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Water Use Efficiency and Economic Feasibility of Laser Land Leveling in the Fields in the Irrigated Areas of Pakistan

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Abstract: This study was conducted from 2008-2010, on five different farmer fields in district Sargodha, Pakistan, to evaluate the effect of precision-land leveling (PLL) on water application, crop yield, water-use efficiency (WUE), soil salinity and soil fertility. At each farm, one field was precisely leveled with laser-land leveler, whereas another unlevel field was treated as control. Except land leveling, all other cultural practices and crop inputs were kept the same in both fields. On an average, 51% water was saved under leveled fields, as compared to unleveled fields in a cropping year. Rice, wheat and maize (fodder) yields from level fields were 6-10% more than from unlevel fields. The average WUE of rice, wheat and maize (fodder) of the level fields was 33-38% higher than those from unlevel fields. The net annual income, obtained from level fields, was 32% higher, as compared to that from unlevel fields. The elevation difference that was ±2 cm immediately after land leveling in 2008 increased to ±3-6 cm by 2010. The cost incurred on laser-land leveling was recovered within one season. There was no significant and systematic effect of PLL on soil salinity and soil fertility.

Key words: Indus basin, Groundwater, Net income, Water saving.

INTRODUCTION

Irrigated agriculture is the backbone of the economy of Pakistan, where over 93% of the available water resources are consumed. However, out of 130 Billion Cubic Meter (BCM) of water available at the canal head works, hardly 50 BCM is being used by the crops. The remaining 80 BCM (61%) is lost during conveyance (through canals, distributaries, minors and watercourses) and during application in the fields (Qureshi, 2011; Briscoe and Qamar, 2006). Moreover, the existing reservoirs have lost almost 35% of their capacity, due to sedimentation (Ashraf *et al.*, 2000). As no additional water has been injected into the system during the last forty years (Briscoe and Qamar, 2006) and there is no chance for such addition in the near future, therefore, much of the future food production will need to come from the efficient use of the available water resources.

Basin irrigation is used extensively to irrigate various types of crops worldwide (Khanna and Malano, 2006) and is one of the most popular types of on-farm surface irrigation, in which water application can achieve high uniformity (Clemmens *et al*., 1981). It is also the predominant method of irrigation in Pakistan, where layout of most of the fields is based on traditional flood basin comprising a number of unwanted dikes and ditches. Moreover, these basins are not properly leveled, resulting in low application efficiencies (Berkhout, 1997; Ahmad, 2005). Pressurized-irrigation systems, such as, sprinkler and drip, have the potential to achieve over 80% application efficiency. However, their installation and operational costs are very high as compared to surface irrigation systems (Jensen, 2007). In Pakistan, a weekly rotational canal water supply prevails, where conversion from surface to pressurized irrigation is neither economically viable nor socially acceptable. Bed and furrow have the potential to save upto 50% of the water applied. However, these methods are energy and labour intensive and are only effective, when lands are properly leveled (Jat *et al.*, 2006; Mahmood *et al.*, 2012).

The water application and water-use efficiency of basin irrigation can be greatly improved by precisely leveling the basin fields. Precision-land leveling (PLL) is a topographic modification, grading and smoothing of land to an even plain, with little or no slope and an elevation difference of only ±2 cm (Gill, 1994). However, only a few studies have been conducted to evaluate the impact of laser-land leveling. Khattak *et al.* (1981) indicated that 34 to 37% water saving could be achieved with land leveling, whereas, Sattar *et al.* (2001) reported that on an average 747 mm water was required to irrigate cotton traditionally leveled field against 548 mm applied to precisely-leveled field. Abdullaev *et al.* (2007) conducted a three years study on the impact of laser-land leveling on cotton yield and water saving in

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Tajikistan. They found that laser-leveled fields saved on an average 81 mm water in comparison to non-leveled fields. The average annual net income was 22% higher than that for the control fields.

On Farm Water Management (OFWM) Departments in Pakistan are providing laser-guided PLL technology to the farmers for attaining higher accuracy in leveling the fields. However, there have been some questions about the effectiveness of this technology, such as, whether leveling, really saves significant amount of irrigation water, improves crop yields and water use efficiency (WUE)? How much does it cost to level the fields and whether leveling also helps to increase the net income of the farmers? Do the fields need to be leveled every year and how many years leveling of the field can last? Does the leveling affect the soil salinity and fertility? This study was conducted to find answers to the above questions. However, the specific objectives were:

- To study the effects of laser-land leveling on water saving, water-use efficiency and soil salinity and fertility status.
- To conduct the economic evaluation of the laser-land leveling.
- To study the effective life of laser-leveled fields.

