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Evaluation of the Impact of Water Management Technologies on Water Savings in the Lower Chenab Canal Command Area, Indus River Basin

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Abstract: Traditional irrigation practices, low crop productivity, unlevelled fields, water losses taking place during conveyance and application phases, as well as low irrigation efficiencies are the main problems of the common farmers in Pakistan. These problems are more noticeable in the command area of Lower Chenab Canal (LCC), which is the main portion of the Indus Basin Project in Pakistan. To overcome these problems, different water management technologies such as precision land levelling (PLL), bed planting, drip irrigation systems, and watercourse improvement were introduced to farmers to increase water savings and crop yields in the area of five distributaries—Khurrianwala, Shahkot, Mungi, Khikhi, Killianwala and Dijkot—during the cropping seasons of 2008 to 2015. The use of drip irrigation resulted in savings of water and fertilizer and increased the crop yields by 30–40%. Three watercourses, one on each site of 1200 m in length, were lined, which resulted in improved conveyance efficiency of 15–20%. If wheat, rice and cotton in the command area of LCC are sown on precisely levelled fields and on beds, then about 2768.1 million m^3 and 3699.3 million m^3 of irrigation water can be saved. These results show the potential of water-efficient technologies for saving water as well as increasing crop yields.

Keywords: precision land levelling; bed planting; wheat; cotton and rice; irrigation water saving

1. Introduction

Pakistan is one of the most water-stressed nations, with a per capita water availability of less than 1000 m^3. The current proportion of agriculture towards the GDP of the country is 21%. Irrigated agriculture in the Indus Basin is the major user of water in Pakistan. About 80% of the cultivated area of Pakistan is under irrigation and about 90% of all food is produced from this area [1]. The population growth rate is very high, particularly in developing countries like Pakistan, which has placed the water supply under stress. The food requirements of this ever-increasing population demands higher food production, which will be possible through water-efficient technologies as water is the basic ingredient for irrigated agriculture. According to [2], to fulfil the food requirement for the future population, it is assessed that water diversions for irrigation should be increased up to 14–17% and food production from irrigated agriculture should be increased up to 40%.

Agriculture in Pakistan is changing rapidly and demanding more water. Irrigated agriculture is a major user of surface water and groundwater resources. Pakistan is a water-stressed country [3] and its available water resources are continuously decreasing. Water for irrigated agriculture in Pakistan is under threat because the farmers are mostly using flood irrigation to irrigate their crops to fulfil the food requirements of the ever-increasing population and wasting a huge quantity of irrigation water. Mismanagement of irrigation water is the main reason of low agricultural production. There are social as well as technical problems associated with the management of irrigation water in Pakistan. Most of the farmers are still using flood irrigation, which wastes about 50–60% of applied irrigation water. Therefore, water-efficient irrigation technologies are required to improve agricultural productivity by preserving water resources [4,5].

Water-efficient technologies such as precision land levelling, bed planting, and drip irrigation system have been introduced in many parts of the world. There is need to adopt these technologies for management and the conservation of the irrigation water in Pakistan.

According to [6], water productivity at field level can be improved by resource conservation technique (e.g., laser land levelling). According to [7], there is 2 to 3 percent increase in cultivable area in Punjab and Sind provinces of Pakistan by precision land levelling. Land levelling of cultivated area which is an imperative process in land preparation, facilitates proficient utilization of threatened water resources by eradication of needless high and low areas in field [8]. According to [9], 30% water is lost in fields due to unevenness and poor farm design. Review of existing literature on land levelling showed encouraging influence on water saving and crop productivity [10–13]. Water distribution, germination and yield of crop can be improved by effective application of precision land levelling [14]. Application efficiency of irrigation water can be improved through precision land levelling which enables even distribution of water and resulted in better crop production [15]. According to [16], about 25 to 30% of applied irrigation water can be saved through laser land levelling without affecting crop yield. According to [17], farmers can enhance their crop production by efficiently using scarce land and water resources with precision land levelling, in areas where farmers are bound to use unfit groundwater with canal water.

Bed planting, which is a proven water-efficient technique, has been tested for different crops and has given better results on cotton, wheat, maize etc. More than three million acres of cotton was under bed planting in 2003 [18]. Bed planting has shown a considerable saving of water as compared to conventional planting method and eliminating the formation of crust on the soil surface [19]. Furrow irrigation under raised bed technology saved more than 30% of irrigation water against traditional flood irrigation [20]. During the 1990s, raised bed technology was introduced for wheat in the rice-wheat areas of the Indo-Gangetic Plain following the success story of maize-wheat on permanent raised beds in Mexico [21]. The permanent raised bed technology is mainly associated with problems of water management; moreover, it diminishes the adverse influence of excess irrigation water on crop yield and/or crop irrigation in arid or semiarid regions. Many advantages of growing wheat on beds including water savings, higher yield, less lodging, better placement of fertilizer, reduced seed rate, opportunities for intercropping, and mechanical weeding [22–26].

Watercourses are used to convey water from canals to a farmer's field. A large amount of water is lost in these watercourses because of high conveyance losses during its way to the farms level. Seepage, percolation, cracking, and damaging of the earthen watercourses are the main causes of poor conveyance efficiency [27]. Water losses in the improved/lined and unimproved/unlined watercourses ranged from 35–52% and 64–68%, respectively [28]. According to [29], farmers had more discharge at the inlet of their fields when conveyance losses reduced which had a significant effect on water distribution.

According to the study conducted by [30] in a water-scarce area of India, using high efficiency irrigation systems can result in a considerable amount of water savings. The study conducted by [31] on cotton seed under different irrigation methods showed that drip irrigation has significantly increased the yield of seed cotton over furrow irrigation. Initial investment for drip irrigation system is high but at the same time this system saves water and fertilizer and minimum labor and no investment is involved in land levelling [32]. According to [33], evaporation and percolation of irrigation water is reduced while crop development is improved by using drip irrigation system in which water is frequently applied to an area near the roots of plants. As compared to bed-furrow and sprinkler irrigation, water use efficiency and crop production is improved with drip irrigation system [34–37]. According to [38–40], use of drip irrigation system with mulching in recent years has resulted in better application of irrigation water along with fertilizers and pesticides.

To overcome the issues and problems of water insufficiency in the farmer field, the Government of Punjab through its Irrigation and Power Department, executed a mega project to improve the irrigation infrastructure and to introduce institutional reforms in irrigation and drainage subsectors in the Lower Chenab Canal (LCC) area of the Indus Basin. Along with these off-farm measures, it was also decided to incorporate an on-farm research and development component to effectively address the challenges being confronted regarding water management at farm level to achieve the potential crop yields on sustainable basis. The on-farm research and development project was executed on six distributaries (Khurrianwala, Shahkot, Dijkot, Killianwala, Mungi, and Khikhi) in the command area of LCC to introduce the water management techniques to local farmers.

The main thrust of the project was to address the issues of water management at the on-farm level by introducing water management technologies such as precision land levelling, bed planting, watercourse improvement and high efficiency irrigation system.

The objective of this study was to investigate the impact of these technologies on water savings and crop yields in the study area and to estimate the water savings in the whole command area of Lower Chenab Canal (LCC) using remote sensing (RS) and geographic information system (GIS).

