in the irrigation system. The rate of interest was taken as 4 percent, which is close to the real interest rate prevailing in Pakistan during the last three years.

After the above calculations were used to estimate the Gross Margins of the farmers and at experimental sites in the first year, the per acre total costs and total benefits were used to estimate the economic returns of perforated pipe and drip irrigation systems at the experimental sites over their entire useful lives. Using these standards, the economic analysis in the later portion of the paper was carried out as given below:

Discounted capital budgeting techniques: Three measures are often used in finding the present worth of the future values of a project: BCR, NPV, and IRR. These were used by Uzunoz and Akcay (2006) and also by Satyasai (2009), and are employed in this analysis. In the BCR and NPV techniques, total costs and benefits in the various years of the useful life of the equipment are discounted using different discount factors. For simplicity, it is assumed in this analysis that costs and revenue stay constant in "current" rupees at observed values in 2012. In other words, we assume zero inflation and that input-to-output prices remain constant. Otherwise we would have to increase the nominal ("current") value of costs, revenue, and margins in the future years and use some forecasts of future relative prices. It is also assumed that perforated pipe and drip irrigation systems have zero salvage value at the end of their useful lives and the total cost of the investment in these projects is made in the first year. BCR, NPV, and IRR have been estimated using the formulas below with the notation in the formulas:

B_t = benefit in each year
C_t = cost in each year
r = discount rate
t= number of years (1, 2, 3 …n)

The BCR is the ratio of the present value of benefits and the present value of costs and is given as:

$$BCR = \sum \frac{B_t}{(1+r)^t} / \sum \frac{C_t}{(1+r)^t}$$

A project is considered viable when the BCR is more than 1.

The NPV is the difference between the present value (PV) of benefits and PV of costs and illustrates the net worth of a project. It is representative of dynamic investment appraisal and a discounted cash flow method given as:

$$NPV = \sum \frac{B_t}{(1+r)^t} - \sum \frac{C_t}{(1+r)^t}$$

The decision criterion is to select projects with a positive NPV and rank the selection of projects as per the magnitudes of NPVs in case of capital rationing.

[1] This markup is to represent the interest rate associated with farmers needing to borrow money to purchase the inputs which make up TVC.

The IRR is considered to be the most appropriate tool to evaluate economic efficiency of drip and perforated pipe irrigation systems because it does not depend on the application of an arbitrary discount factor (Asmon and Rothe, 2006). The earlier two measures are computed at a given rate of discount. Here the implied discount rate is computed such that the PV of benefits equals the PV of costs, and the NPV becomes zero. Thus, the IRR is the interest rate 'r*' at which NPV is zero.