MATERIALS AND METHODS

Description of the study area

The study was carried out in Sargodha district-Pakistan, at five different farmer fields from 2008 to 2010 (Fig. 1, Table 1). The area is located at an elevation of 188 m from the mean sea level. The climate of the area is characterized by large seasonal variations in temperature and rainfall. The temperature during winter ranges from 3 to 27 °C, whereas in summer, the weather is extremely hot with temperature, ranging from 20 to 42°C. The average annual rainfall and reference evapotranspiration are 600 mm and 1600 mm, respectively (Ashraf *et al.*, 2012).

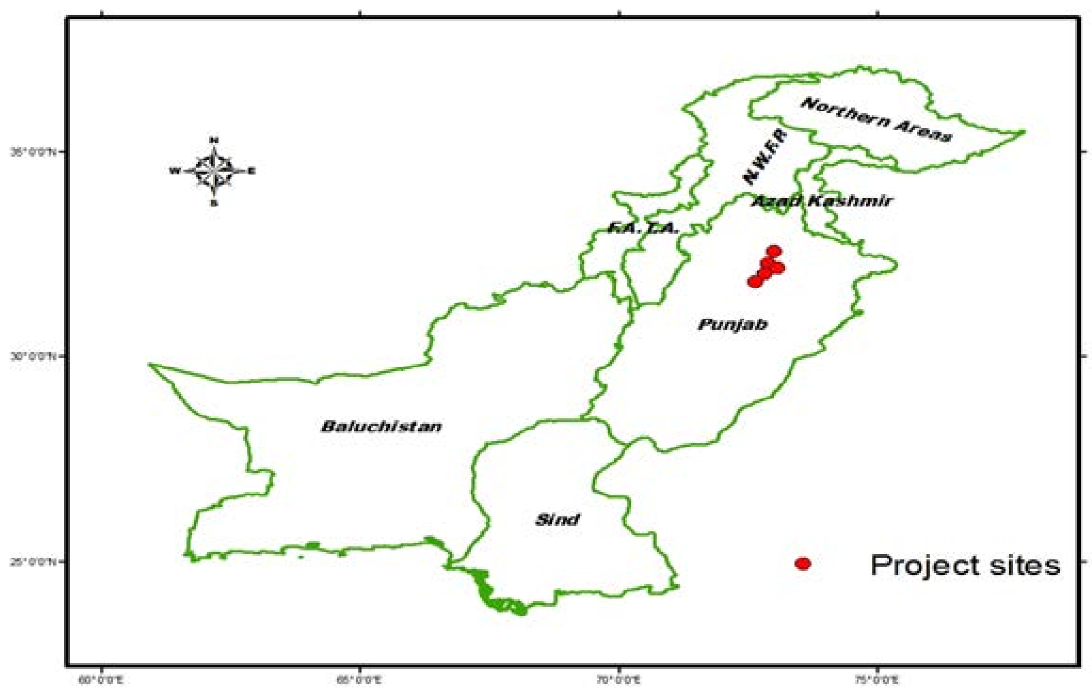

Fig. 1: Location of the study sites.

Sites selection and survey

In Pakistan, the cultivated area is about 20 Mha, out of which about 16 Mha is irrigated. Basmati rice is the principal crop in the Khraif (April-September) season and occupies about 25% of the total cropped area in the season. Wheat is a major staple crop of the Rabi (October-March) season and occupies 75% of the cultivated area in Rabi season (Khan *et al.*, 2006).

Two sites were selected in area of rice-wheat rotation and three in the maize-wheat rotation. The main reasons for the selection of these rotations were the variable use of water and cultural practices during these rotations. Wheat was planted with a Rabi drill. The rice seedlings grown in a nursery (30-35 days) were transplanted manually on the puddled fields, whereas maize was planted with broadcasting. Both rice and maize are labour and water intensive crops. The sites selected were close to Pakistan Council of Research in Water Resources (PCRWR) Field Research Station and the field research staff visited regularly to collect and record the data required for the study. At each site, the selected fields were divided into two fields. One field was leveled with laser-land leveler, whereas the other unleveled field of the same size was treated as a control (Table 1). Unnecessary field ditches/dikes and trees were removed from the fields selected for laser-land leveling. At each selected site, a topographic survey was carried out prior to land leveling and after every year. A grid of 20 m x 20 m was marked in the field and a permanent bench mark (PBM) was also established. From the PBM, the elevation in the center of each grid was determined with a dumpy level. The average field elevation (AFE) and elevation difference from average field level was worked out.

