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EVALUATION OF THE EXISTING WATER PRODUCTIVITY IN THE LOWER BARI DOAB CANAL (LBDC) COMMAND – A CASE STUDY

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A study was conducted in the command area of the Lower Bari Doab Canal to evaluate the existing water productivity situation. Primary information was collected through a specially designed questionnaire from two secondary irrigation canals –Jandraka, located at the head reach of the doab (the area between two rivers) and 15-L, located at its tail. Six watercourses of Jandraka and seven of 15-L were selected for the study. At each watercourse, six farmers were interviewed, two each from the head, middle and tail. At Jandraka, the average yields for wheat, rice, sugarcane and spring maize were found to be 2,884, 2,606, 49,912 and 6,443 kg/ha, respectively, whereas the average water productivities were 0.73, 0.08, 2.01 and 0.54 kg/m^3, respectively. At 15-L, the average yield for wheat, cotton, sugarcane and spring maize were found to be 3,096, 2,056, 49,400 and 8,854 kg/ha, respectively, whereas the water productivities were 0.65, 0.33, 1.08 and 0.80 kg/m^3, respectively. Except for spring maize, the gap between the average yield and the potential yield at both distributaries was more than 50%, whereas the gap between the average and potential water productivity was more than 70%. Hence, there is a vast scope to increase the crops yield and the water productivity by adopting proper management of water and non-water inputs.
Keywords: Crop yield, irrigation scheduling, groundwater, crop zoning

INTRODUCTION

Irrigated agriculture is the largest user of freshwater resources in the world, withdrawing about 69% of the freshwater and approximately 56% of the world-irrigated area is in Asia (Cai and Rosegrant, 2003; Dawe, 2005). Freshwater however, is becoming increasingly scarce in the world, in general and in Asia in particular. In many Asian countries, the per capita water availability has decreased by 40 to 60% from 1955 to 1990 and is expected to decline further by 15-54% over the next 35 years (Gleick, 1993). The widening gap between water demand and supply requires more efforts to find productive use of this resource (Doogers *et al*., 2000).

The Indus Basin of Pakistan has the largest contiguous irrigation system in the world. The system comprises the Indus river and its major tributaries, 3 major storage reservoirs (Tarbela, Mangla and Chashma), 23 barrages/headworks, 12 link canals and 45 canal commands (Tarar, 1999). The average annual inflow from the Indus river system is about 163 x 10^9 m^3 with 84% of it occurring in the monsoon from June to August, while only 16% from September to May (GOP, 2001). Groundwater is another major source of water supplementing over 60% of the surface inflows. However, the water resources of Pakistan, both surface and groundwater, have become insufficient to meet growing demands of irrigated agriculture sector (GOP, 2001). The per capita water availability has reduced from 5600 m^3 to about 1200 m^3 from 1951 to 2003 and it will further reduce to about 1000 m^3 by the year 2010. The present overall shortfall of 11% will increase to 31% by the year 2025 (GOP, 2001).

The shortfall can be met either by constructing new storage reservoirs or by improving the efficiency of the existing water use practices. Both are equally important however, the construction of new storage reservoirs requires huge financial investment along with other constraints such as: limited availability of potential sites, population displacement, environmental, and socio-political issues. Therefore, proper management of existing water resources appears to be an immediate option. Under the present water scarcity conditions, it becomes even more important to use water judiciously and increase the water productivity (Bouman and Toung, 2001; Molden *et al*., 2001; Hussain *et al*., 2007). For proper management of the available water resources, the knowledge of the existing conditions is very important

(Lorite *et al*., 2004). The present study has, therefore, been conducted in the LBDC command of the Indus Basin to identify the problems and constraints affecting the water productivity.