$$IRR = r^* \text{ such that } NPV = 0$$

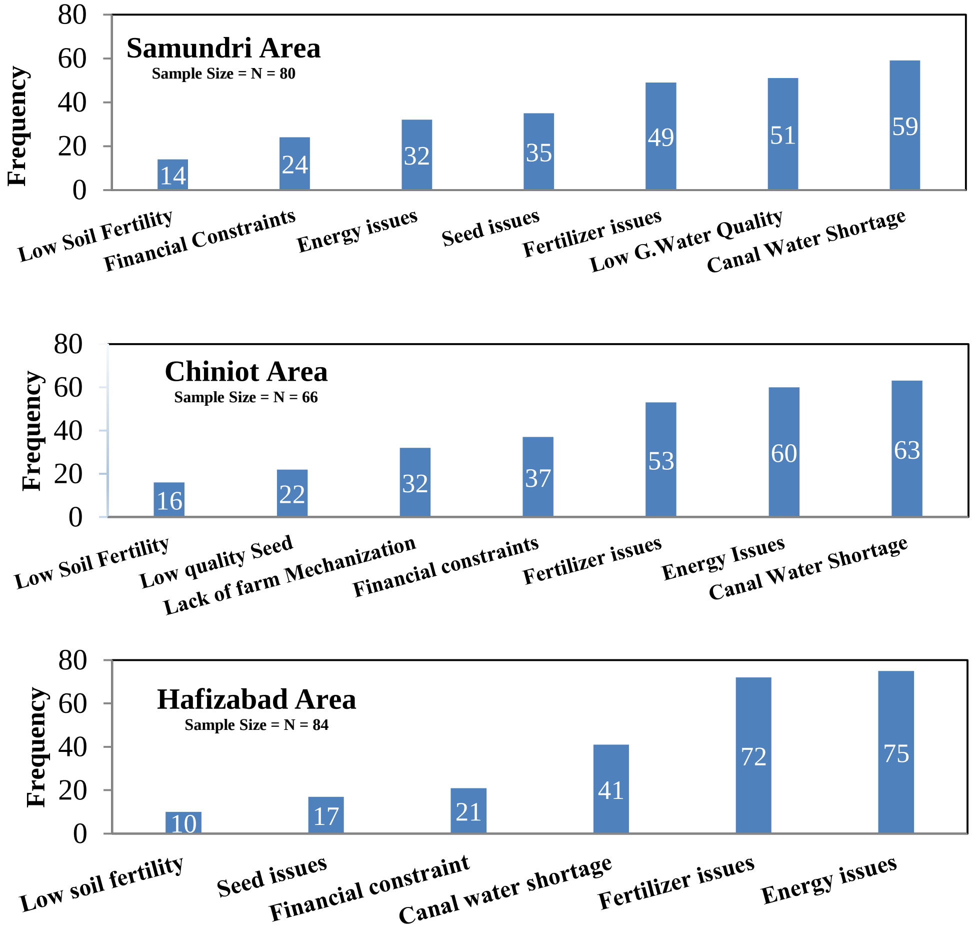
The decision rule would be to select the project with the highest IRR compared to the cost of capital and rank projects based on this comparison.

RESULTS AND DISCUSSIONS

Factors Affecting Water Productivity

From an irrigation standpoint, location of the site was important. The Samundri site was at the tail of the irrigation network commanded by Gogera branch canal. The farmers interviewed in Samundri expressed their concerns about shortages of canal water (74%), poor quality groundwater (65%), and fertilizer issues (61%). Similarly, 95%, 91%, and 80% of the farmers in Chiniot showed concerns regarding canal water shortages, energy, and fertilizer issues, respectively, even though the Chiniot site has good quality groundwater in most of the area. In the Hafizabad area, 89%, 85%, and 49% or farmers ranked their primary concern as energy, fertilizer, and canal water shortages, respectively (Figure 2 shows frequency of the responses).

Figure 2: Factors Identified by Farmers as Affecting Water Productivity at the Samundri, Chiniot, and Hafizabad Areas



This survey shows that a majority of farmers expressed concerns regarding shortages of canal water, energy, and fertilizer issues as the primary factors affecting their water productivity. Other factors such as seed, financial constraints, soil fertility, and lack of mechanization were also reported as affecting their crop yields and land and water productivity.

The majority of the farmers surveyed had an education level under matric (secondary school education) and were 30 to 50 years old. Table 2 shows the education level of respondents in the three areas. Accordingly, 40% farmers have an education level below matric, out of which on average 9% were illiterate across the three sites. Out of those above matric, 40% of the farmers listed matriculation as their education level, while only 6% reported having graduated. In total, 59% of the respondents had a qualification of matric and higher, which might be one of the most important factors contributing towards better farming practices in the study area.

Table 2: Education Level of Respondents

Education Level	Samundri (%)	Chiniot (%)	Hafizabad (%)	Average (%)
Illiterate	17.5	6	2.4	9
Primary	8.75	21.2	21.5	17
Middle	13.75	19.7	11.9	15
Matric	41.25	42.4	35.7	40
Intermediate	13.75	10.6	15.5	13
Graduation	5	-----	13	6

The age of respondents was grouped into four ranges as shown in the Table 3. About 14% of respondents were 20 to 35 years old, 33% were 36 to 50, 33% were 51 to 65, and 20% were more than 65 years old. The results show that 49 percent of the farmers were more than 50 years old, indicating that there is substantial cumulative experience within the surveyed farmers.

