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Low Cost, Innovative Water Conservation Practices in Irrigated Agriculture

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Abstract

Irrigated regions of the world are rapidly approaching to severe water crises due to reduction in per capita freshwater availability. Thus either the supply of water is to be increased through tapping new resources, or wastage of available water sources must be minimized. Pakistan is a typical example of such problems though it possesses the world's largest contiguous irrigation system. With a population of more than 150 million, the country cannot meet its need for food, if adequate water is not available for crop production. Per capita water availability has decreased from 5600 m^3 to less than 1200 m^3 during the last 55 years. Water table has gone down by more than 7 meters in most parts of the country. The present need is to identify and adopt measures that will reduce water wastage and increase crop production. In order to achieve these objectives, the Pakistan Council of Research in Water Resources (PCRWR) has conducted research at farmers' fields to evaluate water use efficiency and economic viability of sprinkler and bed and furrow irrigation systems for growing wheat and rice crops considering the depth of water table. Yields and water use efficiencies were measured on experimental and adjacent fields irrigated by traditional irrigation methods. Sprinkler irrigation of wheat crop resulted in a water use efficiency of 3.95 kg/m^3 of water used compared to 1.34 kg/m^3 in the adjacent flooded basins. In case of rice, this method was able to save water up to 65% of that used in the traditional method. The water use efficiency with sprinkler irrigation was 0.67 kg of grain/m^3 of water compared with 0.20 kg of grain/m^3 of traditional method. The yields for rice were up to 39% higher under bed-and-furrow irrigation than flooded basins and water saving up to 31% with 0.39 kg of grain/m^3 of water. Benefit-cost analysis showed that adoption of such water conservation techniques for agricultural crops is a financially viable option for farmers in irrigated regions. These findings show large potentials for improving water use efficiency in crop production and thus to bring more area under cultivation of growing food crops.

Keywords: Wheat, rice, sprinkler, bed and furrow, Pakistan.

Introduction

In many arid and semi-arid countries where population growth is high, and freshwater is in short supply, there is pressure on the agricultural sector to reduce its water consumption and make it available for the urban and industrial sectors. This drives the demand to produce cereals, especially wheat and rice, using lower amount of irrigation water. Pakistan is no exception to this challenge.

Historically wheat and rice are grown in bunded basins and subjected to continuous flooding. Rice growers in particular, tend to believe that it requires standing water during the growing season to maximize yields. These practices consume water far in excess of crops' evapotranspiration requirements and result in very low irrigation efficiencies. Studies on rice within Pakistan indicate that 13 to 18 cm water is applied per irrigation, which is about 8 cm higher than the consumptive use between two irrigation events (Kahlown *et al.* 2001). Whereas, on-farm irrigation efficiencies range between 23 to 70% (Clyma and Ashraf, 1975; Kalwij, 1997; Kijne and Kuper, 1995; Kahlown *et al.* 1998).

Large reductions in water use can be obtained, if seepage and percolation losses are minimized. Percolation losses in gravity fed irrigation fields can be minimized by modifying soil physical properties by puddling (De Datta, 1981), shallow soil tillage (Cabangon and Tuong, 2000), soil compaction with heavy machinery (Harnpichitvitaya *et al.,* 2001), or by introducing physical barriers beneath the root zone (Garrity *et al.,* 1992). Reduction in water use can also be obtained by managing depth of standing water during growing season by alternate wetting and drying or by saturated soil culture (Bouman and Tuong 2001). Alternatively, pressurized irrigation methods such as sprinklers (Spanu *et al.,* 1996) or drip irrigation (Dunn *et al.* 2004) can be used to grow rice with much less water than required with the conventional methods of irrigation. Another possible modification relates to the method by which the land is prepared. Several researchers (Borrel *et al.,* 1997; Dunn *et al.* 2004; Hossain *et al.,* 2004.) showed that rice can be grown on bed-and-furrows, with less water than flooded basins. Bed-and-furrow method is a modification to furrow irrigation method, where more than one row of crop is grown. It leads to low water losses, because of small stream sizes, wetted areas, and bare soil evaporation.