MATERIALS ANS METHODS

***Description of the study area*:** The study area is located in the Bari Doab (the area between the rivers Ravi and Sutlej) and comprises the command of LBDC (Fig. 1). The area is a part of the vast stretch of alluvial deposits developed by the tributaries of the Indus river over centuries. The parent material is of mixed calcareous alluvium derived from a variety of rocks during the Pleistocene period. The general slope of the area is mild towards the south-west direction, while the average slope ranges from 1:4,000 to 1:10,000. The area, predominantly agricultural, lies at an elevation of 130 to 190 m above the mean sea level. The present sanctioned discharge of LBDC is 279 m^3/sec with a command area of over 0.74 million ha (NESPAK, 2005).

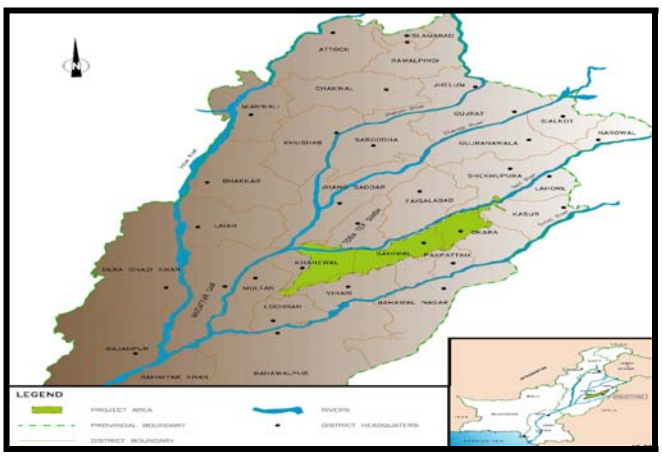

Fig.1. Location map of the study area

Texturally, the soils of the area are 70% medium (loam and silt loam), 20% moderately coarse (sandy loam and fine-sandy loam), 4% coarse (sandy and sandy loam) and 3% moderately fine (sandy-clay loam and silty-clay loam). The remaining 3% area is occupied by miscellaneous land types. The soils of the area are inherently low in organic matter and available phosphorus.

Temperature varies along the length of the doab, increasing towards the west. The mean maximum temperature ranges between 32-36ºC. The average annual rainfall also varies gradually from about 350 mm in the east to 200 mm in the west, most of which falls in the monsoon i.e. in the months of July and August (NESPAK, 2005). The winter precipitation sometimes occurs due to cyclonic storms from the south west. The winter season is mild to cold and extends from November to March. Wheat, rice, maize, sugarcane, and cotton are the predominant crops of the area (Table 1).

***Data collection*:** In the LBDC command, two secondary irrigation canals called distributaries were selected, i.e. Jandraka, located at the head of LBDC having a total command area of 9551 ha, and 15-L, located at its tail with a command area of 47368 ha. The number of watercourses at Jandraka and 15-L were 71 and 295, respectively with average farm size of 3.67 and 6.76 ha, respectively. At Jandraka, six watercourses (tertiary irrigation canals), two each at the head, middle and tail of the distributary were selected. Again on each watercourse, six farms, two each at head middle and tail reach of the watercourse were selected. Similarly, at 15-L, seven watercourses, two at the head, three at the middle and two at the tail end of the distributary were selected. The selection of the farms at each watercourse was made in the similar fashion as that mentioned above. Hence, a total of 78 farms were surveyed during the study. The information regarding field irrigation application practices at these farms were collected through structured interviews.

The water input was calculated based on the sanctioned discharge, number of irrigations and time of irrigation to a particular area. The rainfall and the potential evapotranspiration (ETo) data were collected from the nearest Meteorological Station at Lahore, located at about 90 km from Jandraka and Multan, located at about 70 km from 15-L (Fig. 2-3).