Table 3: Age of Respondents

Age	Samundri	Chiniot	Hafizabad	Average
(Years)	(%)	(%)	(%)	(%)
20-35	23.75	13.6	4.8	14
36-50	37.5	36.4	25	33
51-65	31.25	30.3	38.9	33
65+	7.5	19.7	31.3	20

Table 4 shows the frequency distribution of farm location with respect to canal outlet, i.e. head, middle, and tail, at all sites area. The base survey responses indicate that farm location is potentially correlated to wheat yield. Farms at the head saw the highest wheat yields (results not shown in the table). The field survey indicated that 53% farms were located at the tail of the watercourse and had less canal water availability. For the whole sample, 7% of farmers had land at the head of the watercourse, while 40% farmers were located at the middle.

Table 4: Farm Location of Respondents

Farm Location	Samundri (%)	Chiniot (%)	Hafizabad (%)	Average (%)
Head	17.5	3	1.2	7
Middle	20	18.2	80.9	40
Tail	62.5	78.8	17.9	53

Field Experimental Results

In the following tables and discussion, we present and analyze the results from the experimental field sites.

Table 5 shows the water applied and field irrigation efficiencies for the wheat crop from the experimental sites for the four types of irrigation. The water savings for drip (Samundri site only) and pipe systems compared to conventional irrigation is also shown. The results show that field irrigation efficiency for drip and perforated pipe irrigation was 98% and 77%, respectively, compared to 74% and 63% for open end pipe and conventional. The conveyance efficiency for perforated pipe irrigation was 100%, as the water was conveyed through pipes from the source to the fields, without seepage losses. Water savings over conventional irrigation is 40% for drip and averages 18% for perforated pipe and 12% for open end pipe.

Table 5 : Field Irrigation Efficiencies (%) and Water Savings (%) for Wheat Crop from Experimental Sites

Site	Drip Irrigation		Perforated Pipe Irrigation		Open End Pipe Irrigation		Conventional Irrigation		Water Saving Over Conventional Irrigation		
	WA (mm)	Ei (%)	WA (mm)	Ei (%)	WA (mm)	Ei (%)	WA (mm)	Ei (%)	Drip	Perforated	Open end
Samundri	224.9	98.5	289.1	76.63	-	-	373.3	59.39	40	22	-
Chiniot	-	-	301.7	72.81	296.3	74.07	337.9	64.95	-	10	12
Hafizabad	-	-	316.3	82.43	350	74.47	405.2	64.34	-	22	13
Average	224.9	98.5	302.4	77.29	323.2	74.27	372.1	62.89	40	18	12.5

Note: WA= Water applied; Ei = Field Irrigation Efficiency

Wheat yields under each irrigation method are shown in Table 6. Treatment using drip irrigation produced the maximum wheat yield of 5,076.67 kg ha^{-1}, while the conventional irrigation treatment had the lowest yield, on average, of 3,651.11 kg ha^{-1}, demonstrating that irrigation using traditional watercourses produced lower wheat yields. The results for all treatments were significantly different from each other at the 5% probability level. Drip irrigation and perforated pipe irrigation showed a 39% and 25% increase in yields as compared with conventional irrigation, while open end pipe showed a 19% increase. Similar results have been reported by Mahmood and Ahmad (2005).

Table 6: Irrigation Method Effects on Wheat Yield (Kg ha^{-1})

Treatment	Samundri	Chiniot	Hafizabad	Average
Conventional	3373.33^{c}	3840.00^{c}	3740.00^{c}	3651.11^{d}
Perforated	4230^{b} (25%)	5184.67^{a} (35%)	4370.00^{a} (17%)	4594.89^{b} (25%)
Open End	-	4586.67^{b} (19%)	4123.33^{b} (10%)	4355.00^{c} (19%)
Drip	5076.67^{a} (50%)	-	-	5076.67^{a} (39%)

Note: Treatment means w ith different letters are significantly different from each other at p≤0.05.