Based on the average elevation, the fields were laser leveled to zero slope. The cost involved in laser-land leveling was worked out on the basis of the actual time taken by the tractor to accomplish the task. This was based on the prevailing procedure and the rates charged by the OFWM and the private laser owners. After laser-land leveling, the topographic survey of leveled fields was carried out to check whether the field elevation difference from average field elevation was within the range of ±2 cm (Table 2). The life of the laser-leveled fields was assumed to be three years (6 seasons) and average cost of leveling was worked out accordingly.

Table 1: Study sites and size of the selected sites.

Site No	Farmer name	Farm size (ha)	Selected area (ha)	Source of irrigation	Soil type	Bulk density (g cm^{-3})	Field capacity (%)	Average discharge (lps)
S-1	Rashid Khan	10.1	2.8	Canal, tubewell	Clay	1.35	36.1	25
S-2	Talat Mahmood	6.5	1.6	Canal, tubewell	Clay	1.32	35	40
S-3	Muhammad Azam	10.1	1.6	Canal, tubewell	Clay Loam	1.4	26	25
S-4	Muhammad Akhlaq	4.0	1.6	Canal, tubewell	Clay Loam	1.42	24.5	28
S-5	Abdul Majeed Khan	5.7	1.6	Canal, tubewell	Sandy Loam	1.65	16	30

Table 2: Average field elevation and laser leveling cost during October 2007.

Site No	Cut-fill ratio	Average time for leveling (hr/ha)	Elevation difference before leveling (cm)	Elevation difference after leveling (cm)	Average cost (PKR/ha)*	Average cost/ season (PKR/ha)
S-1	1.67	7.4	± 8	± 2.0	4440	740
S-2	1.44	6.2	± 8	± 2.0	3720	620
S-3	1.48	6.2	± 9	± 2.0	3720	620
S-4	1.25	6.8	± 5	± 1.5	4080	680
S-5	1.31	5.6	± 8	± 1.0	3360	560

*PKR = Pakistani Rupee; US$ 1 = PKR 72 (2008-2009).

Cultural practices and water applications

Except laser-land leveling in the level field, all other cultural practices as well as inputs were kept the same (Tables 3-4). Since the research was conducted at farmer's fields, therefore, selection of variety was based on farmer's preference. Moreover, the same variety was sown on both level and unlevel fields to compare the results. The date of sowing was dependent on the availability of land for cultivation, availability of water and non-water inputs.

Canal water is provided to the farmers on weekly rotational basis. All the selected farmers have installed tubewells to supplement canal water supplies. They use groundwater either in conjunction with the canal water or independently, depending upon the availability of the canal water and the crop water needs. The quality of pumped water measured in 2008 is given in Table 5.

Table 3: Cultural practices during Rabi (October-March) seasons for level and unlevel fields.

Activity		S-1			S-2			S-3			S-4			S-5		
		2008	2009	2010	2008	2009	2010	2008	2009	2010	2008	2009	2010	2008	2009	2010
Ploughing		4	3	3	3	4	4	3	2	3	3	3	2	3	2	4
Planking		3	1	2	2	2	1	2	2	2	1	2	1	1	1	2
Wheat variety		Bh	I	I	I	I	Sa	Bh	I	Sa	I	I	I	I	Bh	I
Seed rate (kg/ha)		123	148	123	111	148	123	111	148	148	111	124	123	111	148	123
Sowing date		01-12-07	29-11-08	15-11-09	29-11-07	27-11-08	20-11-09	30-11-07	26-11-08	16-12-09	04-12-07	07-11-08	12-11-09	07-11-07	27-11-08	18-11-09
Harvesting date		6-5-08	2-5-09	26-4-10	4-5-08	5-5-09	26-4-10	3-5-08	1-5-09	15-5-10	9-5-08	18-4-09	20-4-10	19-4-08	1-5-09	24-4-10
Fertilizers (kg/ha)	N	85	84	84	142	86	140	142	84	140	57	57	57	136	57	136
	P	28	56	49	28	22	22	28	--	--	67	54	54	57	24	57
	K	--	--	--	--	--	--	--	62	--	--	32	30	--	62	--
	Zn	--	--	--	--	--	--	247	--	--	247	--	247	--	--	--

Bh: Bhakar-2000; I: Inqlab-91; Sa: Sahar-2006.

