

ENHANCING LAND AND WATER PRODUCTIVITY THROUGH FURROW IRRIGATED RAISED BED PLANTING - A CASE STUDY OF UNDERUTILIZED LANDS IN PAKISTAN

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In Pakistan, there is dire need to enhance productivity by proper use of underutilized lands through improved agricultural practices/irrigation methods. Study was conducted in the command area of Killianwala distributary to check the impact of raised bed planting for improving productivity potential of underutilized lands. Information regarding area under wheat crop and fallow lands in each village was explored using GIS. Fallow lands in 19,911 ha of Culturable Command Area (CCA) were estimated to be 520 ha, while the remaining cultivated lands were also found to be underutilized in terms of low productivity potential. Reasons found for the lands underutilization were water shortage, salinity and land preparation requirements, with water shortage as major problem along the whole length of distributary. Wheat was planted on raised beds as well as by conventional method at seven sites and average yield increase and water saving of 18% and 49%, respectively, was recorded for wheat under raised bed planting. It was estimated that replacement of conventional sowing method by raised bed planting in the study area can enhance the production of wheat by 10.44 thousand tons, while the achievement of about 50% water saving will also help bringing fallow lands under cultivation, thus giving further boost to production at regional scale.

Keywords: Lands underutilization, GIS mapping, agricultural productivity, water scarcity, raised bed planting

INTRODUCTION

Pakistan is an agriculture based country, as about 43.5% of country's total labor force and over 20.9% of GDP belong to this sector (GoP, 2015). Future population growth, urbanization, development pressure on land and water, increase in energy cost and adverse climate changes are the major factors threatening to the food security of the country. The country is suffering with increasing water shortage and there is already 48.6% culturable waste, while population of Pakistan has risen from 32.4 million in mid-1948 to 144.5 million in 2003, and is estimated to increase to 221 million by 2025 (Khan, 2003). Pakistan is not short of agricultural land, but the problem is in making effective use of these agricultural lands by enhancing their productivity. The agricultural output of a country is closely linked to the supply of irrigation water. In Pakistan, against normal surface water availability of 127.5 Billion Cubic Meters (BCM) at canal heads, it has been fluctuating between 120.5 and 116.0 BCM for the past 10 years (GoP, 2014). The future looks uncertain as no major development in water resources is being made currently. That's why even after highly wet rainy season and floods, the country has to face water shortage situation in winter due to very limited water storage capacity.

Another major issue in the country is low water productivity due to traditional irrigation system. In addition to develop more water resources, there is a dire need to introduce new water saving techniques. Precision farming, lining of irrigation water conveying facilities and adoption of Water Conservation Techniques (WCTs) like Furrow Irrigated Raised Bed (FIRB) planting and pressurized irrigation systems (sprinkler and drip irrigation) help achieving high water productivity to ensure future food security. Total cultivated area in Pakistan is 22.07 million hectares, out of which 6.60 million hectares is current fallow and 15.38 million hectares is net area sown; while the culturable waste area is 8.27 million hectares (GoP, 2014). These areas can be brought into use if water supplies are made available by saving water in already cropped areas using water conservation techniques. In this way both the land and water productivity can be improved.

Raised Bed (RB) planting system is an important water conservation technique in which crops are grown on raised beds and furrows are used for irrigation. Research carried out for wheat crop at the experimental area of Water Management Research Centre of University of Agriculture Faisalabad and at farmers' fields in T.T. Singh has shown greater water productivity (2.35 kg/m³) and yield (3959 kg/ha) in bed planting as compared to flat planting (1.28