2. Materials and Methods

2.1. Study Area

The current study was carried out in the command area of the Lower Chenab Canal (LCC), which is located in Rachna Doab, an area between two rivers—the Ravi and Chenab Rivers—which are tributaries of the Indus River. Rachna Doab lies in the heart of Indus Basin in Pakistan. It constitutes the single largest irrigation system in Punjab, Pakistan, with a gross command area of about 1.5 million hectares and culturable command area of 1.24 million hectares. It is one of the oldest and most developed cultivated areas in Punjab, Pakistan. The climate of the area has large seasonal variations in temperature and rainfall. The summer season is hot and lengthy, which starts in April and ends in September, with an average temperature of 35 °C, ranging from 21 °C to 49 °C. The winter season is short (December to February) and temperature varying from 5 °C to 27 °C with average temperature of 16 °C and sometimes minimum temperature falls below 0 °C during nights. The average annual rainfall in this area is around 500 mm with about 75% of annual rainfall during the monsoon season, which spans from June to September. The main crops in the area are rice, wheat, cotton, maize, sugarcane, vegetables, and fodder which are grown in two growing seasons i.e., Rabi (winter) and Kharif (summer).

The Lower Chenab Canal takes its water from River Chenab at the Khanki Head works. The main branches of LCC are the Upper Gugera (UG) Branch, the Lower Gugera (LG) Branch, the Burala Branch, the Rakh Branch, and the Jhang Branch. The project was implemented on six distributaries of Lower Chenab Canal (Figure 1) from 2008–2015. The whole area of the project was suffering from severe shortage of irrigation water supplies with marginal to low quality groundwater before start of the project.

The main thrust of the project was to introduce the following water-efficient techniques to local farmers so that more crop yield per drop of water can be achieved.

- Precision land levelling
- Bed planting
- Watercourse improvement
- High efficiency irrigation system

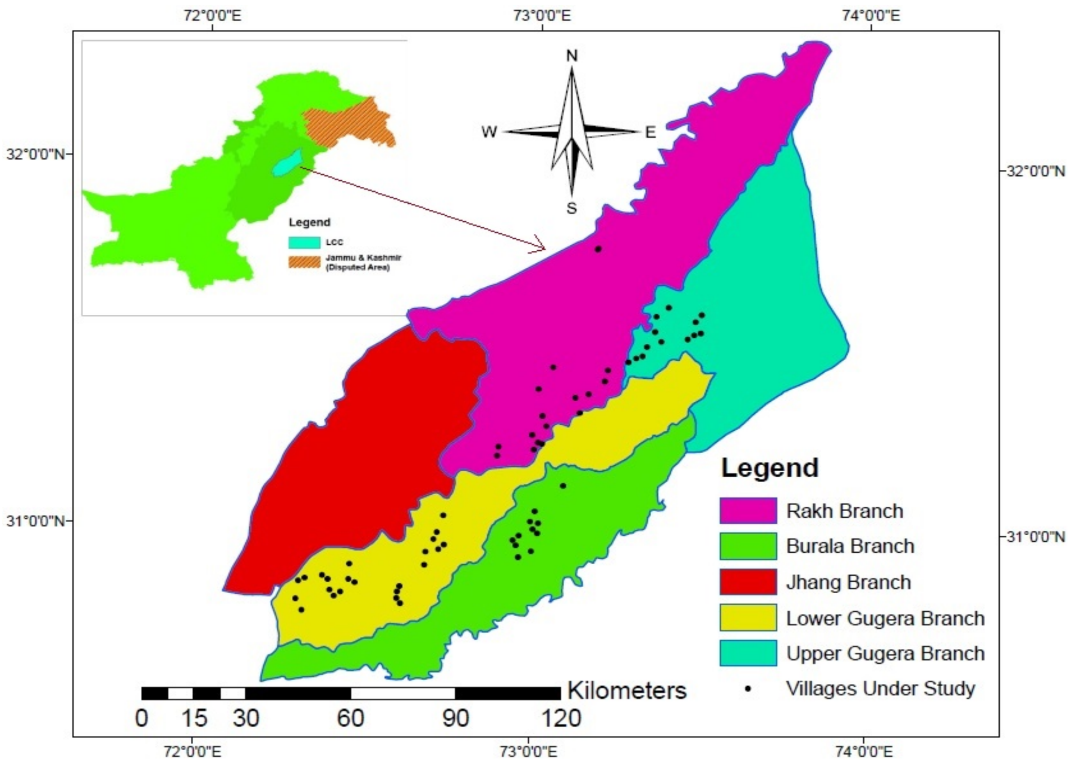

Figure 1. Location of study area.

2.2. *Precision Land Levelling (PLL)*

Precision land levelling is levelling the field within certain degree of desired slope using a laser-guided beam throughout the field. It reduces evaporation and percolation losses from the field by enabling faster irrigation times and eliminating depressions and pounding of water in depressions. PLL helps to save costly farm inputs such as water and fertilizers, improve crop stand and increase crop yield as much as 15 percent. PLL has huge scope in Pakistan as most of the farmer's field area is still irrigated by surface irrigation methods like flood irrigation, basin irrigation, border irrigation, and furrow irrigation. Application efficiency of these irrigation methods is between 30–50%. PLL is essential for these irrigation methods to escalate their application efficiency to 60–80% along with increase in crop yield.

Precision land levelling was one of the main water conservation technology and activities of the on-farm research & development component project. PLL was performed free of cost at the farmer's field according to their land holdings. In the distributaries selected under the project, PLL was done on 2631 hectares. Water savings and increase in crop yield from field area under PLL were calculated by comparison against the field area without PLL. In every village, some fields were intentionally left where no PLL was done. During each irrigation, the irrigation time was noted and flumes were used to measure the volume of water applied to fields with and without PLL. Water saving was calculated from the total volume of irrigation water applied to fields with and without PLL. Crop yields were estimated by taking crop samples before harvesting from an area of 1 m^2 from both the fields i.e., with and without PLL.

2.3. Bed Planting (BP)

Bed planting is another water saving technique, which is very beneficial on precisely levelled fields. Under the project, bed planting was demonstrated at various farmers' fields, which were brought under precision land levelling. Before start of the project, the farmers of the area were not aware of the benefits of the bed planting. All efforts were made by project team to convince the farmers and to introduce bed planting using bed-planting machine. The bed-planting machine prepares two beds and three furrows in one pass that plants four rows for wheat or two rows for cotton and maize on each bed. The bed width is 90 cm whereas the furrow is 30 cm wide and 25.4 cm deep. There is 50% savings of irrigation water and 25% increase in crop productivity under bed planting. All fields under PLL were brought under bed planting. Water savings and increase in crop yield under bed planting were calculated by comparison against conventional planting. In each village, some fields were intentionally left without bed planting and the crop was sown using conventional methods to compare with the crop under bed planting. The geometry of bed planting for different crops is shown in Figure 2a,b.