The data for water productivity for the wheat crop at all the sites with their respective treatments is shown in Table 7. The water productivity for drip irrigation was 2.26 kg m^{-3} as compared with that under conventional method which was 0.90 kg m^{-3} at Samundri. Average water productivity for perforated pipe exceeded open end pipe and conventional. All treatments were significantly different from one another at the 5% probability level.

Table 7: Irrigation Method Effects on Water Productivity for Wheat (kg m^{-3})

Treatment	Samundri	Chiniot	Hafizabad	Average
Conventional	0.90^{c}	1.14^{c}	0.92^{c}	0.98^{d}
Perforated	1.46^{a}	1.72^{a}	1.36^{a}	1.51^{b}
Open end	-	1.55^{b}	1.18^{b}	1.36^{c}
Drip	2.26^{b}	-	-	2.26^{a}

Note: Treatment means w ith different letters are significantly different from each other at p≤0.05.

Economic Results

Table 8 shows the economic analysis for a single year of per acre wheat yield under conventional irrigation, perforated pipe, and drip irrigation systems in district Faisalabad (Samundri site). For the economic analysis, results are presented for conventional irrigation both at the experimental sites and from the farmer surveys. The open end pipe system showed less improvement over the conventional method so it was dropped from this portion of analysis.

The total cost of wheat production was calculated by adding the per acre total variable cost and irrigation investment cost. As most of the farmers own their own land, land rent was not included in the analysis. The per acre total cost incurred under drip irrigation was Rs. 35,015.16, the highest of the three methods. This was due to the high installation cost of the drip irrigation system. The drip irrigation total installation cost per acre was Rs. 120,000 for its 10-year useful life, compared to the lower installation cost of between Rs. 17,000 and Rs. 18,000 for perforated pipe at all three sites with a three-year useful life. As mentioned before, the irrigation investment cost used to calculate gross margin was taken in the form of depreciation cost and interest for one cropping season, as we are only looking at the gross margins for the first year.[2] The installation cost of perforated pipe also increases the total cost compared to conventional irrigation during the single-year study period.

While the irrigation investment costs of these systems raises total cost, the total variable cost of the drip and perforated pipe systems were less than for the conventional irrigation method in both the farmer survey analysis and at the experimental site. This is mainly due to decreases in irrigation and fertilizer costs per acre, as these new irrigation systems allow more efficient input use. The per acre total revenue of wheat production also increases under these systems. This change was dramatic at the experimental site under the drip irrigation system, with a revenue of Rs. 71,848, an increase of 53% compared to conventional irrigation at the experimental site.

The gross margins obtained from the conventional method, for both the farmer survey (Rs. 22,053.69) as well as at experimental station (Rs. 19,199.46), were far below that of the perforated pipe and drip irrigation systems. The gross margin for drip irrigation was calculated to be Rs. 36,832.84, which is the highest amongst the three irrigation systems at this site. It is important to note that the results from the Samundri site are the only ones with a direct comparison between the perforated pipe and drip systems, and drip has an advantage over perforated pipe.

[2] Another method to compute annual cost would be an amortization calculation. When the depreciation plus interest method is compared to amortization for the first year of drip irrigation in Samundri we get irrigation investment cost of Rs. 12,480 and Rs. 14,794, respectively, and for perforated pipe we get costs of Rs. 6,066.66 and Rs. 6,306.10 respectively. Gross margin remains highest (Rs. 34,518) for drip irrigation versus perforated pipe (Rs. 28,145).