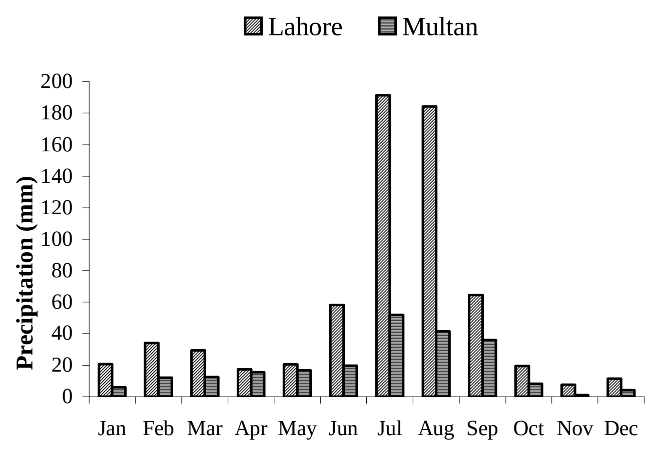

Fig.2. Mean monthly precipitation (mm)

Table 1. Salient features of the major crops grown in the LBDC

Name of crop	Botanical name	Rooting depth (cm)	Sowing month	Harvesting month	Potential water requirements for LBDC (mm)*	Average national yield (kg/ha)**	Potential yield (kg/ha) **	Potential water productivity (kg/m^3)***
Wheat	*Triticum aestivum*	90-150	October/ November	March/ April	278	2,710	6800	2.45
Cotton	*Gossypium Spp*	90-150	April/May	October/ November	777	714	4300	0.55
Sugarcane	*Saccharum officinarum*	60-150	September/ October	November/ December	1,604	49,200	121000	7.54
Maize	*Zea mays*	90-150	July	October	366	2,984	9200	2.51
Rice	*Oryza sativa Linn*	50-100	May/June	September/ October	710	2,116	5200	0.73

Source: OFWM (1997), *Kaleemullah *et al*. (2001), ** (G OP, 2006), *** Calculated from potential yield and potential water requirements

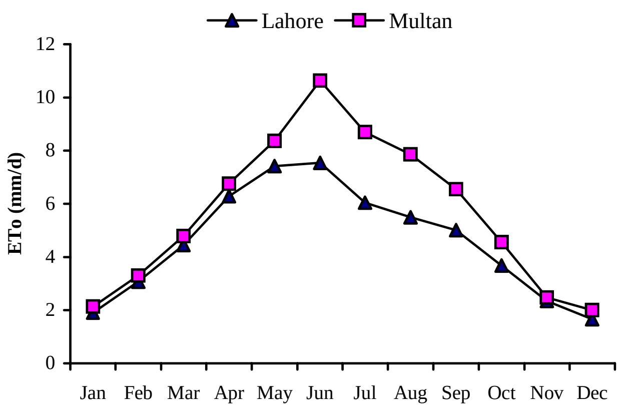

Fig.3. Potential evaportranspiration in the study area

RESULTS AND DISCUSSION

***Water application practices*:** The field data indicates that lack of knowledge about when to irrigate and how much water to apply is the main factor causing low crop water productivity. The farmers keep on applying water, even if the crops do not need water. Particularly, they apply tremendous amount of water to maize, sugarcane, and rice crops (Tables 2-5). There was however, a lot of variation in water application practices among the watercourses and between the distributaries. Moreover, there was no systematic trend found in water applications at head, middle and tails as it depends on the individual farmer and the water available to him. At 15-L distributary, the farmers applied 15% more water to wheat crop than at Jandraka distributary, mostly by pumping groundwater. However, such increased application of water could only increase the yield by 7%. The average water input to wheat crop at Jandraka distributary was 35% more than its potential water requirements (278 mm) and was about 44% more at 15-L. For maize on an average, the farmers of Jandraka distributary applied 38% more water and obtained 27% less yield than those of 15-L. The more application of water at Jandraka distributary may be due to more availability of water as it is located at the head of the LBDC. The average water input to maize crop was 70 and 52% higher than its potential water requirements at Jandraka and 15-L distributaries, respectively. The cotton is commonly grown at the 15-L due to its salt tolerance and of relatively high return value. The average water input to cotton (805 mm) was only 4% higher than its potential water requirements of 777 mm (Table 1). The average water input to rice was 2,936 mm (76% higher) against the potential crop water requirement of 710 mm and the average water input to sugarcane was also very high i.e. more than 4,000 mm (60% more) against its potential water requirements of 1,604 mm. Hukkeri and Sharma (1980) also reported that field water input to rice during crop growth might be more than 3,000 mm. It has been estimated that in rice fields, the seepage and percolation accounts for 50-80% of the total water input to the field, therefore, most of the water saving techniques concentrate on reduction of these flows (Sharma, 1989). The rice and sugarcane are not commonly grown at the command area of 15-L distributary, most probably due to shortage of canal water supplies and deep groundwater. The lack of farmer's knowledge about proper irrigation scheduling is therefore, a major constraint in efficient use of irrigation water.