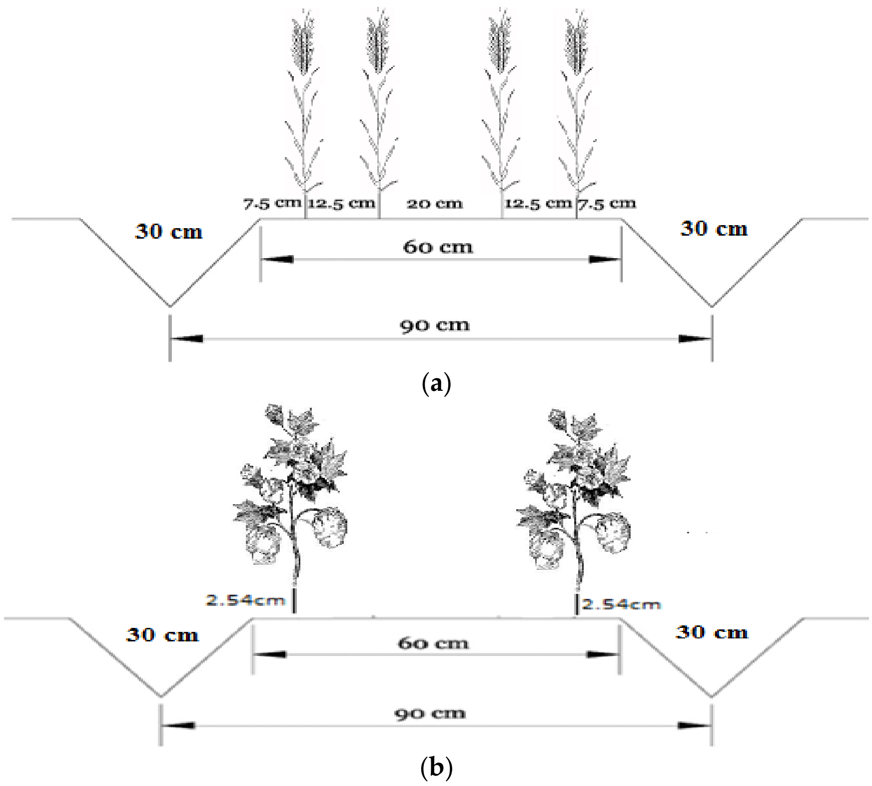

Figure 2. (**a**) Geometry of wheat lines on bed. (**b**) Geometry of cotton and maize on bed.

2.4. Watercourse Improvement

In Pakistan, conveyance efficiency of the tertiary level of the irrigation system, which is watercourse, is very low and a large amount of water is lost in watercourses during its route up to the farmer's field. Watercourse lining and earthen improvements ensure about 30–45% of irrigation water savings. The total length of 4496 m were lined on six watercourses, one on each selected distributary under the project.

2.5. Drip Irrigation System

Drip irrigation provides frequent and slow application of water to the soils through mechanical devices called emitters located at selected points along the water delivery lines i.e., lateral. In drip irrigation, the driving force of water movement is provided by an external energy source. The water is delivered through a closed-pipe system. This differs from surface irrigation technologies (flood, border, furrow and basin irrigation) in which the driving force of water flow is gravity, and the delivery and application structures (canals, ditches, furrows, small ponds and basins) are open to the atmosphere. The emitters in the drip irrigation system moistens the adjacent surface area. The percentage of the wetted surface area and soil volume depends on soil properties, initial moisture level of the soil, the applied water volume, and emitter flow rate. The drip irrigation system was one of the major activities of the project, which was installed at the project distributaries (5 acres at each distributary). Due to high initial cost of the drip irrigation system, only one drip irrigation system for row crops at each distributary of project was installed for research purposes and for demonstration to local farmers.

2.6. Crop Classification in LCC Command Area

Spatial information on different crops grown in the command area of LCC was collected from the MODIS satellite at a resolution of 250 m. Satellite images (MODIS MOD13Q1) of the LCC command area were obtained during Rabi (2007 & 2016) and Kharif (2007 & 2016) i.e., before and after the study period (Table 1). During Rabi and Kharif seasons in 2007 and 2016, extensive field visits were conducted in the villages under study to get the information about the crops grown. The coordinates recorded with GPS device in the fields in different villages of the study area were used to develop signature files of different crops grown in the study area. The satellite images obtained before and after the study period for Rabi and Kharif seasons were classified by using the developed signatures files of different crops of the study area. Image classification was carried out by supervised classification using maximum likelihood classifier in ERDAS 2014 and image processing software (ArcGIS) was used to estimate the area under different crops in LCC command.

Table 1. Acquisition dates of satellite images (MODIS MOD13Q1).

Sr. No.	Date
1	2 February 2007
2	14 September 2007
3	2 February 2016
4	13 September 2016

3. Results

3.1. Land Cover/Land Use Change

The current study was conducted on six distributaries of branches of Lower Chenab Canal (LCC). Shahkot distributary and Khurrianwala distributary of Upper Gugera (UG) Branch, Mungi distributary and Khikhi distributary of Lower Gugera (LG) Branch, Killiwanwala distributary of Burala Branch and Dijkot distributary of Rakh Branch (Figure 1).

The classified LULC maps of LCC command area for Rabi 2007 & 2016 (before and after study period) and Kharif 2007 & 2016 (before and after study period) are shown in Figures 3 and 4.

For Rabi season, wheat was the key crop cultivated on a massive area of all five branches of LCC, including 161,874 hectares on the Lower Gugera Branch and 283,280 hectares on the Rakh Branch with a total area of 493,716 hectares, while sugarcane was the second largest crop with total area of 117,359 hectares followed by other crops (vegetables, orchards, and forest) and fodder (Figure 5). Sugarcane was mainly cultivated in the upper parts of the Lower Gugera Branch with some disperse areas in the Rakh Branch, the Burala Branch, the Jhang Branch and the Upper Gugera Branch. For the Kharif season, other crops (mainly vegetables) were the main crops cultivated on all the branches followed by sugarcane, cotton, rice and fodder (Figure 6). The major area under cultivation of cotton was in the Burala Branch and the Lower Gugera Branch, with some scattered areas in the Jhang Branch and the Upper Gugera Branch. The acreage under rice, cotton, and sugarcane was 238,765 hectares, 80,937 hectares and 214,483 hectares respectively.

After the introduction of water-efficient technologies such as precision land levelling, bed planting and drip irrigation system in the villages under study, of six distributaries of LCC, the cultivation of wheat, cotton and vegetables have increased in the whole command of LCC (Figures 5 and 6).