There have been attempts to adopt pressurized irrigation methods to grow wheat and rice in various countries (Spanu *et al.* 1996). Sprinkler systems such as portable rain-guns can be used to apply a desired depth of water during pre-sowing and subsequent irrigations. The application of irrigation water with sprinklers has improved on-farm irrigation efficiencies up to 80% under the prevailing climatic conditions in the Indian sub-continent (Sharma, 1984). The potential for the adoption of sprinkler and bed and furrow irrigation systems to irrigate wheat and rice has not been evaluated in the Indus Basin of Pakistan, where water is delivered to farms by watercourses based on *warabandi,* a rotational method for equitable allocation of available water, by turn, with a fixed day, time, and duration of supply to each irrigator.

Objectives

The specific objectives of the study were:

i. To evaluate the feasibility of growing wheat and rice with sprinkler irrigation;
ii. To asses whether the water savings resulting from sprinkler irrigation can pay for the additional costs incurred; and
iii. To determine if rice can be grown on bed-and-furrows, and thereby increase water productivity.

Materials and Methods

1. Raingun Sprinkler Irrigation

1.1. Layout and treatments for wheat (2002-2003) & rice (2002)

Trials in (2002-2003) were carried out on Monoo Farm, 6 km from the Regional office of the Pakistan Council of Research in Water Resources (PCRWR) at Lahore. Clay loam soil is dominant in this area. Three different irrigation treatments were evaluated each with three replications and having size of plots, each 36m × 36m. Circular areas within these plots covered by rain-gun water were taken as the actual experimental areas while the remaining area was used as a buffer area (Figure 1). A reservoir (2m × 2m × 2m) was constructed near the trial sites to store water. A 16 HP diesel operated pump was installed to operate the rain-gun system. Pan evaporation and rainfall data were recorded, and daily crop evapotranspiration requirement (ET_c) estimated (equation 1) using daily pan evaporation data (EPan), a pan coefficient (KPan) of 0.7 (Khan, 2001), and a crop coefficient (Kc) (Kaleemullah et al. 2001).

$$ETc = EPan \times Kpan \times Kc \qquad (1)$$

Water flow meters were installed on the supply lines of each rain-gun to measure the cumulative volume discharged. Irrigation was applied twice a week for sprinkler irrigated plots, as a percentage of crop evapotranspiration demand. Adopted irrigation treatments are summarized in Table 1. Water used in the basin irrigation plot was measured with a cut-throat flume.

Table 1: Summary of Irrigation Application Treatments for Wheat and Rice Trials

Treatment	Wheat		Rice	
	2002-03	2003-04	2002	2003
T_1	75% of ET_c	85% of ET_c	100% of ET_c	91% of ET_c
T_2	100% of ET_c	100% of ET_c	125% of ET_c	100% of ET_c
T_3	125% of ET_c	115% of ET_c	150% of ET_c	109% of ET_c
T_4 (Basin)	225% of ET_c	228% of ET_c	192% of ET_c	261% of ET_c

Wheat was sown in second week of November, 2002 and harvested in second week of April, 2003. Seed-bed preparation included one disc ploughing followed by two cultivations and two plankings. A seed rate of 123.5 kg/ha of Inqlab-91 of wheat variety was used. Fertilizers added were 75 kg/ha nitrogen and 70 kg/ha phosphorus at the planting time. For the rice (2002 and 2003) crop, the seedbed was prepared by two disc ploughings and four simple ploughings followed by two plankings and puddling (process of breaking down soil aggregates into uniform mud, accomplished by applying mechanical force to the soil at high water content). The rice variety Super Basmati was transplanted in the first week of June and harvested in last week of October. Fertilizers applied included 155 kg/ha of diamonium phosphate at the time of transplanting and after 25 days urea and zinc sulphate at the rate of 124 kg/ha and 12.5 kg/ha, respectively