***Crop yields*:** The crop yields depend upon a number of factors such as crop variety, quality of seed, seed rate, land preparation, sowing method, irrigation application (quantity, timing of irrigation, duration frequency, etc.) fertilizer applicator, etc. The crop yields are low at both the distributaries (Table 3 and 5). The wheat and sugarcane yields were not statistically different at Jandraka and 15-L distributaries. The average wheat yield was 6-12% higher than the national average yield and was 54-58% lower than its potential yield. The average yield of cotton seed was 65% higher than the national average and 52% less than the potential yield. However, the maize yield was significantly higher (at 5% significance level) at 15-L than at Jandraka distributary. The average yield of maize at both distributaries was 54-66% higher than national average and was 4-30% less than the potential yield. Hybrid varieties of maize are mostly grown in the area and show high potential of maize yield in the country. These varieties under optimum conditions (temperature, soil, fertilizer and water), can yield up to a maximum of 9,880 kg/ha (OFWM, 1997), about three times more than the synthetic maize varieties. Therefore, the quality of seed is very important to get higher yields and productivity. The sugarcane yield was almost the same as the national average and was 59% lower than its potential. The rice yield was 19% higher than the national average yield and was 50% less than the potential yield. Therefore, there is considerable scope to increase the crops yield.

***Water productivity*:** Water productivity is defined as the physical or economic out put per unit of water application (Cai and Rosegrant, 2003). Due to relatively low yields and high application of water, the

Table 2. Number and time of irrigations applied to some major crops at Jandraka distributary

Watercourse No.	Sanctioned discharge (lps)	Location	Number of irrigations				Time of irrigations (hrs/ha)			
			Wheat	Rice	Sugarcane	Maize (spring)	Wheat	Rice	Sugarcane	Maize (spring)
11,290 L	29	Head	4.4±0.5	36.5±4.9	-	21.5±6.6	8.6±2.3	5.8±1.9	-	5.9±1.1
28,500 R	25	Head	4.3±0.3	32.7±2.5	18.0±0	19.5±2.1	7.4±2.1	8.6±1.7	13.0±2.6	5.2±0.4
56,000 R	28	Middle	3.6±0.5	30.0±7.1	26.5±12.0	18.5±13.4	8.6±0.6	9.9±2.5	7.4±0.9	6.8±0.9
634,300 L	53	Middle	4.5±0.5	35.0±5.0	21.5±2.1	14.5±2.1	6.1±3.2	9.6±3.5	8.6±4.5	5.2±0.4
87,473 L2	29	Tail	4.0±0.6	33.3±1.5	18.0±2.8	13.7±2.5	8.4±1.0	10.7±5.1	10.2±3.1	6.6±1.6
35,730 TF	42	Tail	4.6±0.4	34.0±2.8	27.5±5.0	17.5±2.4	9.9±1.9	8.2±0.7	12.0±3.2	5.5±0.5
Average	32		4.2±0.4	33.6±2.2	22.3±4.5	17.5±3.0	8.2±1.3	8.8±1.7	10.2±2.3	5.9±0.7

Table 3. Yield and total water applied to some major crops at Jandraka distributary