kg/m³, 3487 kg/ha) as reported by Ahmad and Mahmood (2005). It is important to mention that Warabandi or irrigation rotational system in Pakistan is time-based and farmers get a fixed turn time for irrigation in a week on the basis of their land holdings. However, due to much application losses under conventional irrigation method, farmers are unable to irrigate their whole land holding in their allocated time. Therefore, either they have to keep about half of their land as fallow in a season or they rely on groundwater use for the remaining land, which has its own issues viz. high energy cost, poor quality of groundwater resulting in low productivity and secondary salinity, etc. Bed-furrow irrigation is considered about 70% efficient as water has to move only in furrows and therefore, a field can be irrigated using this technique in 50% less time than that is taken by conventional irrigation method. It is, therefore, believed that replacement of conventional flat sowing by FIRB planting may provide about 50% time saving to be used to irrigate those lands which remain fallow due to non-availability of water. However, this concept still needs to be promoted by establishing demo plots at farmers' fields and convincing them that about 50% less application of water doesn't result in any crop stress, but only reduces the losses. The RB planting system is considered a suitable surface/gravity irrigation system all over the world for improving water productivity and thus addressing increasing water shortages. Qureshi and Aslam (1986) recorded 20-25% yield increase and 25-50% water saving in non-permanent bed/ridge and furrow irrigation methods for wheat as compared to traditional flat sowing. Khurshid and Chaudhry (1990) investigated the benefits of cotton sowing on furrow ridges over the flat sowing. They recorded 50% saving of irrigation water in addition to other benefits of growing cotton on furrow ridges as compared to flat sowing. Syre and Ramos (1997) reported that yield of crops in bed planting is increased through better nutrient management and efficient irrigation and because of the reduced risk of lodging. Dhillon *et al.* (2000) conducted experiments by growing wheat on flat border and bed-furrow systems. They showed that wheat can be successfully grown on beds, with the advantages of reduced irrigation water requirement, sowing rate and lodging. Peries *et al.* (2001) reported that improvement of root proliferation in bed planting ensures better crop stand and yield. Timsina and Connor (2001) reported that soil, water and nutrient management strategies, such as reduced tillage and use of raised beds that avoid the deleterious effects of puddling on soil structure and fertility, improve water and nutrient use efficiencies, and thus, increase the crop productivity of Rice-Wheat cropping system. Fahong *et al.* (2003) reported that changing to a raised bed planting system from conventional flat planting with flood irrigation can give 35% savings in water and also resists the soil surface to become hard. Hobbs and Gupta (2004) concluded that bed planting has been found to show

improved water distribution efficiency, fertilizer use efficiency, reduced weed infestation and lodging. The technique also requires reduced seed rate without sacrificing crop yield as compared to flat sowing. Peries *et al.* (2004) reported that crops on raised beds experienced a better soil environment compared to crops on the flat and these differences lead to significant improvements in crop productivity resulting from improved drainage and water availability to plant.

Geographic Information System (GIS) is a unique tool for achieving multidimensional objectives. The geographic information of an area alongwith other data of soil, water, cropping pattern, etc. can be explored using GIS tools on a regional scale, with the overall objective being more efficient use of land and water resources to enhance their productivity. Chandna *et al.* (2004) applied remote sensing/GIS methodology to determine accurate distributions and extent of underutilized lands in the district of Ballia, eastern Uttar Pradesh, India. To assess crop distribution and identify underutilized lands, IRSID-LISS III satellite data on four different dates were utilized. Land classification performed by LISS III images permitted the identification of all major categories of underutilized lands during the post-rainy rabi season, with an accuracy of approximately 90%. The identified underutilized land types included current fallows, excessive moisture areas, waterlogged areas, salt affected lands and diara lands (riverside areas). Total underutilized land in 2001-02 covered 76,347 ha, which represented 26.7% of the district's total cultivable area. Current fallows were the predominant category of underutilized land, accounting for 48% of the total. Different techniques like zero tillage, bed planting, surface seeding and boro rice were suggested for different categories of underutilized lands depending upon their suitability. Wesseling and Feddes (2006) performed aggregation of the various simulation units in a GIS-environment by overlaying the thematic maps of spatial variables like weather, land use, soil, irrigation, groundwater level and groundwater quality. In order to analyze water productivity at regional scale, the output of the independent model runs was finally synthesized with the help of post-processors and GIS. It was concluded that by the described approach of applying soil and crop models both at field and regional scale in combination with GIS and satellite data, it is possible to analyze an entire irrigation district in detail and give specific recommendations for improvement.

In this study, GIS methodology was utilized to present the extent and spatial distribution of underutilized lands and factors responsible for underutilization in the command area of Killianwala distributary in Faisalabad district of Punjab, Pakistan. The impact of raised bed planting of wheat to enhance the land and water productivity at a canal command level was assessed.