Table 4: Cultural practices during Kharif (April-September) seasons for level and unlevel fields.

Activity		S-1			S-2			S-3			S-4			S-5	
		2008	2009	2010	2008	2009	2010	2008	2009	2010	2008	2009	2010	2008	2009	2010
Ploughing		4	3	3	4	3	2	2	4	2	5	3	3	4	4	3
Planking		1	2	1	1	2	1	1	1	2	1	1	1	1	2	1
Variety		SB	SB	SB	M	M	M	M	M	M	SB	SB	SB	M	M	M
Seed Rate (kg/ha)		15	15	14	55	60	55	50	50	50	10	12	12	40	60	60
Sowing date		19-07-08	25-07-09	19-07-10	7-07-08	24-08-09	19-08-10	23-08-08	25-08-09	22-08-10	6-08-08	9-07-09	30-07-10	3-08-08	20-08-09	23-08-10
Harvesting date		28-10-08	2-11-09	30-10-10	22-10-08	15-11-09	9-11-10	15-11-08	30-11-09	18-11-10	23-10-08	25-10-09	4-11-10	12-11-08	8-11-09	16-11-10
Fertilizers	N	57	135	44	50	40	45	57	42	22	43	56	57	57	37	57
	P	--	56	114	79	27	57	--	12	57	56	--	--	--	29	-
	K	93	--	--	--	--	--	--	--	--	62	185	-	--	--	--
	Zn	25	7	25	--	--	--	--	--	--	37	10	25	--	--	--

SB: Super Basmati rice; M: Maize (fodder).

Table 5: Groundwater quality at different sites.

Site	Water table depth (m)	EC (dS/m)	SAR	RSC (meq/l)	pH
S-1	4.6	4.37	19.81	5.1	7.65
S-2	3.0	1.04	3.72	2.5	7.01
S-3	2.4	0.99	5.81	5.1	7.55
S-4	6.0	1.24	8.85	6.7	7.64
S-5	15.2	0.97	1.20	0.5	7.06

The farmers used basins to irrigate their crops in level and unlevel fields. Before each irrigation, the soil samples were collected up to 90 cm depth at an interval of 15 cm from level and unlevel fields. The soil moisture content was determined gravimetrically to calculate the soil moisture deficit (SMD) in the root zone before each irrigation. The SMD was calculated as the moisture content at the field capacity minus the available moisture at the time of sampling (before irrigation). The SMD reported in this paper is the average of three locations (i.e., head, middle and tail). Discharge was measured with cutthroat flumes installed in the field channels at each site. The cutthroat flumes with size of 9 cm × 20 cm were installed under free-flow conditions. Based on SMD, irrigation was applied to the fields. The irrigation was applied to level and unlevel fields on the same day. The farmers cutoff the irrigation supply when water reached to the other end of the field. The farmer's fields took more time to irrigate the same size of the field. From the time of irrigation, the depth of water applied was calculated using Eq. 1 (PARC, 1982):

$$QT = 27.78\ Ad \quad \ldots \quad (1)$$

where:

T is the time of irrigation (hrs)

d is the depth of water applied (cm)

A is the area to be irrigated (ha)

Q is the discharge (lps).

A rain gauge was installed at each site to record the rainfall data. The average monthly rainfall during the study period is shown in Fig. 2. The effective rainfall was calculated with CropWat model, using USDA soil conservation method. There was high temporal variability of rainfall. During 2009-10, the average rainfall was 51% and 68% higher than those in 2007-08 and 2008-09, respectively. The rainfall was assumed to be uniform over both the fields because of their smaller size.

Crop yield and net income

The crop in level and unlevel fields was harvested manually and the yields were measured by weighing the grain with a balance on whole field basis. As the cost of wheat straw is almost the same as that of grain, the farmers did not leave any straw in the fields. Gross income is a monetary measure for the total production and was calculated, using the average prices for wheat grain and straw during the year. The cost of production varies mainly due to land leveling in level field and the amount of water used for level and unlevel fields. Cost for non-water inputs was the same for level and unlevel fields. The net income was calculated using Eq. 2.

$$NI = P_y Y - \sum_i P_i X_i \quad \ldots. \ (2)$$

Where NI is the net income, P_y is the farm gate price of a given crop product, Y is the quantity of crop output per hectare, P_i is the price of the i^{th} variable input used to produce a given crop product and X_i is the quantity of the i^{th} variable input per hectare used in production. $P_y Y$ represents the gross income (total revenue). Therefore, the gross income minus total cost of production gives the net income.