Watercourse No.	Location	Yield (kg/ha)				Water applied (m^3/ha)			
		Wheat	Rice	Sugarcane	Maize (spring)	Wheat	Rice	Sugarcane	Maize (spring)
11,290 L	Head	2,964±638	3,829±1218	-	6,093±3280	3,950	22,100	-	13,242
28,500 R	Head	2,519±831	2,186±375	39,520±0	5,681±1048	2,864	25,308	21,058	9,125
56,000 R	Middle	2,523±1034	2,579±1186	88,920±13,972	6,299±4366	3,121	29,935	19,765	12,680
634,300 L	Middle	3,335±957	2,890±1334	51,047±24,368	6,422±3493	5,237	64,104	35,276	14,385
87,473 L2	Tail	3,290±663	2,223±654	25,935±1,747	6,093±1588	3,508	37,196	19,166	9,439
35,730 TF	Tail	2,675±1064	1,927±324	44,138±21,113	8,069±755	6,885	42,151	49,892	14,552
Average		2,884±369	2,606±687	49,912±23,660	6,443±836	4,261 ±1,533	36,799 ±15,294	29,032 ±13,425	12,237 ±2,395

Table 4. Number and time of irrigations applied to some major crops at 15 -L distributary

Watercourse No.	Sanctioned discharge (lps)	Location	Number of irrigations				Time of irrigations (hrs/ha)			
			Wheat	Cotton	Sugar-cane	Maize (spring)	Wheat	Cotton	Sugar-cane	Maize (spring)
4,300 L	62	Head	4.6±0.5	5.4±1.0	-	13.7±1.5	3.7±0	4.1±0.5	-	5.0±1.3
56,765 L	34	Head	5.0±0.7	5.3±1.2	-	13.0±1.0	5.9±1.3	6.8±2.6	-	6.8±2.6
104,950 L	38	Middle	6.5±0	6.2±0.6	36±0	-	6.2±0	7.4±1.2	9.3±0	-
78,750 L	52	Middle	6.2±0.3	8.0±0.7	-	13.7±1.5	5.5±0.7	6.4±0.2		4.1±0.7
158,640 L	39*	Tail	5.0±0.4	8.3±2.4	-	-	6.5±1.0	4.9±2.9	-	-
200,300 TL	34	Tail	6.9±0.5	7.8±1.2	-	14.0±1.0	5.5±0.6	5.8±2.4	-	5.4±0.7
40,311 TR	81	Tail	5.4±0.5	7.2±1.3	-	-	4.0±1.2	9.5±1.6	-	-
Average	49		5.7±0.9	6.9±1.2	36±0	13.6±0.4	5.3±1.1	6.4±1.8	9.3±0	5.3±1.1

* including tubewell discharge

Table 5. Yield and total water applied to some major crops at 15-L distributary

Watercourse No.	Location	Yield (kg/ha) Wheat	Cotton	Sugarcane	Maize (spring)	Water applied (m^3/ha) Wheat	Cotton	Sugarcane	Maize (spring)
4,300 L	Head	3,643±468	2,482±514	-	8,726±287	3,799	4,941	-	15,288
56,765 L	Head	2,829±524	2,322±210	-	8,891±496	3,611	4,411	-	10,819
104,950 L	Middle	2,569±300	2,270±276	49,400±0	-	5,513	6,276	45,797	-
78,750 L	Middle	3,540±755	1,951±664	-	9,139±349	6,383	9,584	-	10,514
158,640 L	Tail	3,359±636	2,038±281	-	-	4,563	5,710	-	-
200,300 TL	Tail	2,519±466	1,243±556	-	8,660±250	4,645	5,537	-	9,253
40,311 TR	Tail	3,211±447	2,085±678	-	-	6,298	19,944	-	
Average		3,096±458	2,056±402	4,9400±0	8,854±213	4,973±1,121	8,057±5,502	45,797±0	7,646±6264

Table 6. Water productivity (kg/m^3) of some major crops at the two distributaries