MATERIALS AND METHODS

Description of study area: Study was conducted in the command area of Killianwala distributary which off takes from Burala Branch at Kanya works near Satiana in Faisalabad district and tails at Mamukanjan area near Ravi river in the south-east (Fig. 1). The command area spans in the south-west direction between $31^{\circ}07'36.91''\text{N}$, $73^{\circ}04.11'27''\text{E}$ and $30^{\circ}47'31.32''\text{N}$, $72^{\circ}51'12.54''\text{E}$, with average altitude of 170 m above mean sea level. Killianwala distributary has design discharge of 212 cusecs through its 147 outlets along 46,061 m length. It irrigates about 19,911 ha of command area distributed among 13,760 shareholders. The climate of Faisalabad is semi-arid to arid with maximum temperature crossing 45°C in summer and minimum temperature falling sometimes down to the freezing point in winter. Soil type in the study area was found as silty-clay to silty-loam. Surface water availability is limited throughout the area as the system was designed for low cropping intensity. Another reason of low surface water supplies is the conveyance water losses due to poor maintenance of distributary and watercourses. Groundwater quality is poor in the head and middle reach and not fit for irrigation. However, some villages falling in the tail reach of canal command area have good quality groundwater (DLR, 2006), possibly due to nearness to Ravi river. To consider groundwater as good/fit for irrigation, the quality standards utilized by DLR (2006) were: $\text{EC} < 1.5 \text{ dS/m}$, $\text{SAR} < 10$, and $\text{RSC} < 2.5 \text{ me/L}$. Based on these standards, detailed mapping of fit and unfit groundwater areas have been presented in the section of results.

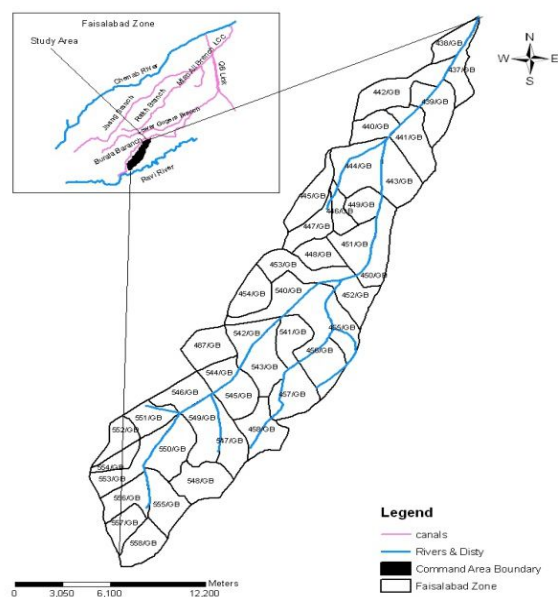


Figure 1. Geographic location of study area along with villages map.

The area has limited agricultural mechanization and preliminary survey in the study area revealed that only about 25% of the farmers have their own tractors and rest of 75% hire their services for farm cultural practices. Out of 25% tractor owners about 15% have some better farm machinery and 10% have commonly used cultivators and scrapers. There was almost no or very less adoption of latest WCTs like RB planting and drip irrigation system and about 70% of the farmers were still using conventional methods of sowing and irrigation. However, these modern techniques have been disseminated to farmers for the last seven years under On-Farm Research & Development Component Project funded by Japan International Cooperation Agency (JICA) and the farmers are now adopting these techniques for improving land and water productivity.

GIS mapping and digitization of study area: Village base map of Faisalabad Irrigation Zone along with the list of villages in the command area of Killianwala distributary developed by Provincial Irrigation Department Faisalabad were used for this purpose. Villages in the list were located on the map and command area of the distributary was delineated manually. This manually delineated command area map was scanned and taken into GIS environment for geo-referencing. The distributary along with its branch, minors and sub minors and the villages' boundaries were digitized.

Mapping of land use and groundwater patterns: There were 42 villages in the command area of Killianwala distributary. Information regarding total area of each village along with its agricultural area and the area under wheat crop in Rabi 2007-08 was obtained from the office of Farmers Organization (FO) and from the area farmers. A questionnaire was developed to determine the extent of underutilized lands and investigate the factors responsible for it. Five farmers in each village were interviewed using this questionnaire and the extent and spatial distribution of lands underutilization was explored using GIS mapping on village basis.