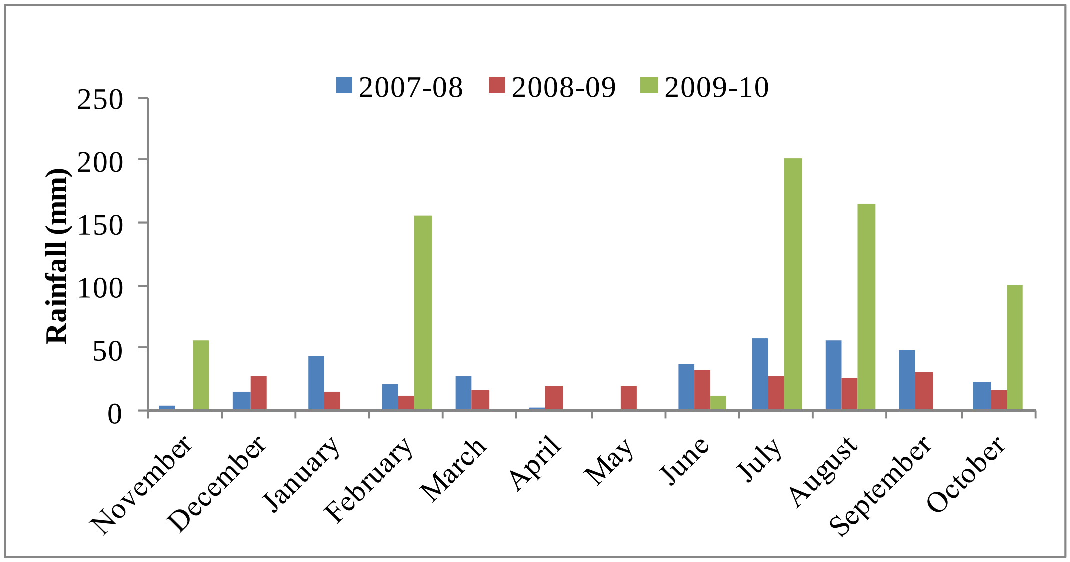

Fig. 2: Average rainfall during study period.

RESULTS AND DISCUSSION

Land leveling

A number of factors, such as, ploughing, planking, ridging and particularly puddling (ploughing of land for rice cultivation with a tractor in the standing water), affect land leveling. The average elevation and elevation difference measured after every year are given in Table 6. Immediately after one year (the fields were leveled during October 2007, Table 2), the elevation difference which was ±2 cm on leveled fields increased to about ±3 cm during 2008 and to ±3.5 cm during 2009. The average elevation increased to above ±4 cm during 2010 showing that the field needs to be re-leveled after three years. The changes in elevation levels were mainly due to extensive ploughing and planking used before sowing as on average six ploughings and three plankings were used by the farmers in a year (Tables 3 and 4). The field elevations were disturbed more in sandy loam (Site 4) soil and reached to ±6 cm during three years. However, the elevations of the leveled fields were still better than unleveled fields which were ±8 cm before leveling.

Table 6: Change in elevation differences with time (cm).

Site	Average elevation	Before leveling	Elevation differences		
			2008	2009	2010
S-1	941	± 8	± 3	± 3	± 3
S-2	941	± 8	± 5	± 3.5	± 5
S-3	983	± 9	± 3.5	± 3.5	± 4
S-4	983	± 5	± 3.5	± 3.5	± 4
S-5	980	± 8	± 3	± 3.5	± 6

Irrigation Applications, Crop Yield, WUE and Net Income

Rabi season – wheat crop: Soil moisture deficit is the amount of water required to bring the soil moisture content back to the field capacity. Table 7 shows the soil moisture deficit in level and unlevel fields for wheat. Except for 2008, there was no significant difference of SMD between the level and unlevel fields. The small difference was mainly due to non-uniformity in water application to the unlevel fields. However, there was significant difference at 5% significance level for depth of water applied, wheat yield and WUE between level and unlevel fields. On an average, 71 mm less water was applied to level fields as compared to unlevel fields, giving water saving of 23%.

The water requirement of wheat for the area is 401 mm (PARC, 1982). On the level fields, 302-320 mm of water was applied to wheat crop. The remaining water requirement of wheat was probably met from the rainfall as the groundwater contribution was zero. In case of rain, the interval between two irrigations was increased. However, under unlevel fields, the water applied to wheat ranged from 368-

399 mm because it was always difficult to apply right amount of water, due to non-uniformity of water application.