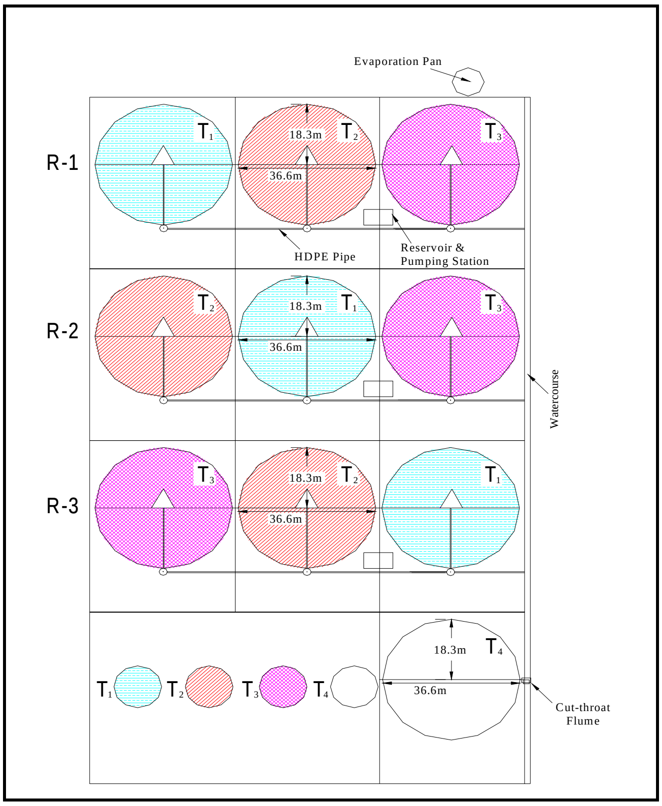


Figure 1: Layout of Study for Wheat and Rice 2002-2003

1.2. Layout and treatments for wheat (2003-2004) and rice (2003)

Trials on wheat and rice were again conducted (2003-2004) at the Inam Ilahi Farm, at Mouza Sheikh Da Kot, about 13 km from the Regional Office of the PCRWR at Lahore. Clay loam soil is dominant in the area. Three different irrigation treatments were evaluated each with three replications. Since variations among yields of (2002-2003) treatments were small, it was decided to minimize the variation in water applications among sprinkler-irrigated treatments (2003-2004). In addition to this, moisture stress condition was also considered for rice trials. Nine plots, each covering one of the half circle areas shown in Figure 2, each measuring 561 m^2 (18.9 m radius) were prepared for the trials. The irrigation supply was same as in the previous year. Adopted irrigation treatments are summarized in Table 1.

Crop water requirements were usually met using canal water with private tubewell water used when canal water was not available. Irrigation volumes were measured with flow meters for sprinkler-irrigated plots, and with a cut-throat flume for surface irrigated plots. Water savings were calculated by subtracting the volume of water applied for the first three treatments from the amount of water applied for basin-irrigated plots.

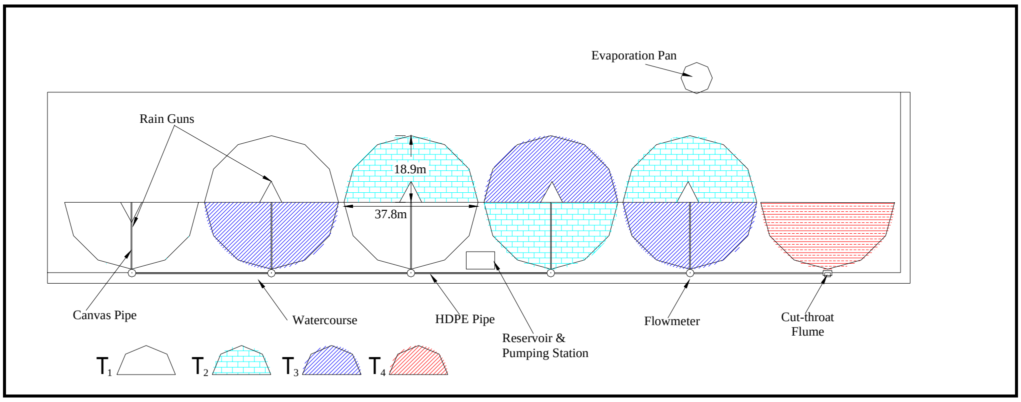


Figure 2: Layout of Study for Wheat and Rice 2003-2004

Wheat was grown on the same plots during second week of November, 2003 and harvested in third week of April, 2004. Tillage included three ploughing including one disc ploughing followed by two planking. Fertilizer addition and crop variety used were the same as in the previous year. For rice (2003), the seedbed preparation included five ploughings with four planking. Super Basmati was transplanted at the end of May and harvested in end of October. The crop was fertilized with 155 kg/ha of DAP at transplanting and 124 kg/ha of Urea 25 days later. Yield of both the crops were measured for the entire treatment area of each replication.