Major factors responsible for land underutilization in the study area were investigated. In addition to other reasons, farmers were also interviewed regarding groundwater levels and the information regarding groundwater quality was obtained from Faisalabad zone groundwater quality map of 2006 developed by Directorate of Land Reclamation, Irrigation & Power Department. The digitized command area map of Killianwala distributary was overlaid on that map and groundwater quality data within the command area boundary was extracted. Finally, the groundwater level and quality maps of the study area were developed to have better insight into the reasons of underutilization of lands.

Raised bed planting of wheat: RB planting is an important water conservation technique in which the crop is planted on raised beds while furrows are used for irrigation. Keeping in

view the multi-dimensional benefits of this technique as already discussed, wheat was planted on raised beds by Wheat Bed Planting Machine developed locally by Water Management Research Center at University of Agriculture Faisalabad. Schematic diagram of the bed-furrow system developed by the machine is shown in Fig. 2.

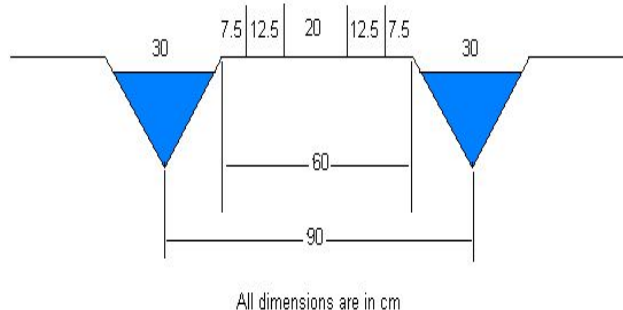


Figure 2. Four-row wheat bed planting system of machine.

The machine develops two beds of 60 cm and three furrows of 30 cm each. There are sown four lines of wheat on a bed with distance of side lines as 7.5 cm from furrows and that of inner lines from side lines as 12.5 cm (Fig. 2). In this way, a plant density equivalent to conventional drill sowing is maintained by sowing four lines of wheat in 90 cm. Moreover, there is kept a buffer zone of 20 cm between inner lines, which is used for safe salts accumulation without their negative effects on crop. Wheat crop stand on raised beds is shown in Fig. 3. The technology was promoted under JICA funded project by planting wheat on beds at about 150 acres in the command area of Killianwala distributary. Seven farmers' sites were selected in this study for data collection regarding water saving and yield to see the impact of this technique in enhancing land and water productivity.



Figure 3. Wheat crop stand on raised beds.

At all of the seven study sites, four to five irrigations were applied following conventional practice of applying each irrigation after 25-30 days interval. However, it was ensured

that irrigations were applied on same dates for both flat sowing and RB planting. Similarly, discharge was kept same by measuring using cut-throat flume or by using same full watercourse for both treatments. Irrigation timings in minutes to irrigate the area were noted for both bed planted wheat as well as for conventional flat sowing and the percent water saving in RB planting was calculated in comparison to flat sowing. At the time of harvesting three "one square meter crop samples" were collected from every flat sown and RB planted field from all the study sites and grain yield of the wheat was determined per hectare under both methods. Average percentage increase in grain yield under RB planting of wheat in comparison to flat sowing was calculated and the significance of results was also checked statistically by using MSTATC software. For this purpose, paired-t test was applied at 99% significance level with seven numbers of variables representing seven sites, as the sites belonged to different soil and water conditions regarding salinity profile, organic matter content, water quality, etc.

Scope for the adoption of technology from socio-economic point of view was also assessed by taking views of farmers regarding benefits of technology and constraints in its adoption, as well as by performing cost-benefit analysis.