Jandraka Watercourse No.	Location	Wheat	Rice	S. cane	Maize (spring)	15-L Watercourse No.	Location	Wheat	Cotton	S. cane	Maize (spring)
11,290 L	Head	0.75	0.17	-	0.46	4,300 L	Head	0.96	0.50		0.57
28,500 R	Head	0.88	0.09	1.88	0.62	56,765 L	Head	0.78	0.53		0.82
56,000 R	Middle	0.81	0.09	4.50	0.50	104,950 L	Middle	0.47	0.36	1.08	
63,4300 L	Middle	0.64	0.05	1.45	0.45	78,750 L	Middle	0.55	0.20		0.87
87,473 L2	Tail	0.94	0.06	1.35	0.65	15,8640 L	Tail	0.74	0.36		
35,730 TF	Tail	0.39	0.05	0.88	0.55	200,300 TL	Tail	0.54	0.22		0.94
Average		0.73±0.2	0.08±0.05	2.01±1.4	0.54±0.08	40,311 TR	Tail	0.51	0.10		
						Average		0.65±0.18	0.33±0.16	1.08±0	0.80±0.16

Table 7. Yield and water productivity gap in the LBDC

Major crops	Area (ha)	Average yield (kg/ha)	Yield gap (%)	Present LBDC yield (million ton)	Potential LBDC yield (million ton)	Average water productivity (kg/m^3)	Water productivity gap (%)
Wheat	336,642	2,990	56	1.01	2.29	0.69	72
Cotton	193,194	2,056	52	0.40	0.83	0.33	40
Sugarcane	30,770	49,656	59	1.53	3.72	1.55	80
Spring maize	110,623	76,49	17	0.85	1.02	0.67	73
Rice	65,239	2,606	50	0.17	0.34	0.08	89

water productivity of all crops in the command area was very low (Table 6). The water productivity of wheat and sugarcane was not significantly different at both the distributaries. However, maize water productivity was significantly different (at 5% significance level), at both the distributaries. The water productivity of wheat, cotton, and spring maize were about 70, 40 and 68-79% less than their potentials. In the irrigated farmland of China, the water productivity of winter wheat and spring maize were found to be 1.32 and 1.70 kg/m^3, respectively (Duan and Zhang, 2000). The water productivity of sugarcane was 73-86% less than its potential. Singh *et al*. (2007) obtained mean water productivity of 7.1 kg/m^3 and 6.3 kg/m^3 for plant and rotten sugarcane crops, respectively in a field trial in the northern India. The average water productivity for rice, however, was particularly very low and it was about 90% lower than its potential. The low water productivity of rice was due to lack of knowledge about irrigation scheduling, soil texture and poor water management practices. Jehangir *et al*. (2007) in a field study, found water productivity of rice and wheat as 0.23 and 1.48 kg/m^3, respectively. Since rice is grown in standing water resulting in more evaporation than other crops, therefore, its water productivity is relatively lower than the other crops (Dawe, 2005). Passioura (2006) reported upper limit of water productivity of well-managed, disease free, and water limited cereal crops as 2.0 kg/m^3. Therefore, the water productivity of these crops can be increased substantially by improving the water management practices.

Table 7 shows the average yield and water productivity at the two distributaries as well as the yield and the water productivity gap. Except for spring maize, the gap between the average yield at the two distributaries and the potential yield was more than 50%, and the gap between the average water productivity and potential water productivity was more than 70%. Therefore, with the proper management of water and non-water inputs, the existing crop yields can be doubled with the same quantity of water. This would provide food security in the country and also in the region.

Causes of low water productivity: Based on the field survey, review of the secondary data and discussions with the multidisciplinary professionals, the following are the major causes of the low water productivity:

***Lack of crop zoning*:** Due to lack of crop zoning, high-water demanding crops such as sugarcane and rice are being grown without considering the soil type, water availability and climate. The high water-demanding crops should therefore, be restricted to specific zones of high rainfall and water availability. Particularly, rice should only be grown on heavy-textured soils and in areas of high rainfall. Moreover, the areas under rice and sugarcane cultivation need to be rationalized. Short duration, low-water demanding and high-value crops should be introduced in the water-scared areas.