Table 8: Economic Analysis (Single Year) of per Acre Wheat Production Under Three Different Irrigation Systems in District Faisalabad (Samundri site)

Activity	Conventional Method (Farmer Survey, N=80)	Conventional Method (Experimental Data)	Perforated Pipe (Experimental Data)	Drip Irrigation (Experimental Data)
Total Variable Cost (Rs.)	26,097.31	27,743.04	24,412.04	22,535.16
Land Preperation	2,915.78	3,000.00	3,000.00	3,000.00
Seed	1,235.81	1,800.00	1,800.00	1,800.00
Fertilizer	9,477.71	7,800.00	7,800.00	5,850.00
Irrigation	3,734.14	4,698.76	1,237.00	1,543.00
Manual Labor Charges	2,113.35	2,100.00	2,100.00	2,100.00
Mark Up (at 4% interest)	345.57	344.28	275.04	242.16
Harvesting	3,000.41	4,000.00	4,000.00	4,000.00
Threshing	3,274.54	4,000.00	4,200.00	4,000.00
Irrigation Investment Cost (Rs.)	0.00	0.00	6,066.66	12,480.00
Depreciation	0.00	0.00	5,833.33	12,000.00
Interest Charge	0.00	0.00	233.33	480.00
Total Cost (Rs.)	26,097.31	27,743.04	30,478.70	35,015.16
Total Revenue (Rs.)	48,151.00	46,942.50	58,863.75	71,848.00
Gross Margin (Rs.)	22,053.69	19,199.46	28,385.05	36,832.84

Table 9 depicts the economic analysis of per acre wheat production in district Chiniot. The results are in line with the previous results from the Samundri site, although drip irrigation was only carried out at Samundri. The total cost under perforated pipe was highest, with a cost of Rs. 29,985.66, and the total revenue earned from perforated pipe was also the highest at Rs. 73,458. The results show that the gross margin was again lower for the conventional irrigation and perforated pipe had the highest gross margin, at Rs. 43,472.34.

Table 9: Economic Analysis of Per Acre Wheat Production Under Conventional and Perforated Pipe Irrigation Systems in District Chiniot

Activity	Conventional Method (Farmer Survey, N=66)	Conventional Method (Experimental Data)	Perforated Pipe (Experimental Data)
Total Variable Cost (Rs.)	24,970.17	24,559.80	23,919.00
Land Preperation	3,023.67	3,000.00	3,000.00
Seed	1,358.99	1,750.00	1,750.00
Fertilizer	8,589.00	7,800.00	7,800.00
Irrigation	3,700.00	1,540.00	1,000.00
Manual Labor Charges	2,128.68	2,190.00	2,100.00
Mark Up (at 4% interest)	331.43	279.80	269.00
Harvesting	3,000.00	4,000.00	4,000.00
Threshing	2,838.40	4,000.00	4,000.00
Irrigation Investment Costs (Rs.)	0.00	0.00	6,066.66
Depreciation	0.00	0.00	5,833.33
Interest Charge	0.00	0.00	233.33
Total Cost (Rs.)	24,970.17	24,559.80	29,985.66
Total Revenue (Rs.)	51,897.57	54,404.00	73,458.00
Gross Margin (Rs.)	26,927.40	29,844.20	43,472.34

Table 10 repeats the same analysis for the Hafizabad site. The results reveal that the total cost, Rs. 24,813.32, was highest for the perforated pipe system. Again, the total cost was high due to the installation cost of perforated pipe that was included in form of depreciation with an interest charge. Nevertheless, the gross margin was Rs. 31,586.68 for perforated pipe, which was higher than the conventional irrigation method, whether having been reported by farmers or observed at the controlled experimental site.