RESULTS AND DISCUSSION

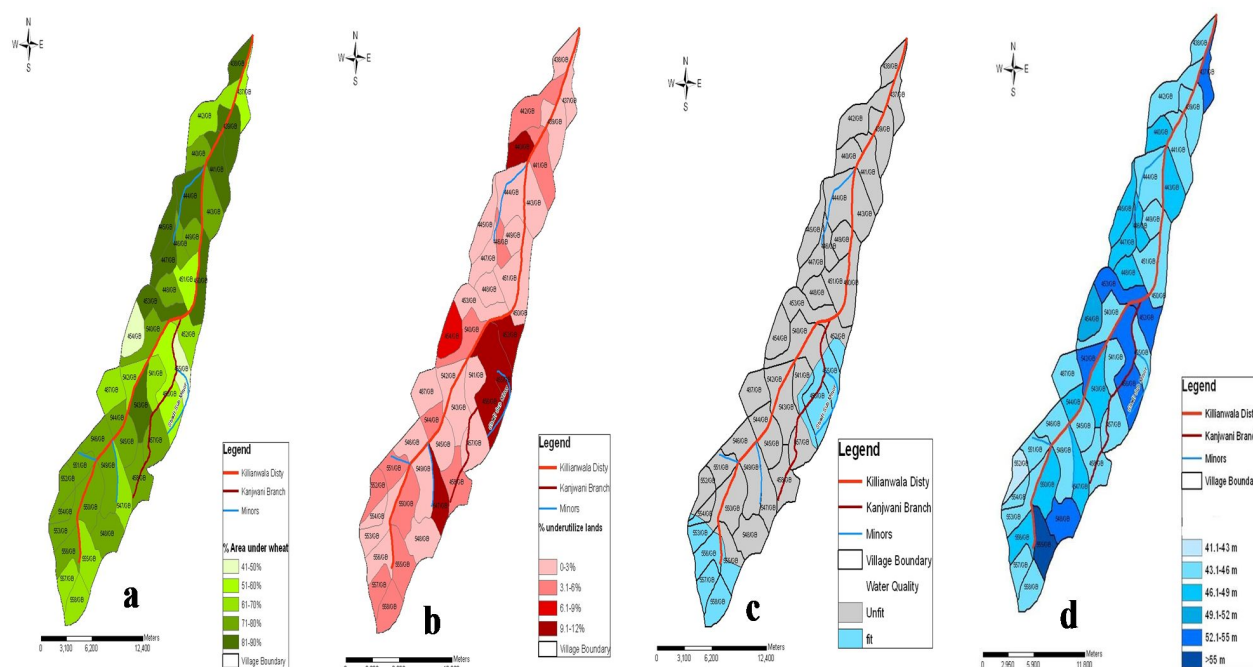
Area under wheat: Percentage area under wheat crop to the total culturable command area (CCA) of each village in Rabi 2007-08 is shown in Fig. 4(a). It was found that 73% of CCA was under wheat on average with minimum 40% in village No.455/GB and maximum 88% in village No.441/GB. Total area under wheat in Rabi 2007-08 was estimated to be 14501 ha out of 19911 ha CCA of the distributary. Figure 4(a) shows that majority of villages lied in the range of "71-80% area under wheat" locating along the whole length of distributary. A good number of villages were found in 81-90% range and majority of these villages was in the head reach of distributary.

Unutilized lands: Figure 4(b) shows the spatial distribution of different classes developed on the basis of extent of unutilized lands. The average extent of unutilized lands was found to be 2.6% of CCA with variation from no unutilized lands in many villages to 11.4% unutilized lands in village No.547/GB. Other villages found in severe problem were 440/GB, 452/GB, 454/GB, 455/GB and 456/GB. Total unutilized area was estimated to be 520 ha in the whole command area. It is important to mention that it included only that area which was uncultivated, whereas the remaining cultivated lands were also found to be underutilized in terms of their low productivity.

Reasons of lands underutilization: Major reasons for the agricultural lands in the area to be underutilized or remain fallow included water shortage, salinity, land preparation

Table 1. Overall water savings (%) for RB planting in comparison to flat sowing.

Site #	Irrigation timing for RB planting (min)	Irrigation timing for flat sowing (min)	Time difference of irrigation (min)	Water saving in RB planting (% time)
1	355	699	344	49.21
2	346	695	349	50.22
3	357	693	336	48.48
4	322	652	330	50.61
5	340	668	328	49.10
6	343	664	321	48.34
7	358	690	332	48.12
Mean	345.86	680.14	334.29	49.16

**Figure 4. Spatial distribution of (a) percent area under wheat, (b) percent unutilized lands, (c) groundwater quality, and (d) groundwater depth (depth of borehole).**

requirements, etc., same as reported by Chandna *et al.* (2004) for the Ballia district in India. However, the factors like excessive moisture areas, waterlogged areas and diara lands (riverside areas) as reported by Chandna *et al.* (2004), were not found in the study area. In villages along the head reach, major factor found responsible for lands underutilization was salinity as in village No.440/GB, 442/GB and 446/GB. Water shortage was found as the most important factor of lands underutilization in the whole area, especially in the middle and tail reaches of distributary. In village No.455/GB there was observed some culturable waste area due to sandy heaps, which can be brought under cultivation after proper land management if additional water supplies are available, thus indirectly related with water shortage. Another factor of lands underutilization was the late harvesting of the

preceding crop due to which either such areas were not brought under wheat or wheat was cultivated very late resulting in low productivity.