2. Bed and Furrow Irrigation

During 2001, the study was conducted at the PCRWR Lahore Research Station. In 2002 the study was conducted on the Monoo Farm about 6 km from Lahore and in 2003 it was conducted on Inam Elahi farm at Sheikh Dakot Village, about 13 km out of Lahore. A rain gauge and an evaporation pan were placed at each site to help decide when to irrigate. Land in the bunded basin areas and the bed-and-furrow areas had been leveled prior to these studies. The beds and furrows were formed with tractor-mounted equipment, which is available in most parts of the Pakistan. This equipment reduces cost of constructing these beds and furrows to a small fraction of the amount paid to laborers to construct the bed and furrows. There were three replications of each of the bed-and-furrow treatments indicated in Figure 3. The furrows were compacted by pounding the soil with a metal block attached to a wooden handle. A wheel-type packing device could achieve similar packing and leave the furrow bed smoother. The objectives of the packing included smoothing the furrow and reducing its friction coefficient so the water could move more quickly and with less head loss from the supply side to the far side of the field and thereby improve the uniformity of the irrigation. The furrows with smoother perimeters also have water levels at the far end of the furrow, which are closer to those at the supply end during the rest of the application time.

In the last two years of the study, cooperating farmers, with fields adjacent to the bed-and-furrow research plots, informed us when they would be irrigating, so we could measure the flow rate and time of their application. Their water use and yields of these fields provided the data listed under “Basin flooding” in 2002 and 2003. Cutthroat flumes and timers were used to measure flow rates into the farmers basins and the bed-and-furrow plots. “Super Basmati” rice was sown in nurseries about the end of May and was transplanted into the beds and furrows. Amounts of water applied in each irrigation, to each treatment were measured.

The yield, water use and water productivity values given for the bed-and-furrow treatments in subsequent tables are averages of these three replications. The values given for the much larger adjacent fields, which were irrigated by farmers, are not replicated. Fertilizer was applied to all plots including the farmers’ fields at the NPK rate of 120-60-60 kg/ha respectively as recommended by the Punjab Agriculture Department. The phosphorus, potash and half of the nitrogen were applied before transplanting. The rest of the nitrogen was applied about 50 days later. Zinc sulfate (20%) was applied at the rate of 25 kg/ha about one month after planting to avoid zinc deficiency, which is common in this area. To control weed growth during the initial stage of the rice crop, a weedicide was applied 4 days after transplanting at the rate of 2.5 liters/ha. Razex granular was applied at the rate of 24 kg/ha. Yields were measured on a whole plot basis.

3. Benefit-Cost analyses

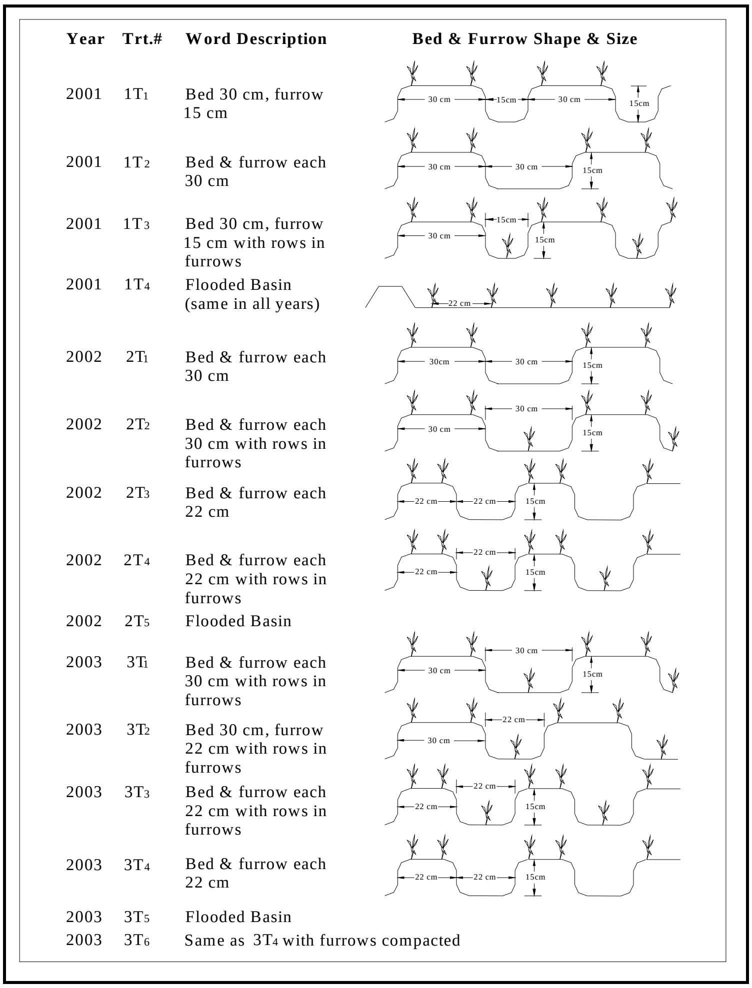
The benefit-cost analysis of this study involves the assessment of the benefits and costs of sprinkler and basin flooding irrigation for wheat and rice. The financial feasibility of adopting rain-gun sprinkler irrigation to grow wheat and rice was determined by benefit-cost analyses, based on results obtained from wheat trials (2003-2004) and rice trials (2003), which involved the following (McConnell and Brue, 2005):