Table 10: Economic Analysis of Per Acre Wheat Production Under Conventional and Perforated Pipe Irrigation Systems in District Hafizabad

Activity	Conventional Method (Farmer Survey, N=66)	Conventional Method (Experimental Data)	Perforated Pipe (Experimental Data)
Total Variable Cost (Rs.)	22,912.80	19,564.04	18,451.98
Land Preperation	4,063.50	3,950.00	3,950.00
Seed	1,340.20	1,400.00	1,400.00
Fertilizer	7,317.09	7,850.00	7,850.00
Irrigation	2,730.16	1,447.90	954.70
Manual Labor Charges	2,189.17	2,625.00	2,016.00
Mark Up (at 4% interest)	307.20	291.14	281.28
Harvesting	2,485.41	N/A	N/A
Threshing	1,686.86	N/A	N/A
Combine Harvesting and Threshing	793.21	2,000.00	2,000.00
Irrigation Investment Costs (Rs.)	0.00	0.00	6,361.34
Depreciation	0.00	0.00	6,116.67
Interest Charge	0.00	0.00	244.67
Total Cost (Rs.)	22,912.80	19,564.04	24,813.32
Total Revenue (Rs.)	44,943.43	45,420.00	56,400.00
Gross Margin (Rs.)	22,030.63	25,855.96	31,586.68

Note: N/A represents that farmers in the experimental sites used a combined harvesting and threshing method

The data from the Hafizabad area and district Faisalabad show lower values of total revenue and gross margin than in district Chiniot across all three columns. Comparing Hafizabad and Faisalabd, we see that Faisalabad had higher revenues in all three columns, yet Hafizabad saw higher gross margins at the experimental sites under conventional and perforated pipe. This difference is due to the lower total variable costs incurred at the experimental site in Hafizabad.

Overall the results from Tables 8-10 show that new irrigation methods have a significant advantage, in terms of gross margin, over the conventional method. Drip irrigation was only tested in Faisalabad, and there it was found to have an advantage over both perforated pipe and conventional. Perforated pipe was also shown to have a higher gross margin than the conventional method in Faisalabad. The highest gross margin was seen for perforated pipe in Chiniot, being 45.7% higher than for the conventional method at the experimental site. The analysis from the Hafizibad site concurs, showing that perforated pipe has an advantage over the conventional method when it comes to gross margins.

Moving to the discounted capital budgeting techniques discussed before, Table 11 shows the BCR and NPV at different discount rates for wheat production on a per acre basis under the drip irrigation system. The BCRs and NPVs at different discount rates were calculated using total revenue from Table 8 as annual benefits. Annual costs were the sum of total variables costs, irrigation investment cost, and a yearly irrigation system operation and maintenance cost (5% of the irrigation investment cost, not shown in Table 8) beginning in the second year. Total revenue, total variable costs, and the operation and maintenance cost for each year of the 10-year useful life of the drip irrigation system were discounted back to a present value as per the previously presented formulas. The entire investment cost for the irrigation system is assumed to be made entirely in the first year (hence does not need to be discounted). This upfront investment replaces the depreciation and interest on irrigation investment shown in Table 8.

At a 2% discount rate, the BCR for drip irrigation was 1.74, its highest level, which declined at the 4%, 6%, and 8% discount rates to 1.69, 1.63, and 1.58, respectively. The IRR was found to be 36%. The rule of thumb for embarking on a project, or making an investment, is that the IRR should exceed the discount rate. Thus, the results illustrate that drip irrigation is a viable project/investment in district Faisalabad.[3]

Table 11: BCR, NPV, and IRR (Per Acre) for Drip Irrigation (10-year useful life) at Different Discount Rates

District	2%		4%		6%		8%		IRR (%)
	BCR	NPV (Rs.)	BCR	NPV (Rs.)	BCR	NPV (Rs.)	BCR	NPV (Rs.)	
Faisalabad	1.74	268,552.57	1.69	227,956.87	1.63	192,874.20	1.58	163,137.26	36%

Table 12 shows per acre BCR, NPV, and IRR for the wheat crop from data collected at the experimental sites under perforated pipe irrigation. The BCRs and NPVs are calculated as described above, using the data from Tables 8-10, but over the three-year useful life of the perforated pipe system.[4] It is evident from the table that across all discount rates, the BCR was the highest for district Chiniot and lowest for district Faisalabad. Likewise, NPV was also highest for Chiniot district and lowest for district Faisalabad. District Hafizabad was in the middle for both BCR and NPV. With regards to IRR, again district Chiniot was the highest with a positive IRR of 277%, with district Faisalabad again at the bottom, and Hafizabad in between them.