Groundwater status: The groundwater quality map of the study area on the basis of two classes i.e. fit or unfit for irrigation purpose, has been shown in Figure 4(c), while the spatial distribution of groundwater depth (depth of borehole) in the study area has been presented in Figure 4(d). Figure 4(c) shows that only a few numbers of villages at the tail and some patches of area near to tail have good quality groundwater. The reason for good quality water formations in these areas may be their closeness to River Ravi. Groundwater depth in majority of the command area of distributary was about 45 m, while some villages in the upper middle reach on the side of Burala Branch had

average borehole depth of 50 m. Villages in the middle reach of distributary had average groundwater depth of about 55 m and these also included some areas having better quality water. From the inspection of Figures 4(c) and 4(d), it can be seen that the formations having good and poor quality water are lying adjacent to each other, thus posing the danger of saline water intrusion into fresh water zones under the existing high pressure on groundwater use. The situation will further enhance the problem of secondary salinity as a reason of lands underutilization or less productivity in the area, which can only be controlled by adopting water conservation technologies and reducing over-exploitation of groundwater.

RB planting – Water saving and productivity enhancement potential

Water saving: Total irrigation timings for RB planting and flat sowing for the whole season along with overall water savings (%) at all the study sites have been presented in Table 1. Average water saving in FIRB planting was found to be 49.16%, which is within the range of 25-50% as reported by Qureshi and Aslam (1986) and is near to that observed at the experimental area of WMRC (50%) as reported by Khurshid and Chaudhry (1990) (50%).

Crop yield: Table 2 shows the wheat grain yield results at all the study sites under conventional and RB planting. RB planting gave invariably higher yields compared with conventional planting at different farm fields varying in soil conditions and other crop inputs.

Table 2. Wheat grain yield under conventional and RB planting.

Site #	Wheat grain yield (kg/ha)	Increase in grain
	RB planting	yield for RB
	Conventional	planting (%)
	sowing	
1	3952	8
2	3656	27
3	4248	7
4	4347	20
5	4446	20
6	4742	19
7	3162	25
Mean	4079	18

Table 3. Paired-t test for grain yield under conventional and RB planting.

	N	Mean	St. Dev.	SE
				Mean
RB planting	7	4079.00	533.95	201.81
Conventional planting	7	3359.29	603.67	228.17
Difference	7	719.71	294.98	111.49
95% CI for mean difference: (446.898, 992.531)				
t-Test of mean difference = 0 (vs not = 0):				
t-value = 6.46 P-value = 0.001				

The average grain yields were found to be 4079 kg/ha and 3359 kg/ha for RB and flat planting, respectively, which were in close agreement to those reported by Ahmad and Mahmood (2005). Overall increase in grain yield for bed planting in comparison to conventional sowing was found to be 18%. The results concluded that the crop under low water application in RB planting did not feel any water stress causing reduction in yield, but only reduced amount of over irrigation causing losses. Moreover, the crop under this technique gave better yield due to better water distribution and sunlight collection and reduced weeds in case of raised beds, as also reported by Peries *et al.* (2004). Applying yield increase results to the total area under wheat in the distributary command, it was concluded that the adoption of RB planting in the area would result in 10.44 thousand tons more grain yield from the existing area under wheat. Table 3 shows the paired-t test for grain yield of wheat, which shows that the results were found statistically significant at 99% probability level.

Adoption of RB planting– Farmers' views and cost analysis:

For socio-economic analysis, five farmers were interviewed in each village regarding their views about RB planting and constraints, if any, in its adoption. About 80% farmers were of the view that RB planting is a good time-efficient and hence, a water saving technology. About 65% farmers showed their consent to its ability to increase yield per hectare, while the remaining were of the view that yield under both RB planting and conventional sowing is almost same. Regarding problems/constraints in the adoption of RB planting, 80% farmers considered non-availability of bed planting machinery as a major obstacle, whereas 63% farmers considered high cost of machine as a limiting factor as well. About 25% respondents were of the view that there is need to create further awareness among the farmers regarding sustainable adoption of the technology. It was suggested by 90% respondents that Government should provide subsidy on bed planting machinery, while 80% endorsed the view that Government should provide easy loans for the sustainable adoption of RB planting.