Gross Income (GI) = Average Price of Crop (APC) x Crop Water Productivity (CWP)….. (2)

Net Income per Cubic Meter (NICM) = GI – Cost of Cubic Meter of Water (CCMW)….. (3)

Net Income per Water Saved (NIWS) = NICM- Net Income of Basin Irrigation (NICT)… (4)

Benefit-Cost Ratio = NIWS/CCMW ……………… (5)



Year	Trt.#	Word Description
2001	$1T_1$	Bed 30 cm, furrow 15 cm
2001	$1T_2$	Bed & furrow each 30 cm
2001	$1T_3$	Bed 30 cm, furrow 15 cm with rows in furrows
2001	$1T_4$	Flooded Basin (same in all years)
2002	$2T_1$	Bed & furrow each 30 cm
2002	$2T_2$	Bed & furrow each 30 cm with rows in furrows
2002	$2T_3$	Bed & furrow each 22 cm
2002	$2T_4$	Bed & furrow each 22 cm with rows in furrows
2002	$2T_5$	Flooded Basin
2003	$3T_1$	Bed & furrow each 30 cm with rows in furrows
2003	$3T_2$	Bed 30 cm, furrow 22 cm with rows in furrows
2003	$3T_3$	Bed & furrow each 22 cm with rows in furrows
2003	$3T_4$	Bed & furrow each 22 cm
2003	$3T_5$	Flooded Basin
2003	$3T_6$	Same as $3T_4$ with furrows compacted

Figure 3: Shape and Size of Beds and Furrows

Results and Discussions

1. Raingun Sprinkler Irrigation

1.1. Wheat water productivity of (2002-03) and (2003-04) trials

Results of Wheat (2002-03) trials are summarized in Table 2. Up to 67% more water was applied to the basin irrigated plots than sprinkler irrigated plots. The water savings when compared with basin irrigation for T_1 (75% of ET_c), T_2 (100% of ET_c) and T_3 (125% of ET_c) were 67, 56 and 45% higher respectively than the basin irrigation. All rain-gun treatments produced more yield than basin irrigation treatment. Crop water productivity of sprinkler irrigated treatments was also higher than that of basin irrigation. The treatment T_1 resulted in highest crop water productivity of 4.29

kg/m^3 of water and treatment of basin irrigation produced the lowest crop water productivity of 1.3 kg/m^3.

Trials on wheat-water productivity (2003-04) generally showed that more water was applied to the basin irrigated plots than the sprinkler irrigated plots (Table 2). The water savings when compared with basin irrigation for T_1 (85% of ET_c), T_2 (100% of ET_c) and T_3 (115% of ET_c) were 74, 65 and 58 percent respectively higher than basin irrigation (Table 2). Rain-gun treatment T_3 (115% of ET_c) produced maximum yield of 5036 kg/ha. Crop water productivity of sprinkler irrigated treatments was 70% higher than that of basin irrigation (Table 2). The T_1 treatment resulted in highest crop water productivity of 5.21 kg/m^3 of water while the basin irrigation treatment resulted in the lowest crop water productivity of 1.38 kg/m^3.