***Cost of water*:** The canal water is being supplied at a flat rate of $5.56/ha/year (1 US$ = Rs. 60). Fifty percent rebate on water charges is provided to the farmers of the tail reach of the distributary. However, charges incurred on groundwater pumping are about $2.27/hr for a diesel engine operated well and about $5.83/hr for a tractor operated well, respectively. As almost 7 hrs are required to irrigate one hectare, therefore, the cost of pumped water with a diesel engine becomes $16/ha, and that for a tractor operated well $40/ha. It shows a huge difference in cost of canal and tubewell water and low cost of surface water is therefore, a main cause of low water productivity. The cost of water has a direct impact on net return and the increasing cost of diesel is becoming a big issue.

***Small and fragmented land holdings*:** Small land holding is a major issue affecting the water availability. Average farm size was found to be 3.67 ha and 6.76 ha at Jandraka and 15-L, respectively. As the small farmers are relatively poor and illiterate therefore, they do not have resources for proper inputs. They normally grow wheat and fodder, the food for themselves and their animals.

Fragmented land is another issue (Table 8). A number of farmers have fragmented land holdings, even on a single watercourse. For example, Mr. Sarwar, Village No. 30 GD, owns 10.5 ha of land at watercourse No. 30,730 TF, whereas his 2.8, 3.2, 1.0, 1.4, and 2 ha are located at Square No. 32/34, 41, 45, 48, and 51, respectively. This creates problems in managing land for irrigation, ploughing, sowing and harvesting etc. particularly, irrigation to such lands is a big issue because a farmer has to irrigate his field at different places, and at different times of the day.

***Traditional irrigation systems*:** Despite enormous losses in the irrigation system and reduced surface water supplies, the farmers are still using highly inefficient and obsolete methods of irrigation. Moreover, the fields are not precisely leveled. Basin irrigation with broad casting is the predominant method of irrigation. Sugarcane is normally grown in furrows and later on the beds of the furrows are ploughed to remove the weeds. The furrows are stretched due to ploughing. At the end of a year, there are hardly any furrows left. Cotton is mostly sown by drilling. Hoeing is done after each irrigation resulting in loss of water, requiring more time of irrigation during the subsequent irrigation. Hybrid maize is a dominant Rabi crop and is grown on furrow beds and ridges. The beds are quite large with wide and deep furrows like channels. The beds vary from 55 to 80 cm and furrows from 65-70 cm. The depth of furrows varies from 20-24 cm and the plant to plant distance from 15 to 25 cm.

***Improper irrigation scheduling*:** Proper irrigation scheduling helps when to irrigate and how much water to apply in each irrigation event. In Pakistan however, farmers normally over irrigate their fields due to (i) lack of proper knowledge about irrigation scheduling, and (ii) with the intention to get more yield, whereas more water applications result in low water productivity. Moreover, over irrigation leaches the nutrients out of the root zone and decreases the crop yield and the net income (Ashraf *et al*., 2001). Over irrigation also contributes to waterlogging and groundwater pollution.

CONCLUSIONS

In the Indus basin of Pakistan, the crops yields and water productivity are far less than their potentials. At Jandraka distributary, the average yields of wheat, rice, sugarcane, and spring maize were 2,884, 2,606, 49,912 and 6,443 kg/ha, respectively, whereas their average water productivities were 0.73, 0.08, 2.01 and 0.54 kg/m^3, respectively. At 15-L distributary, the average yields of wheat, cotton, sugarcane and spring maize were 3,096, 2,056, 49,400 and 8,854 kg/ha, respectively, and their water productivities were 0.65, 0.33, 1.08 and 0.80 kg/m^3, respectively. Except spring maize, the yield gap for the major crops was more than 50%. The average water input to wheat, cotton, rice, sugarcane and maize (spring) was 35-44, 3.5, 76, 60 and 52-70% more than their potential water requirements, respectively. Except for cotton, the water productivity gap was more than 70%. Therefore, there is a vast scope to increase the crops yield and the water productivity in the Indus basin.

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