Economic benefits of adopting RB planting were assessed from its results observed under this study and cost analysis was performed for comparing it with the benefits. Table 4 shows brief results regarding comparison of costs and benefits of implementing raised bed planting and conventional flat sowing.

From Table 4, it can be seen that keeping all other inputs same, shifting from conventional sowing to RB planting will result in an additional cost of Rs.1000/ha only, whereas it will result in a benefit of Rs.23000/ha approximately in terms of yield increase. It is worth mentioning that irrigation costs have not been included here assuming canal water availability and its negligible cost. However, in most cases, tube well water has to be used to make up the canal water deficiency, particularly in case of conventional sowing

Table 4. Costs and benefits under RB planting in comparison to flat sowing.

Description	RB planting	Flat sowing
Costs		
Cost of tillage practices (ploughing, planking, etc.)	Rs.7500/ha	Rs.7500/ha
Cost of sowing (bed planter/ rabi drill)	Rs.3000/ha	Rs.2000/ha
Cost of seed @ Rs.50/kg for 130 kg/ha seed rate	Rs.6500/ha	Rs.6500/ha
Cost of fertilizers (DAP, Urea, SOP, etc.)	Rs.15000/ha	Rs.15000/ha
Cost of spray	Rs.2500/ha	Rs.2500/ha
Harvesting charges @ 7-8 mounds/ha	Rs.10000/ha	Rs.10000/ha
Threshing charges	Rs.7500/ha	Rs.7500/ha
Cost of Production per hectare	Rs.52000/ha	Rs.51000/ha
Benefits		
Average Yield* (kg/ha)	4079.00	3359.29
Income from grain yield @ Rs.32.50/kg	Rs.132570/ha	Rs.109180/ha
Fixed income from dry matter yield	Rs.35000/ha	Rs.35000/ha
Economic Benefits per hectare	Rs.167570/ha	Rs.144180/ha

method requiring more water under flood irrigation. Therefore, about 50% water saving in RB planting will require less water and less operational hours of tube well resulting in less energy cost. Moreover, water savings from bed planted fields will provide additional benefit in terms of more area under crop, which was previously fallow due to non-availability of water, and hence, more production on regional scale.

Conclusions: This study was conducted mainly to assess the extent and reasons of lands underutilization in irrigated agriculture of Punjab-Pakistan and scope of RB planting to address the issue and improve water productivity. As the irrigation rotational system of Pakistan is time based, irrigation time saving under RB planting of wheat was used as a very helpful parameter to estimate its water saving and productivity enhancement potential at a canal command scale.

Area under wheat in the command area of Killianwala distributary was found to be 14,501 ha out of 19,911 ha CCA (72.8%), whereas the underutilized lands were found to be 520 ha (2.6%). Major reason of lands underutilization in the area was canal water shortage along with other minor reasons of salinity and land management problems. Reasons of lands underutilization in terms of low water productivity included traditional irrigation practices, use of poor quality groundwater and the late planting of wheat due to late harvesting of preceding crop resulting in low production.

Based on 18% yield increase in RB planting in comparison to conventional planting, it was concluded that complete replacement of flat sowing by RB planting will result in 10.44 thousand tons increase in wheat grain yield from the existing area under wheat.

Similarly, replacement of conventional method by raised bed planting giving 49% water saving will save water for lands which remain fallow due to water shortage and will decrease the pressure on groundwater use. This all will help

enhancing land and water productivity on a canal command level.

However, other management options like improvement of irrigation infrastructure, promotion of laser land leveling and high efficiency irrigation systems, farm mechanization, reclamation of soils where needed, etc. are also equally important to address different reasons of lands underutilization in an area and are needed to be tested separately for their worth and scope.

Acknowledgements: This study was conducted as a Master's Degree thesis research in parallel to the research & development activities of On Farm Research & Development Component Project of Rehabilitating LCC Systems (Part-B), funded by JICA. The authors acknowledge the support provided by the project team for data collection and other activities.

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