1.2. Rice water productivity of (2002) and (2003) trials

Results from rice (2002) trials are summarized in Table 3. The number of irrigations applied to the basin irrigated plots were half as compared to the sprinkler irrigated plots, reflecting water availability constraint with *warabandi* system, although much water was supplied than to the sprinkler irrigated plots. The water savings when compared with basin irrigation for T_1 (100% of ET_c), T_2 (125% of ET_c) and T_3 (150% of ET_c) were 48, 35 and 22% respectively higher than basin irrigation. Rain-gun treatment with 100% of ET_c produced 3105 kg/ha of rice yield with highest crop water productivity of 0.55 kg/m^3 while conventional basin flooding resulted in the lowest productivity of 0.29 kg/m^3. Treatments with 125% and 150% of ET_c increased the yield by only 2.1 and 2.9 percent respectively compared with treatment 100% of ET_c but the crop water productivity became much lower as compared to T_1. Similar to rice crop (2002), the number of irrigations in basin irrigated plots (2003) were around half of those with sprinkler irrigated plots due to rigidity of *warabandi* system. However, water applied was again higher than the sprinkler irrigated plots. The water savings compared with basin irrigation for T_1 (91% of ET_c), T_2 (100% of ET_c) and T_3 (109% of ET_c) were 65, 62 and 58% respectively higher than basin irrigation (Table 2). Rain-gun treatment T_3 produced maximum yield (3359 kg/ha) but the crop water productivity was lower than other sprinkler treatments of T_1 and T_2 by 10% and 3% respectively. The basin irrigated field produced up to 31% less rice than the rain-gun irrigated fields, possibly due to excessive leaching of nutrients.

Crop water productivity of sprinkler irrigated treatments was higher than that of basin irrigation by 225%. Treatment T1 resulted in highest crop water productivity, but did not differ much from crop water productivity of other two sprinkler irrigated treatments. Despite minimizing the variation in water application from 100% to 91%, no significant impact was observed on crop water productivity

Table 2: Water Applied (m^3/ha) and Water Savings for Wheat Trials

Treatment	Volume of Water Applied (m^3/ha)	Water Saving (%)	Yield (kg/ha)				Crop Water Productivity (kg/m^3)			
			R1	R2	R3	Avg.	R1	R2	R3	Avg.
2002-03										
T_1 (75% of ET_c)	945	67	4058	4049	4043	4050	4.294	4.285	4.278	4.29
T_2 (100% of ET_c)	1260	56	4007	4014	4027	4016	3.180	3.186	3.196	3.187
T_3 (125% of ET_c)	1575	45	3949	3930	3938	3939	2.507	2.495	2.500	2.501
T_4 (225% ET_c)	2882	-	3752				1.302			
2003-04										
T_1 (85% of ETc)	813	74	*4246*	*4225*	*4240*	*4237*	*5.223*	*5.197*	*5.215*	*5.212*
T_2 (100% of ETc)	1061	65	*4992*	*4998*	*4971*	*4987*	*4.705*	*4.711*	*4.685*	*4.700*
T_3 (115% of ETc)	1310	58	*5039*	*5048*	*5021*	*5036*	*3.847*	*3.853*	*3.833*	*3.844*
T_4 (228% of ETc)	3073	-	*4229*				*1.376*			

Table 3. Water Applied (m^3/ha) and Water Savings for Rice Trials

Treatment	No. of Irrigations	Volume of Water Applied (m^3/ha)	Water Saving (%)	Yield (kg/ha)				Crop Water Productivity (kg/m^3)			
				R1	R2	R3	Avg.	R1	R2	R3	Avg.
2002											
T_1 (100% of ET_c)	39	5612	48	3096	3116	3103	3105	0.552	0.555	0.553	0.55
T_2 (125% of ET_c)	39	7015	35	3173	3181	3156	3170	0.452	0.453	0.450	0.45
T_3 (150% of ET_c)	39	8417	22	3208	3194	3183	3195	0.381	0.379	0.378	0.38
T_4 (192% of ET_c)	19	10795	-	3123				0.29			
2003											
T_1 (91% of ET_c)	*23*	*4552*	*65*	*3042*	*3022*	*3029*	*3031*	*0.668*	*0.664*	*0.665*	*0.67*
T_2 (100% of ET_c)	*23*	*4987*	*62*	*3275*	*3252*	*3244*	*3257*	*0.657*	*0.652*	*0.650*	*0.65*
T_3 (109% of ET_c)	*23*	*5434*	*58*	*3361*	*3371*	*3345*	*3359*	*0.619*	*0.620*	*0.616*	*0.62*
T_4 (261% of ET_c)	*13*	*13020*	-	*2562*				*0.20*			