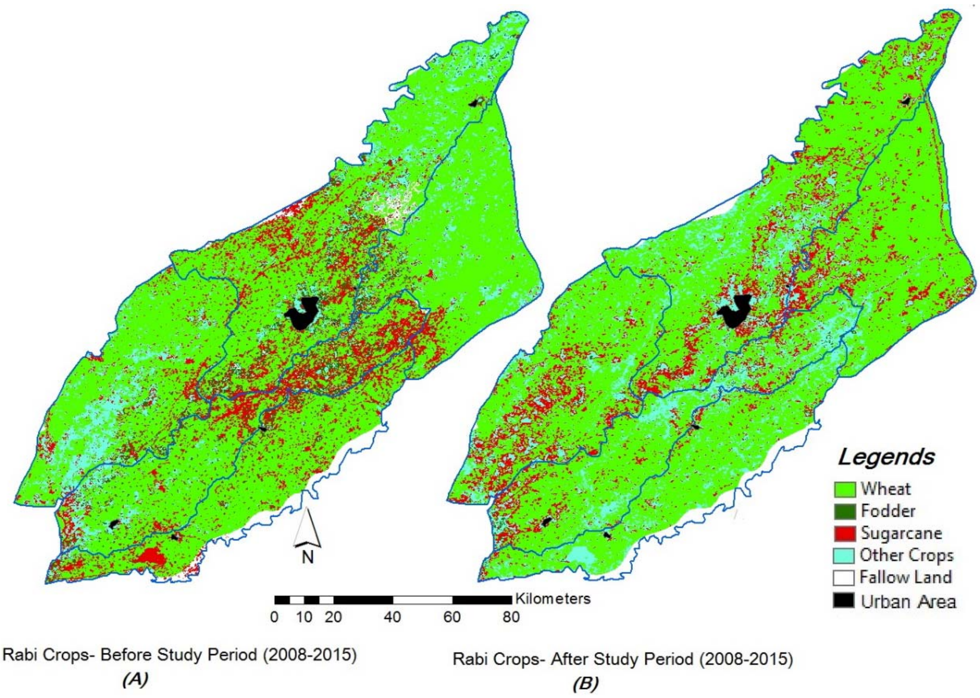

Figure 3. Land use change in the Rabi Crops (**A**—before study period, **B**—after study period).

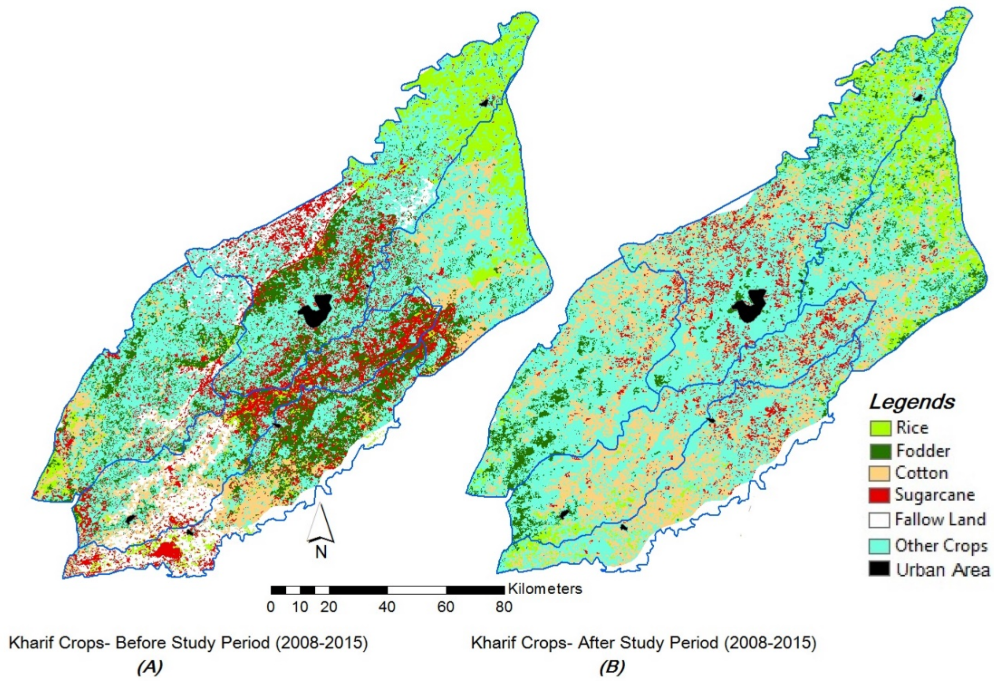

Figure 4. Land use change in the Kharif Crops (**A**—before study period, **B**—after study period).

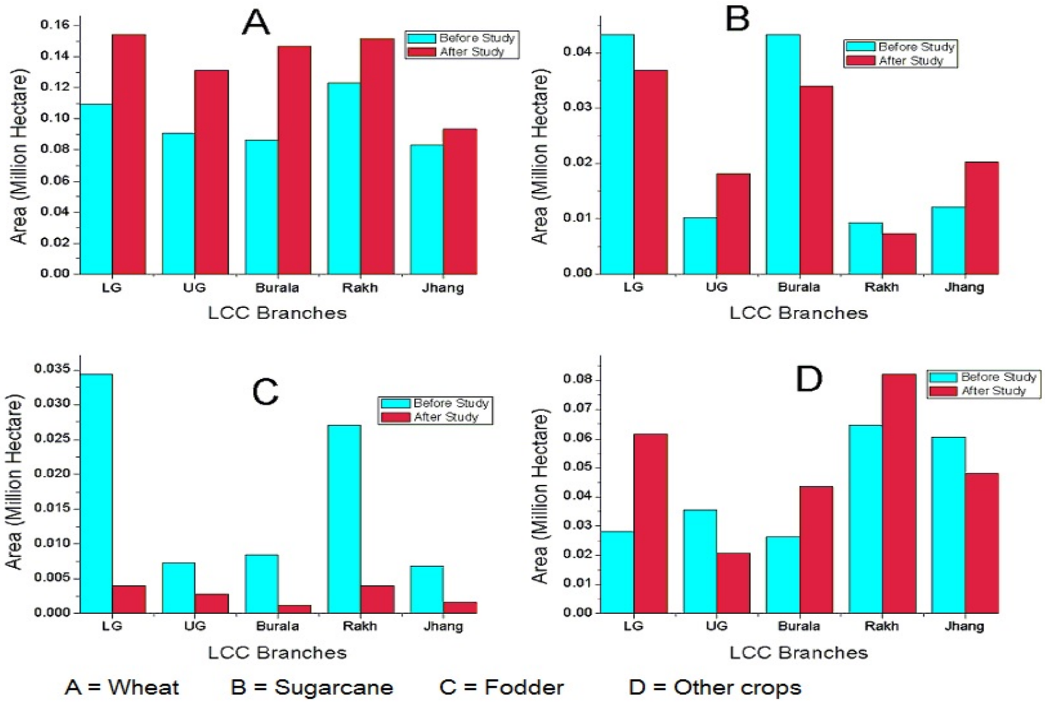

Figure 5. Rabi crops acreage on branches of LCC.