The crop yield is affected by a number of factors among which irrigation is a major factor. Level field plays an important role in even distribution of soil moisture throughout the field length that enhances the seed germination rate, smooth crop growth and ultimately the yield. Table 7 shows that in level fields, 8% more wheat yield was obtained, as compared to unlevel fields.

Table 7: Depth of water applied, wheat yield and water use efficiency.

Year	Soil moisture deficit (mm)		Depth of water applied (mm)		Crop yield (kg/ha)		WUE (kg m^{-3})	
	Level	Unlevel	Level	Unlevel	Level	Unlevel	Level	Unlevel
2008	206^b	226^a	302^b	399^a	3962^a	3729^b	1.31^a	0.94^b
2009	202^a	214^a	320^a	368^a	4283^a	3903^b	1.35^a	1.12^b
2010	212^a	218^a	312^b	381^a	2618^a	2371^a	0.84^a	0.63^b
Ave	207^a	220^a	312^b	383^a	3621^a	3335^b	1.17^a	0.87^b
LSD	16.8		22.3		145.2		0.08	

Water-use efficiency is an indicator that tells how much of the water (irrigation/rainfall) has been used for crop production. Any effort that tends to increase crop yield or reduces the amount of water needed, without reducing the crop yield, increases the WUE. Enhancing WUE will be a key pathway to future food security (Mu *et al.*, 2009).

In the literature, WUE and water productivity are used interchangeably (Molden *et al.*, 2010; Singh *et al.*, 2006; Playan and Luciano, 2006). In this study, WUE, however, has been calculated as kg of crop yield per cubic meter of water applied. Since, land leveling helped save water and increase in crop yield, it subsequently improved the WUE. On average 26% higher WUE was achieved in level fields as compared to unlevel fields (Table 7). Low crop yield and higher amount of water applied resulted in low WUE in unlevel fields.

Net income of farmers is the most important indicator for the success of any crop or management practice. A higher gross income resulting from a high cost of production may not be an appropriate option as high portion of the income may be offset by the corresponding high cost of production. There was significant difference at 5% significance level for gross income and net income between level and unlevel fields (Table 8). On average, there were 3% less cost of production, 8% more gross income and 13% higher net income in level fields compared to unlevel fields. Therefore, cost incurred on laser land leveling was recovered in one wheat season only. Walker *et al.* (2003) and Abdullaev *et al.* (2007) reported that the net income was negative during the first year. However, the present study shows that in leveled fields, net income was increased by 25% compared with that for unleveled fields during first year.

Table 8: Cost of production, gross income and net income for wheat.

Year	Cost of production (Rs/ha)		Gross income (Rs/ha)		Net income (Rs/ha)	
	Level	Unlevel	Level	Unlevel	Level	Unlevel
2008	21030^a	21806^a	71795^a	67584^b	50765^a	45777^b
2009	25572^a	26897^a	101736^a	92697^b	76163^a	65800^b
2010	24001^a	24362^a	62178^a	56307^a	38177^a	31945^a
Ave	23535^a	24355^a	78570^a	72196^b	55035^a	47840^b
LSD	2578		3400		4826	

Means with the same letters are not significantly different at P = 0.05

Kharif season – rice crop

For rice crop, there was no significant difference between SMD, crop yield and WUE at 5% significance level between level and unlevel fields (Table 9). However, there was significant difference for depth of water applied for the two treatments. Under level field, the water applied to rice ranged from 602-719 mm whereas it varied from 761 to 1002 mm under unlevel fields. The reported water requirement for rice in the area is 710 mm (Kaleemullah *et al.*, 2001). The remaining water requirement was therefore, met from the rainfall as there was 220 mm of effective rainfall during Kharif season. With level fields, it is possible to apply small depth of irrigation water, which is not possible on unlevel fields. Ashraf *et al.* (2010) reported that in the Lower Bari Doab Canal (LBDC) command area, on average, the farmers were applying 3680 mm of water to rice crop. Lack of precision land leveling was found to be one of the major factors for applying over irrigation. In level fields, on average, 33% (220 mm) less water was applied, 6% more yield and 27% higher WUE were obtained as compared to unlevel fields.

Rice is labour-water intensive crop. Its cost of production, therefore, was 24 and 42% higher, as compared to those for wheat and maize, respectively. However, there was no significant difference for cost of production, gross income and net income for rice between the two treatments (Table 10).

Table 9: Depth of water applied, rice yield and water use efficiency.