2. Bed and Furrow Irrigation

Calculations using evaporation pans and other climatic data indicate that the seasonal evapotranspiration for rice is about 60 cm of water. Total water supplied to these crops of 84 to 151 cm in Lahore, indicates that we have potential for significant reduction in the use of water for rice production. Thus, the amount of water applied to the bed-and-furrow system was generally 10 to 30% less than the amount applied by farmers to their flooded basins (Table 4). In 2001 and 2003 the yields on the bed-and-furrow systems were from 1 to 38% higher than on the flooded basins. However in 2002 the farmers flooded basin yields slightly exceeded those on the bed-and-furrow systems. The water productivity on the bed-and-furrow systems always exceeded those on the flooded basins.

Table 4: Rice Yields, Water Use and Water Use Efficiencies

Treatment Number	Treatment Description	Yield kg/ha	Water Use centimeters	Water productivity kg grain/m^3 water
1T$_1$	Bed-and-furrow	3850	131	0.29
1T$_2$	Bed-and-furrow	3710	143	0.26
1T$_3$	Bed-and-furrow	4202	132	0.32
1T$_4$	Basin flooding	3700	151	0.25
2T$_1$	Bed-and-furrow	2559	83	0.31
2T$_2$	Bed-and-furrow	2885	87	0.33
2T$_3$	Bed-and-furrow	2799	85	0.33
2T$_4$	Bed-and-furrow	2964	87	0.34
2T$_5$	Basin flooding*	3010	115	0.26
3T$_1$	Bed-and-furrow	3229	99	0.33
3T$_2$	Bed-and-furrow	3288	95	0.35
3T$_3$	Bed-and-furrow	3217	91	0.35
3T$_4$	Bed-and-furrow	3537	93	0.38
3T$_5$	Basin flooding*	2562	130	0.20
3T$_6$	Bed-and-furrow compacted	3437	88	0.39

- In the years 2002 and 2003 the Basin Flooding treatments were managed with respect to timing and amounts of irrigation by the adjacent cooperating farmers who had some canal water and also had access to tubewell water. PCRWR staff measured the amount of water applied and the yields on those fields.

In the bed-and-furrow studies reported here, irrigations were applied soon enough to “keep the soils nearly saturated” because we believed that the saturated soil condition was optimum for rice production. However our sprinkler studies indicate that rice can tolerate and produce well when the soil water content is near or slightly less than field capacity. When soil water contents were kept near saturation the water was fairly mobile and much of it moved downward due to gravity. At soil water contents less than field capacity, which is equal to about 33 centibars of soil water tension, the rate of downward movement of water becomes practically negligible. The sprinkler studies in fields with tensiometers are indicating that irrigation can be withhold from rice until soil water tensions are up around 50 centibars without reducing yields. If irrigation is withheld from rice until these tensions are reached in bed-and-furrow systems and light irrigations are then applied through the furrows, the water will be sucked out of the furrows quickly and the soil water tension will reach 33 centribars within a few hours after the water leaves the furrow. This drier condition, keeping water content at or below field capacity most of the time, should reduce downward leaching of water.

The traditional method of reducing downward movement of water in rice fields is to puddle the soil before planting rice. This breaks down the structure of the soil, destroying most of the large pores in which water moves rapidly. Keeping soil water tensions up to 33 centibars, allows air to fill those large pores in the soil so that water cannot pass through them. Consequently, irrigation methods such as sprinkler and bed-and-furrow, which can maintain tensions above 33 centibars in the soil most of the time, can eliminate the need for puddling soils for rice production. This would be a positive step because puddling is expensive and because it accelerates the destruction of organic matter and reduces the ability of the soil to provide conditions optimum for growth of other crops.