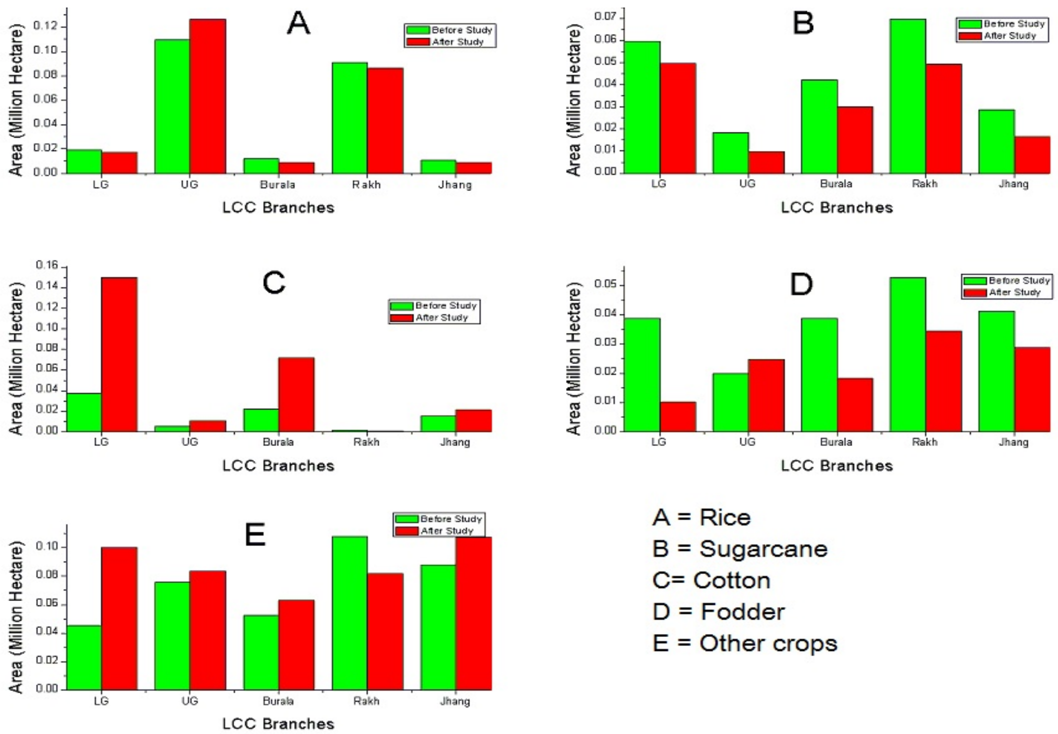

Figure 6. Kharif crops acreage on branches of LCC.

3.2. Precision Land Levelling (PLL)

Precision land levelling was done on an area of 2631 hectares at six distributaries selected under the project. Water savings and increase in crop yields for different crops i.e., wheat, cotton and rice from area under precision land levelling (PLL) were calculated by comparison against the area without precision land levelling. Wheat was grown at all distributaries whereas cotton was grown at Mungi, Killianwala and Khikhi distributaries. Rice was grown on only Khurrianwala and Shahkot distributaries. Comparison of yield for wheat, cotton and rice under PLL and without PLL is shown in Figure 7, whereas average water saving from precision land levelling of wheat, cotton and rice is given in Tables 2–4 respectively.

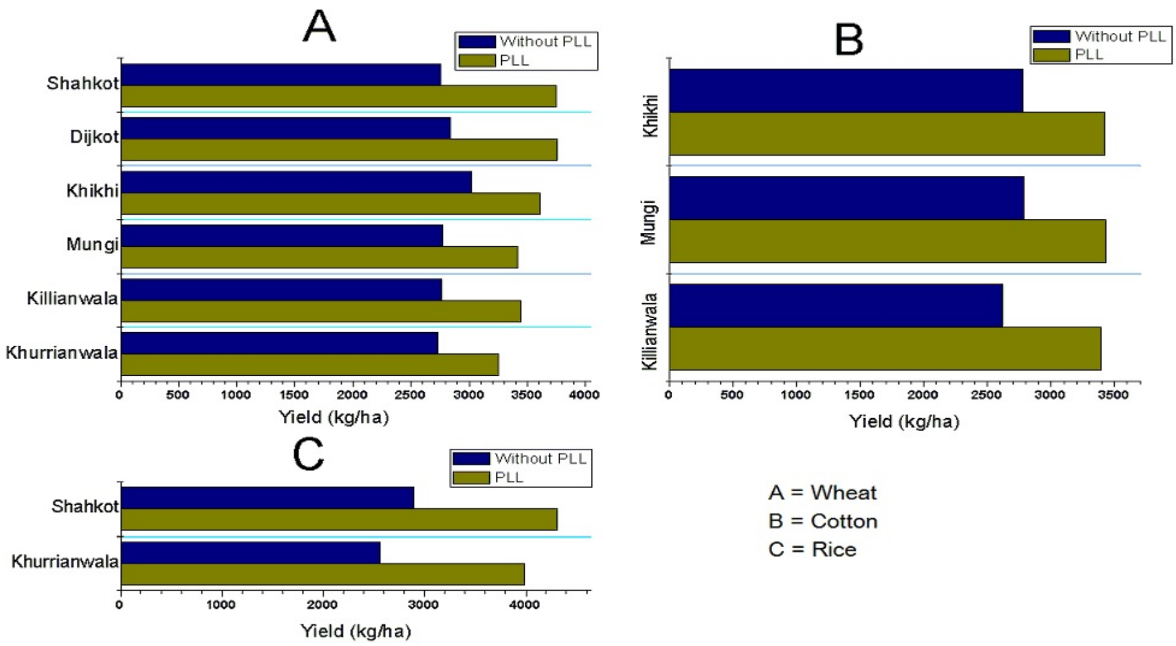

Figure 7. Yield comparison of wheat, cotton and rice with and without PLL.

So, the total water savings from precision land levelling from villages under study was 4.3 million m^3. If all the crops in the command area of LCC will be sown on laser-levelled fields, then a huge amount of irrigation water (about 2768.1 million m^3) can be saved including 1384.7 million m^3 from rice, 699.2 million m^3 from wheat and 684.2 million m^3 from cotton. Rice was mainly cultivated at the Upper Gugera and Rakh branches and cotton was mainly cultivated at the Lower Gugera and Burala branches while wheat was evenly cultivated at all five branches of the LCC. The detail is shown in Figure 8 for wheat, cotton and rice.

Table 2. Water savings from wheat under PLL.

Distributary	Total Irrigation Time (Hours/Hectares)		Area under PLL (Hectares)	Per Hectare Water Saving (m^3)	Total Water Saving (m^3)
	Without PLL	PLL			
Khurrianwala	31.1	25.3	607.0	766.2	465,083.4
Killianwala	32.4	26.3	607.0	822.9	499,500.3
Mungi	27.1	22.0	809.4	716.5	579,935.1
Khikhi	25.7	20.9	247.3	823.7	203,701.0
Dijkot	27.3	22.2	174.8	964.7	168,629.6
Shahkot	23.5	19.1	184.9	613.0	113,343.7
					Total Water Saving = 2,030,193.1 m^3

Table 3. Water savings from cotton under PLL.

Distributary	Total Irrigation Time (Hours/Hectares)		Area under PLL (Hectares)	Per Hectare Water Saving (m^3)	Total Water Saving (m^3)
	Without PLL	PLL			
Killianwala	61.8	49.4	202.3	2519.0	509,593.7
Mungi	60.0	48.2	202.3	2236.9	452,524.9
Khikhi	65.7	52.6	60.7	2937.2	178,288.0
					Total Water Saving = 1,140,406.6 m^3

Table 4. Water savings from rice under PLL.