Year	Soil moisture deficit (mm)		Depth of water applied (mm)		Crop yield (kg/ha)		WUE (kg m^{-3})	
	Level	Unlevel	Level	Unlevel	Level	Unlevel	Level	Unlevel
2008	532^{a}	613^{a}	751^{b}	1006^{a}	4446^{a}	4127^{a}	0.59^{a}	0.41^{a}
2009	457^{a}	511^{a}	652^{a}	863^{a}	4451^{a}	4345^{a}	0.71^{a}	0.56^{a}
2010	395^{a}	470^{a}	579^{a}	776^{a}	3408^{a}	3098^{a}	0.61^{a}	0.42^{a}
Ave	461^{a}	531^{a}	661^{b}	881^{a}	4102^{a}	3857^{a}	0.63^{a}	0.46^{a}
LSD	113		196.16		1076		0.074	

Means with the same letters are not significantly different at P = 0.05.

Table 10: Cost of production, gross income and net income for rice.

Year	Cost of production (Rs/ha)		Gross income (Rs/ha)		Net income (Rs/ha)	
	Level	Unlevel	Level	Unlevel	Level	Unlevel
2008	41939^{a}	45122^{a}	133370^{a}	123810^{a}	91431^{a}	78688^{a}
2009	32775^{a}	35834^{a}	91480^{a}	89419^{a}	58705^{a}	53585^{a}
2010	29633	32073^{a}	105908^{a}	96409^{a}	76275^{a}	64336^{a}
Ave	34783^{a}	37676^{a}	110253^{a}	103212^{a}	75470^{a}	65536^{a}
LSD	4378		30995		27731	

Means with the same letters are not significantly different at P = 0.05

Kharif season-maize (fodder)

For maize (fodder), there was significant difference in depth of water applied, yield and WUE between level and unlevel fields (Table 11). On average, 24% (35 mm) less water was applied, 10% more yield and 31% higher WUE were obtained in level fields compared to unlevel fields.

Under level fields, the irrigation water applied to maize ranged from 124-169 mm whereas under unlevel fields, it ranged from 155-195 mm. The reported maize water requirement for the area varies from 302 mm to 342 mm (PARC, 1982). There was 140 mm of effective rainfall during maize season.

There was no significant difference between the two treatments in terms of cost of production, gross income and net income for maize (fodder) (Table 12). Nevertheless, on average, 4% less cost of production, 10% more gross income and 15% higher net income were achieved in level fields compared to unlevel fields.

Table 11: Depth of water applied, yield and water use efficiency for maize (fodder).

Year	Soil moisture deficit (mm)		Depth of water applied (mm)		Crop yield (kg/ha)		WUE (kg m^{-3})	
	Level	Unlevel	Level	Unlevel	Level	Unlevel	Level	Unlevel
2008	228^{a}	255^{a}	179^{b}	220^{a}	36326^{a}	35488^{a}	20.62^{a}	16.16^{a}
2009	93^{a}	102^{a}	143^{a}	171^{a}	39520^{a}	34777^{a}	30.16^{a}	20.89^{a}
2010	72^{a}	84^{a}	107^{b}	144^{a}	40967^{a}	35651^{a}	39.68^{a}	25.68^{b}
Ave	131^{a}	147^{a}	143^{b}	178^{a}	38938^{a}	35306^{b}	30.15^{a}	20.91^{b}
LSD	126.6		29.1		2435		5.83	

Means with the same letters are not significantly different at P = 0.05.

Table 12: Cost of production, gross income and net income for maize (fodder).

Year	Cost of production (Rs/ha)		Gross income (Rs/ha)		Net income (Rs/ha)	
	Level	Unlevel	Level	Unlevel	Level	Unlevel
2008	22072 a	23139 a	63374 a	59792 a	41302 a	36653 a
2009	13604 a	13958 a	48412 a	42945 a	34808 a	28987 a
2010	14293 a	14647 a	54076 b	47059 a	39783 b	32412 a
Ave	16656 a	17248 a	55287 a	49932 a	38631 a	32684 a
LSD	13225		31558		19240	

Means with the same letters are not significantly different at P = 0.05.