3. Benefit-cost analysis – wheat (2003-04) and rice (2003)

The benefit-cost analysis of wheat (2003-04) showed that the benefits occurred from net product value resulting from the use of rain-gun method (method cost includes irrigation cost, US$ 0.017 per cubic meter). Average price of wheat was considered as US$ 0.17 per kg. Equations 2 to 5 were used to estimate benefit-cost ratios of Wheat, 2003-04 (Table 5). Benefit-cost ratios of all two sprinkler irrigated treatments were higher than 1. Therefore, it appears that investing in a rain-gun sprinkler unit and irrigating wheat between 85% and 115% ET_c is a financially viable proposition at current market costs and prices.

Table 5: Benefit-Cost Analysis of Growing Rice and Wheat Based on Water Saved

Treatment	Crop Water Productivity (kg/m^3)	Gross Income (US$/m^3)	Cost of water (US$/m^3)	Net Income (US$/m^3)	Net Income based on water saved (US$/m^3)	Benefit-Cost Ratio
Wheat (2003-04)						
T_1 (85% of ET_c)	5.21	0.868	0.143	0.725	0.512	3.58
T_2 (100% Et_c)	4.70	0.783	0.119	0.664	0.451	3.79
T_3 (115% ETc)	3.84	0.640	0.104	0.536	0.323	3.11
T_4 (228% ET_c)	1.38	0.230	0.017	0.213	-	-
Rice (2003)						
T_1 (91% of ET_c)	0.67	0.161	0.057	0.104	0.073	1.28
T_2 (100% of ET_c)	0.65	0.156	0.055	0.101	0.070	1.27
T_3 (109% of ET_c)	0.62	0.149	0.054	0.095	0.064	1.19
T_4 (261% of ET_c)	0.20	0.048	0.017	0.031	-	-

Benefit-cost analysis of rice (2003) showed benefits occurred in the form of net product value resulting from the use of rain-gun method, which included irrigation cost (US$ 0.017 per cubic meter of water), capital and maintenance cost of the sprinklers, pump and water holding reservoirs. Average price of rice used was US$ 0.24 per kg.

Equations 2 to 5 were used to estimate benefit-cost ratios of Rice 2003 (Table 5). Since the ratio is greater than 1 for T_1 for all three treatments, therefore, investing in a rain-gun sprinkler unit and irrigating between 91 to 109 % ET_c is a financially viable option at current costs and production prices.

Conclusions and Recommendations

Irrigation interval, amount and its uniform distribution greatly affected the water use efficiency and yield of wheat and rice crops. Results showed that, less irrigation water was needed when both wheat and rice were irrigated with rain-gun sprinklers and water use efficiency was much higher than for basin irrigation. Average crop water productivity of wheat and rice were 3.95 and 0.55 kg/m^3 with sprinkler irrigation and 1.34 and 0.25 kg/m^3 with basin irrigation. Benefit-cost analyses based on water saved indicated that investing in rain-gun system to irrigate wheat and rice is a financially viable option for farmers.

Bed and furrow irrigation systems are feasible for rice production. Water use efficiency can be raised to at least 0.39 kg/m^3 of water, compared to values of 0.14 to 0.25 commonly obtained. A major portion of the water used in the production of rice in flooded basins, percolates down through the soil profile. By reducing application of water and keeping the water content of the soil at or below the field capacity, most of the time, deep percolation of the water can be reduced. Growing rice on beds between furrows, rather than in flooded basins enables the farmer to decrease the amount of water used. There was no indication that these reductions in soil water content and associated increases in soil water tension were reducing rice yield. The associated decrease in water content in the soil does not decrease rice yield if the furrows are refilled with water, on the day after free water left the furrows. This change in irrigation practice almost doubled the water productivity.

Studies should be conducted with less water applied, using tensiometers to monitor the soil water tensions and measuring yields, which would determine how much soil water tension rice can tolerate without reduction in yield. Water saved can be used to grow rice in additional area. Low cost compaction of the furrows, using a rolling wheel type compactor should be evaluated in terms of water use and uniformity of water application at the top and bottom ends of the furrows. Farmers, irrigation and extension department personnel should be alerted to the fact that rice can be grown on beds between irrigation furrows and use less than 100 cm of irrigation water, rather than the 150 cm which is presently allocated.

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