Table 12: BCR, NPV, and IRR (Per Acre) for Perforated Pipe Irrigation (3-year useful life) at Different Discount Rates

District	2%		4%		6%		8%		IRR (%)
	BCR	NPV (Rs.)	BCR	NPV (Rs.)	BCR	NPV (Rs.)	BCR	NPV (Rs.)	
Faisalabad	1.90	78,616.82	1.88	73,576.70	1.87	68,940.02	1.85	64,667.24	187%
Chiniot	2.40	121,273.67	2.39	113,834.98	2.37	106,985.78	2.35	100,668.55	277%
Hafizabad	2.22	87,589.42	2.20	82,014.69	2.18	76,885.46	2.16	72,158.13	197%

Comparing results for Faisalabad across the two tables, while the BCRs for drip irrigation show that it is a good investment, it has a slightly lower BCR than for perforated pipe across all discount rates. Although drip results in higher total revenue and lower total variable costs each year, the slightly lower BCR than for perforated pipe is due to the initial investment in drip irrigation being significantly higher. This higher investment cost also drives the differences between the IRRs for drip and perforated pipe. While all IRRs show a positive return on investment well above the discount rate, the IRRs for perforated pipe are larger than for drip. Comparing the Faisalabad sites again, the higher yields and lower variable costs with drip irrigation still cannot overcome the large upfront investment required, leading to a lower IRR than for perforated pipe.

[3] Tables 11 and 12 parallel Tables 8-10 in assessing the multi-year total benefits and costs for each irrigation system. An alternative approach for calculating BCRs, NPVs, and IRRs would be to use incremental benefits and costs, i.e. the difference between annual benefits and costs of the new irrigation systems and those under the conventional method. This would directly show the incremental change from the irrigation investment. Using this approach, the BCRs change slightly and the IRRs decline. For example, the IRR for drip irrigation falls from 36% to 15% and from 187% to 66% for perforated pipe in Faisalabad. Complete results are available from the authors on request.

[4] In Table 11 the BCR and NPV of drip irrigation were calculated over a 10-year period, whereas it is three years in Table 12. This shorter time frame means that the NPVs in Table 12 are lower than in Table 11, as there are fewer years of net benefits. If we compute the perforated pipe NPV over 10 years, accounting for the need to repurchase the system every 3rd year, the NPVs are roughly three times what is presented in the table. BCRs are essentially unchanged by a longer time frame, as they are the ratio of benefits and costs, which remain quite similar for different time horizons.

CONCLUSIONS AND RECOMMENDATIONS

This study investigated the causes of low water productivity and aims to demonstrate feasible and efficient irrigation techniques for its improvement. To investigate improving water productivity, the study was executed in three phases. In the first phase, a comprehensive questionnaire was developed for farmers in three cropping zones, cotton-wheat (Samundri), mixed (Chiniot) and rice-wheat (Hafizabad) for identifying the factors affecting crop water productivity. In the second phase, field experiments were performed at the three sites to demonstrate various irrigation techniques to improve wheat water productivity. And, in the third phase, economic analysis was carried out to assess the viability of the irrigation techniques. The following are the salient conclusions drawn from the study:

Field Survey

- Broken down by the three areas in the study, the following are the issues affecting water productivity ranked in order:
  - As reported from the Samundri area: canal water shortages, poor groundwater quality, fertilizer, seed, energy, financial constraints, and low soil fertility.
  - As reported from the Chiniot area: canal water shortages, energy, fertilizer, financial constraints, lack of farm machinery, low quality seed, and soil fertility.
  - As reported from the Hafizabad area: energy, fertilizer, canal water shortages, financial constraints, seed and low soil fertility.