Distributary	Total Irrigation Time (Hours/Hectares)		Area under PLL (Hectares)	Per Hectare Water Saving (m^3)	Total Water Saving (m^3)
	Without PLL	PLL			
Khurrianwala	136.3	105.5	161.9	5510.4	892,133.8
Shahkot	132.6	103.2	40.5	5245.9	212,459.0
					Total Water Saving = 1,104,592.8 m^3

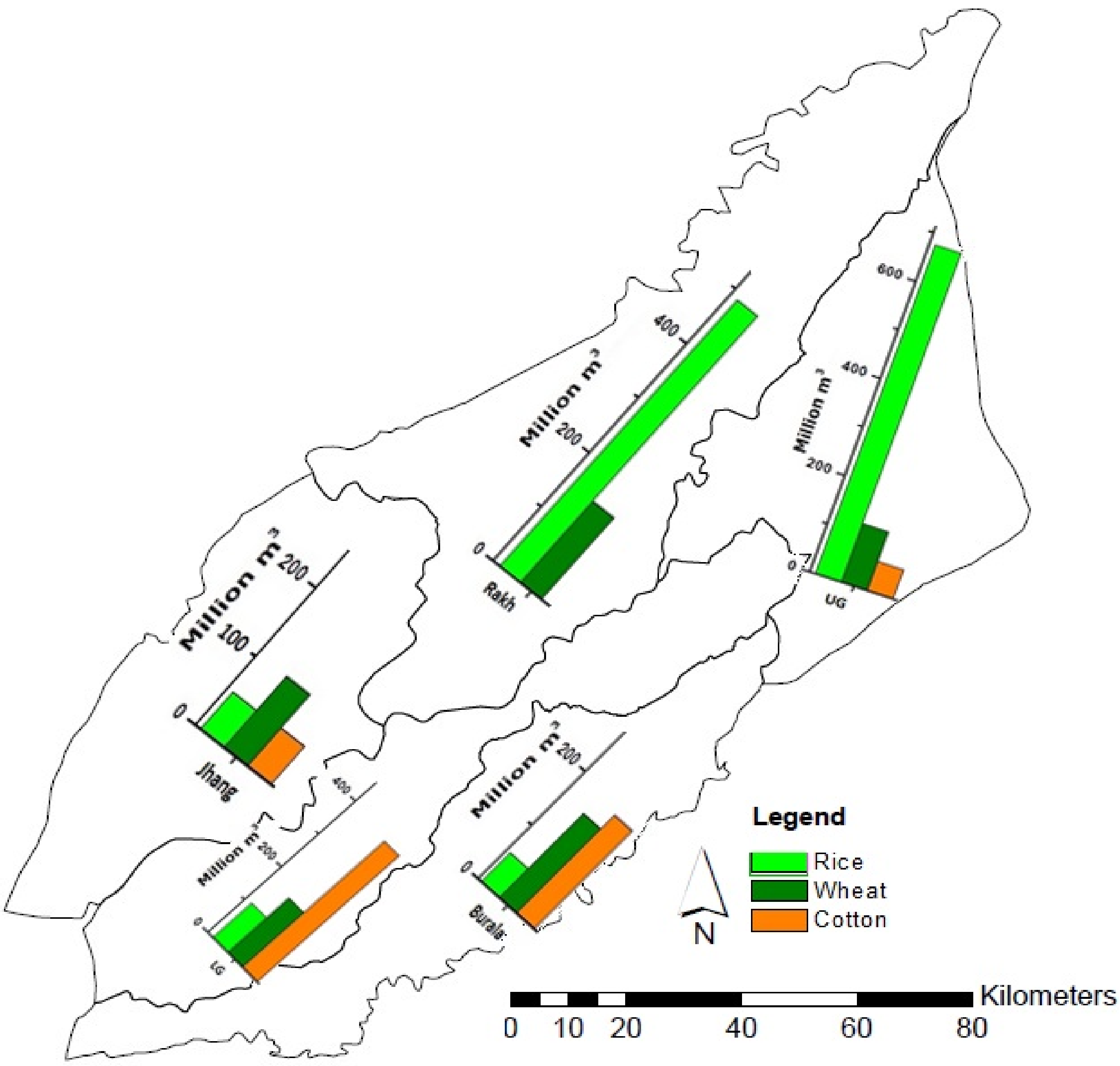

Figure 8. Water saving from PLL in the command area of LCC.

3.3. Bed Planting

Bed planting is a proven technology for water saving. Water can be saved efficiently from bed planted fields only if area is properly levelled. All fields under PLL were brought under bed planting. Increase in crop yields and water savings for wheat, cotton and rice under bed planting at the distributaries of the project was calculated by comparison against the conventional planting. The yield has been increased from 8% to 16.6%, 8.6% to 14.5% and 25.1% to 28.1% for wheat, cotton, and rice respectively. Yield comparison of wheat, cotton and rice at the project distributaries under bed planting and conventional planting is shown in Figure 9, whereas average water savings from bed planted field of wheat, cotton and rice is given in Tables 5–7 respectively. Total water savings from bed planting of wheat, cotton and rice at villages of study under project was 7.8 million m^3. If wheat, cotton and rice in the whole command area of LCC will be sown on beds, then about 3699.3 million m^3 of irrigation water can be saved including 1431.7 million m^3 from wheat-planted fields, 1339.2 million m^3 from rice planted fields and 928.4 million m^3 from cotton planted fields (Figure 10).

Table 5. Water savings from four irrigations of wheat under bed-planted field.

Distributary	Total Irrigation Time (Hours/Hectare)		Area under BP (Hectare)	Per Hectare Water Saving (m^3)	Total Water Saving (m^3)
	Conventional Planting	Bed Planting			
Khurrianwala	25.3	13.1	607.0	2173.3	1,319,193.1
Killianwala	26.3	14.4	607.0	2116.0	1,284,412.0
Mungi	22.0	12.2	809.4	1763.3	1,427,215.0
Khikhi	20.9	10.4	247.3	1873.5	463,316.6
Dijkot	22.2	11.3	174.8	1944.1	339,828.7
Shahkot	19.1	10.3	184.9	1578.2	291,809.2
					Total Water Saving = 5,125,774.6 m^3

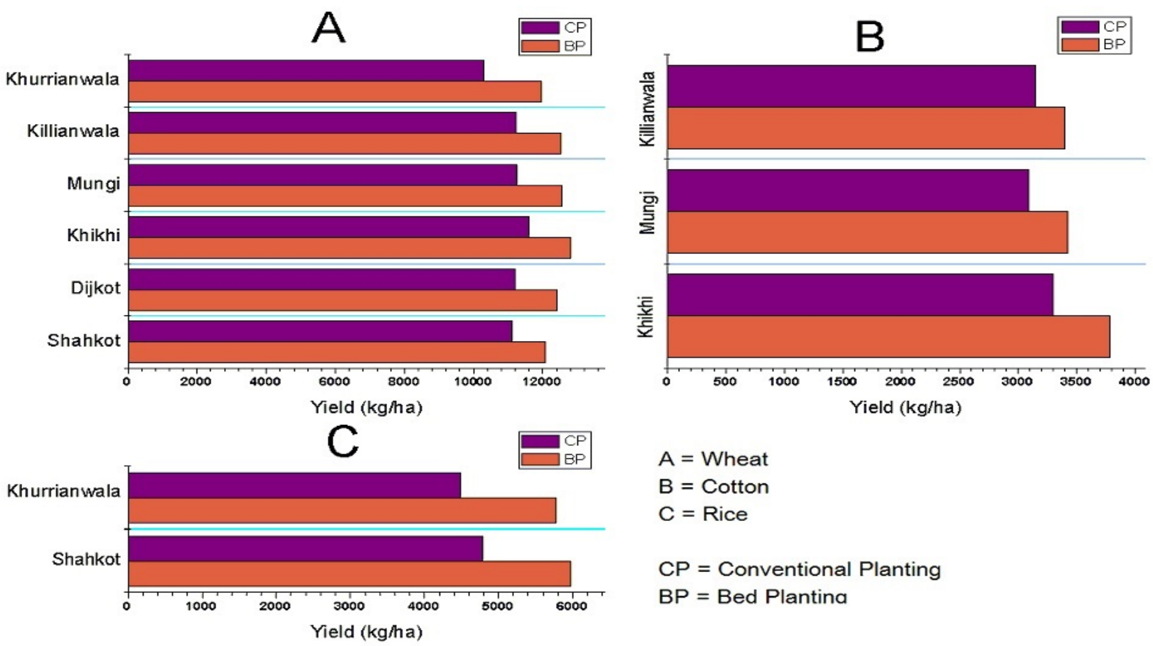

Figure 9. Yield comparison of wheat, cotton and rice under BP and CP.

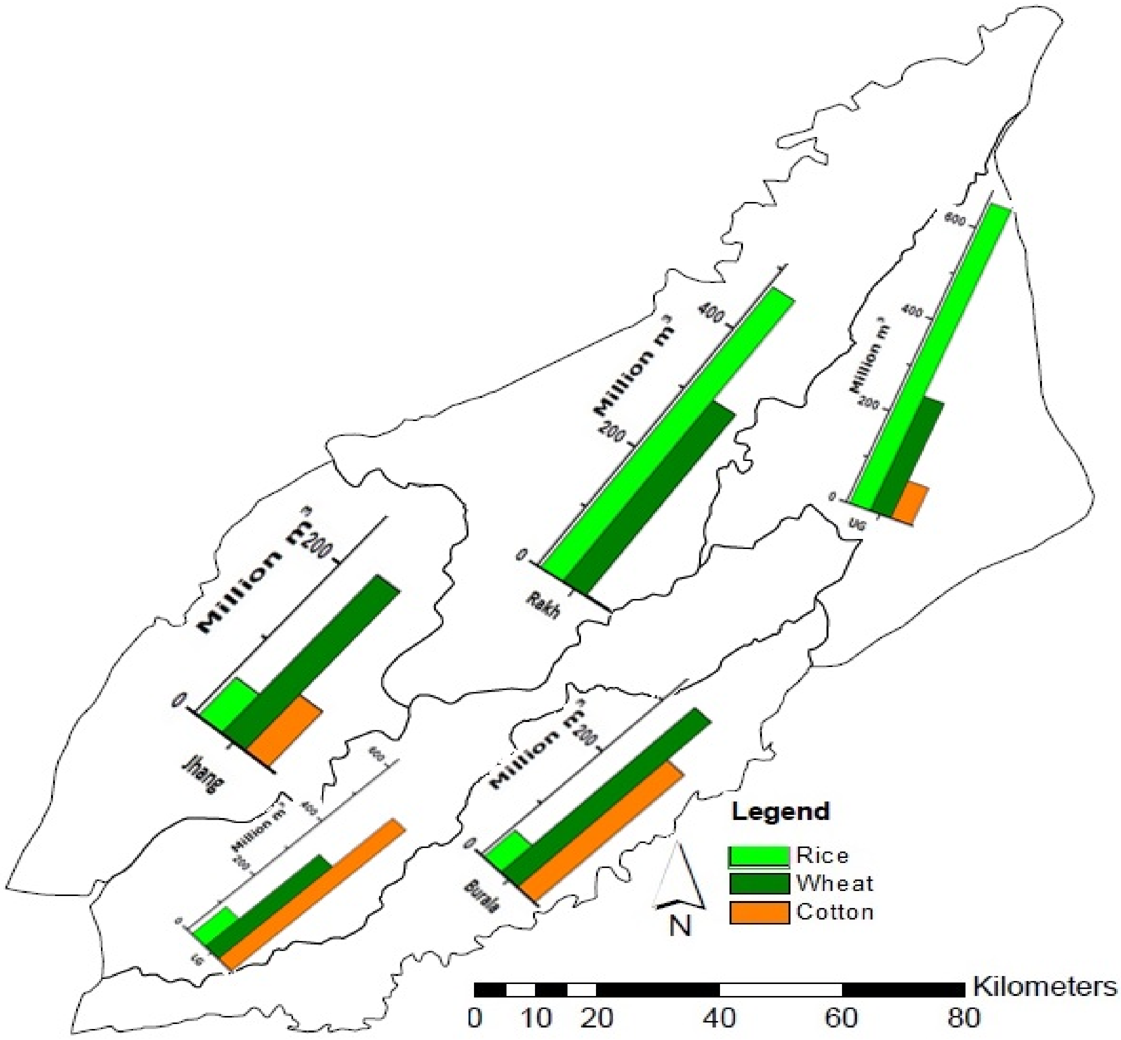

Figure 10. Water saving from bed planting in the command area of the LCC.

Table 6. Water savings from cotton under bed-planted fields.

Distributary	Total Irrigation Time (Hours/Hectare)		Area under BP (Hectare)	Per Hectare Water Saving (m^3)	Total Water Saving (m^3)
	Conventional Planting	Bed Planting			
Killianwala	51.9	34.6	202.3	3526.7	713,451.4
Mungi	49.4	33.8	202.3	2935.9	593,932.6
Khikhi	51.1	33.3	60.7	3990.2	242,205.1
					Total Water Saving = 1,549,589.1 m^3

Table 7. Water savings from rice under bed-planted fields.

Distributary	Total Irrigation Time (Hours/Hectare)		Area under BP (Hectare)	Per Hectare Water Saving (m^3)	Total Water Saving (m^3)
	Conventional Planting	Bed Planting			
Khurrianwala	110.4	79.0	161.9	5598.6	906,413.3
Shahkot	105.0	78.1	40.5	4805.1	194,606.6
					Total Water Saving = 1,101,019.9 m^3

3.4. Watercourse Improvement

Watercourse lining and earthen improvements ensure about 30–45% water savings. Before lining, conveyance efficiency and losses of selected watercourse at each distributary were determined by measuring discharge at different point using a cutthroat flume. The conveyance efficiency and losses of selected watercourses is given in the Table 8.

Table 8. Conveyance efficiency and losses of selected watercourses.

Sr. No.	Watercourse No.	Village/Chak No.	Distributary	Conveyance Efficiency	Conveyance Losses
1	28780-L	441 GB	Killianwala	74%	26%
2	12022-R	49 RB	Khurrianwala	80%	20%
3	102190-R	262 GB	Mongi	79%	21%
4	7996-R	259 RB	Dijkot	82%	18%
5	80746-R	331 GB	Khikhi	70%	30%
6	52810-L	83 RB	Shahkot	77%	23%

After the lining, the convey efficiency improved to more than 95% and conveyance losses reduced to minimum.

3.5. Drip Irrigation System

Drip irrigation is a much-needed technology for the near future, keeping in view the existing water shortage scenario under increasing cropping intensity and area of agriculture of the country. Drip irrigation model farms on five acres, one on each selected distributary of the project, were established and different crops were grown at these farms for dissemination purpose. The data regarding water savings and increase in crop yields from these drip irrigation systems showed that there was savings of not only water (60–80%) but also fertilizer, and a 30–40% increase in crop yield. The drip irrigation systems at Khurrianwala, Killianwala and Mungi distributaries were installed for row crop i.e., maize. Comparison of water savings and increase in crop yield for drip irrigation and bed planting during different years is shown in Table 9. The drip irrigation systems at Shahkot, Dijkot and Khikhi distributaries were installed for fruit crop i.e., Citrus. These drip systems were installed during the last year of project that's why yield comparison at these sites could not be possible.