Field Experiments

- Drip irrigation, perforated pipe irrigation, and conventional irrigation practices gave field irrigation efficiencies of 98%, 76%, and 59%, respectively, for wheat at the Samundri site.
- Overall, the perforated pipe system showed field irrigation efficiencies in the range of 72% to 82%, which was about 15% more than that of conventional irrigation methods.
- Drip irrigation and perforated pipe irrigation showed a 39% and 25% increase in yields as compared with conventional irrigation.
- Drip irrigation, perforated pipe irrigation, and conventional irrigation produced water productivities of 2.26, 1.46, and 0.90 kg m^{-3}, respectively, for wheat at the Samundri site.
- Overall, perforated pipe irrigation and conventional irrigation produced water productivities in the range of 1.36 to 1.72 kg m^{-3}, and 0.90 to 1.14 kg m^{-3}, respectively.
- The gross margin for the drip irrigation system was Rs. 36,832.84, higher than perforated pipe in the same area, and also showed a BCR of 1.69 at 4% discount rate and an IRR of 36% in district Faisalabad.
- For perforated pipe irrigation, gross margins were superior compared to conventional irrigation in the first year of production in all districts. The highest gross margin of all systems was in perforated pipe in Chiniot. For the whole useful life of perforated pipe, the BCRs ranged from 1.88 to 2.39 at a 4% discount rate, depending on site conditions, and was found to be profitable at all discount rates in all the districts. The IRRs were 187%, 277%, and 197% in districts Faisalabad, Chiniot, and Hafizabad, respectively.

Policy Recommendations

There are many ways to improve crop water productivity and field irrigation efficiency, however, solutions need to be site specific. Every method is not viable at every farm. There is a need to develop technology packages for each zone based on its characteristics such as soil type, topography, crops grown, water source and its quality, and, above all, skill and commitment of the farmers. Following are the proposed policy recommendations based on the field survey, field experiments, and observations to promote adoption of HEIS for improving water productivity and farm income:

1. Drip irrigation is the most efficient, but at the same time, it is an expensive option. It also requires more technical knowledge and intensive training for successful operation. In the scenario at hand, there is a need for cheap and easy to operate interventions which still ensure improvements in irrigation efficiency. Perforated pipe irrigation provides an option to convey water with 100% efficiency from the source to the field along with improving irrigation efficiency because of enhanced water supplies at the field outlet.

2. To minimize use of conventional methods, perforated pipe irrigation needs to be promoted by making it available in markets and made of durable material. As well, workshops should be set up to demonstrate its use in the fields.
3. Currently, there is lack of technically viable HEIS design. There is an urgent need for such systems from the technical professionals who are not directly involved in the sale of the system (i.e. third party design or farmer friendly design).
4. Prior to the installation of HEIS, farmers need to be properly trained on the system. Farmers will be the actual operator/user of the system and must understand its proper use.
5. Currently, little support is available to farmers for operating and maintaining HEIS systems. Service centers need to be established at the local level to provide spare parts, as well as services, for successful system operation.
6. Indigenization of the system and its components should be encouraged.
7. Initially the system needs to be installed at a small scale, two to five acres, for the farmer to learn and understand how to operate the system and to show its economic value. If the farmer understands the system fully, and is convinced of its feasibility, then they should increase the acreages under the system.
8. Based on size of land holdings, cropping zone, cropping pattern, product demand, water availability and its quality, and socio-economic conditions, different packages, in addition to HEIS, for improving water productivity and irrigation efficiency need to be developed for guiding farmers, e.g. bed planting, precision land leveling, and narrow borders.
9. Institutional support is required for building the capacity of manufacturers, suppliers, installers, local technicians, service providers, and farmers within the HEIS market.
10. Irrigation scheduling, along with fertigation schemes, for different crops under different efficient irrigation systems are not available and need to be developed based on research data to help decrease the cost of inputs and increase their efficiency.
11. For sustainability of the soil and water system, salts built up during application of HEIS must be flushed and farmers must be taught the best practices to do so.

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