Table 9. Water saving and yield increments of maize crop under drip irrigation.

Distributary	Irrigation Method	Year	Grain Yield (kg/ha)	Plant Height (cm)	No. of Grains/Cob	Irrigation Water Depth (mm)
Khurrianwala	Drip Irrigation	2013	6926	172.4	372	481
		2014	7582	163.7	365	498
		2015	7940	167.3	410	473
	Bed Planting	2013	5816	164.8	355	724
		2014	6835	152.6	347	767
		2015	6842	162.7	382	671
Killianwala	Drip Irrigation	2013	7249	177.3	374	487
		2014	7782	167.6	362	507
		2015	8027	172.5	427	494
	Bed Planting	2013	6637	166.8	349	739
		2014	6995	158.5	353	774
		2015	7037	165.8	359	697
Mungi	Drip Irrigation	2013	7926	179.2	387	478
		2014	8274	180.5	376	482
		2015	8549	181.3	400	474
	Bed Planting	2013	6986	170.2	349	747
		2014	7269	172.6	350	786
		2015	7358	174.1	365	708

4. Discussion

Water scarcity is a consistent problem in the country, especially in the irrigated areas of the Lower Chenab Canal (LCC). According to [41], there is an intense scarcity of irrigation water in the command area of the LCC, which is threatening irrigated agriculture. The main cause of this problem is the mismanagement of available resources of irrigation water. This key crisis is the reason that government is focusing on management of irrigation water at farm level through different water-efficient technologies. Under the on-farm research and development project, water-efficient techniques such as precision land levelling, bed planting, and drip irrigation systems were introduced to farmers of six distributaries in the command area of the LCC.

LU/LC of different crops on the branches of the LCC has changed a lot after the promotion of water-efficient technologies. The cultivation of wheat, cotton and vegetables increased a lot especially because of promotion of precision land levelling and bed planting and drip irrigation (Tables 10 and 11).

Table 10. Acreage (hectare) of Rabi crops on branches of the LCC.

Crops		Branches of LCC				
		LG	UG	Burala	Rakh	Jhang
Wheat	Before Study	109,670	90,650	86,200	123,430	83,370
	After Study	154,190	131,120	146,900	151,760	93,480
Sugarcane	Before Study	43,300	10,120	43,300	9310	12,140
	After Study	36,830	18,210	33,990	7280	20,230
Fodder	Before Study	34,400	7280	8500	27,110	6880
	After Study	4050	2830	1210	4050	1620
Other Crops	Before Study	28,330	35,610	26,300	64,750	60,700
	After Study	61,510	20,640	43,710	82,150	48,160

Table 11. Acreage (hectare) of Kharif Crops on branches of the LCC.

Crops		Branches of LCC				
		LG	UG	Burala	Rakh	Jhang
Rice	Before Study	19,020	109,710	11,740	90,650	10,520
	After Study	17,000	126,300	8900	86,200	8500
Cotton	Before Study	37,640	5670	22,260	1210	15,380
	After Study	149,330	10,930	72,030	809	21,040
Sugarcane	Before Study	59,490	18,210	42,090	69,610	28,730
	After Study	49,780	9710	30,070	49,370	16,590
Fodder	Before Study	38,850	19,830	38,850	52,610	41,280
	After Study	10,120	24,690	18,210	34,400	28,730
Other Crops	Before Study	45,320	76,080	52,610	108,050	87,820
	After Study	100,360	83,370	63,130	81,750	107,240

According to [42], the acreage under wheat and sugarcane during the Rabi season 2007–2008 was 497,214 hectares and 126,883 hectares, respectively, which was almost the same as reported in Table 8 for wheat and sugarcane. The acreage reported in Table 9 for rice, cotton, and sugarcane is in accordance with the area reported by [42] for rice, cotton and sugarcane during the Kharif season 2007 i.e., Rice cultivated area was 252,756 hectares, cotton cultivated area was 76,740 hectares and the sugarcane cultivated area was 198,419 hectares.

Precision land levelling has resulted in 22% savings of irrigation water along with 10% higher production in the rice-wheat system [8]. Precision land levelling not only curtailed the cost of operation but also helped in uniform crop stand through better application of fertilizer. The farmers of the villages under study have now become aware of the advantages of precision land levelling. They are now levelling their lands every year for irrigation water savings and better crop production. If all the crops in the command area of LCC will be sown on laser-levelled fields then about 2768 million m^3 of irrigation water can be saved and used to irrigate more area.

Bed planting is another proven technology for savings of irrigation water. Bed planting is useful only on precisely levelled fields. During this study, higher water and fertilizer use efficiency was achieved in bed-planted fields. Bed planting has resulted in 30–50% savings of irrigation water and 20–25% increase in crop yield. According to [20], furrow irrigation under raised bed technology saved more than 30% of irrigation water against traditional flood irrigation. Bed planting is a new technology for the farmers of the command area of LCC. The need is to focus on this technology and 3699 million m^3 of irrigation water can be saved by sowing crops on beds in the command area of LCC.

The drip irrigation system is the most efficient water-saving technology that used irrigation water, fertilizers and other nutrients the most efficiently for better crop production. The most efficient water saving technology (drip irrigation) helped small farmers of the study area to improve their livings by using agricultural inputs (water and fertilizers) more efficiently. Drip irrigation also helped the farmers to improve the quality and yield of crops especially vegetables. During the last 30–40 years, numerous efforts were made to introduce drip irrigation system in Pakistan, but no remarkable attainment were observed [43,44]. The high initial cost of drip irrigation systems impeded the adoption of it on a large scale in Baluchistan [45]. During the last few years, the government of Punjab, through its Agricultural Department, has started a project wherein drip irrigation systems are being installed on 48,562 hectares of land on a cost-sharing basis [46]. To lower the burden of the high initial cost of drip irrigation systems on farmers and to promote the adaptation of drip irrigation systems in the whole country, such projects needs to be started whereby drip irrigation systems should be installed on a cost-sharing basis.

5. Conclusions

This study was conducted in the villages where the project was successfully implemented from October 2008 to June 2015 in the command area of the Lower Chenab Canal, in the main part of Indus Basin, Pakistan.

From the findings of the seven-year study, it can be concluded that water-efficient techniques have a huge scope in the command area of the Lower Chenab Canal. The cultivated area of cotton, wheat, and other crops (vegetables and maize) is increased by about 200%, 37% and 19%, respectively, after the introduction of water-efficient irrigation techniques especially precision land levelling and bed planting. Besides the increase in crop yield, a huge amount of irrigation water (2768.1 million m^3) from precision land levelling and (3699.3 million m^3) from bed planting can be saved by adopting these water savings irrigation technologies in the whole command area of the Lower Chenab Canal.

On basis of the findings of this study, the water-efficient irrigation technologies—precision land levelling, bed planting, watercourse improvement, and drip irrigation—needs to be adopted for water savings and better crop yields in all of the irrigated districts in Punjab.

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