Soil salinity and fertility status

During PLL, some top soil is removed from the crest and moved to the trough. There are some apprehensions that PLL affects the soil salinity and fertility of the soil. Walker *et al.* (2003) indicated that yields can be reduced during first year after PLL in many soil types and the reduction may or may not be related to nutrient. As in PLL, soil was displaced only from the top soil layer (Table 2), therefore, salinity and fertility of the 0-15 cm depth for leveled and unleveled fields are presented in Table 13. The high salinity and sodicity might be due to the use of highly saline-sodic water for irrigation (Table 5). Tyagi (1984) also showed that leveling was profitable even in sodic soils of Indo-Gangetic plain. Soil pH in level fields decreased at all sites. However, there was no significant difference and systematic salinity trend under level and unlevel fields. The soil salinity depends on a number of factors such as quantity and quality of irrigation water, depth of water table, soil type, rainfall, etc.

Fertility in the soil also depends on the quantity of the fertilizers applied, nutrients taken up by the crops and crops grown. However, there was no significant difference for available nitrogen, phosphorous, potassium and organic matter in level and unlevel fields.

Table 13: Effect of laser land leveling of soil salinity and fertility.

Parameter	Field		
	Level	Unlevel	LSD
EC (dS/m)	3.40 a	3.45 a	1.15
SAR	10.36 a	10.29 a	2.97
ESP (%)	11.70 a	11.59 a	2.81
pH	7.22 a	7.68 a	0.48
Available Nitrogen (%)	0.063 a	0.058 a	0.009
Available Phosphorus (mg/l)	13.40 a	12.14 a	5.14
Available Potassium (mg/l)	174 a	182 a	23.11
Organic matter (%)	1.28 a	1.19 a	0.19

Means with the same letters are not significantly different at P = 0.05; EC = Electrical Conductivity; SAR: Sodium Adsorption Ratio; ESP: Exchangeable Sodium Percentage.

On an average 51% water was saved under level fields in a cropping year (Rabi plus Kharif). The saving was due to the fact that laser-land leveling reduces undulations in the fields, resulting in reduction in time of advance. The unlevel fields result in under and over irrigation and uneven distribution of water and increase the deep percolation losses. The deep percolation of water leaches the essential nutrients out of the root zone and adversely affects the crop yields (Ashraf and Saeed, 2006), whereas, effective land leveling increases crop germination and yields and improves water distribution (Rickman, 2002). The water saving was, however, more pronounced in rice, as compared to wheat and maize. In rice, there was 220 mm (33%), in wheat 71 mm (23%), and in maize 35 mm (25%) water savings. On average, 2,920 and 1,060 m^3 of water per hectare was saved in level fields in rice-wheat and maize-wheat cropping, seasons, respectively. Farmers also sell and purchase water. The cost of water was PKR 1.47/m^3 of water and was calculated on the basis of the prevailing water rate charged by the tubewell owners, i.e., PKR 150/hr (where the discharge of the well was about 30 lps). Therefore, in a year, PKR 4,292/ha and PKR 1,558/ha were saved in level fields as compared to the unlevel fields in rice-wheat and maize-wheat cropping patterns, respectively.

The average WUE of rice, wheat and maize (fodder) in level fields was 33, 38 and 37% higher than those from the unlevel fields, respectively. The reported average WUE of wheat in Pakistan Punjab, Indian Punjab and Imperial Valley USA is 0.45, 0.8

and 1.0 kg/m^3, respectively (Briscoe and Qamar, 2006). The average WUE of wheat of level fields was 1.15 kg/m^3 which was much better than the reported average of Pakistan and Indian Punjab and comparable with the reported average from the USA.

A review of the studies, conducted by Kahlown *et al.* (2002), Kahlown *et al.* (2006), Farooq *et al.* (2007), Humphreys *et al.* (2005), Humphreys *et al.* 2010), Gupta and Seth (2007), Jat *et al.* (2009), Jat *et al.* (2011), shows that laser land leveling helps reduction of water applications at the field between 20-50%, as compared to the conventional fields, increase yields between 10-20% and is a pre-requisite for all surface irrigation methods. However, Keller *et al.* (1996), Seckler (1996), Perry (1999), Ahmad *et al.* (2002), Tuong *et al*. (2005) and, more recently, Ahmad *et al*. (2014) argue that the field scale reduction in irrigation application do not translate into real water savings especially in the areas where deep percolation from the root zone can be reused as groundwater irrigation and the water savings at the field scale disappears when one goes up in scale.

Vazifedoust *et al*. (2008), however, argue that under water scarcity conditions, both percolation and evaporation from the stored soil moisture are generally considered as losses and are the main causes of reduction in water productivity, whereas Hafeez *et al*. (2007) concludes that water use becomes more efficient with increasing scale because of water reuse as the amount of water reuse increases with increasing spatial scale. According to Turral *et al*. (2010), technological improvements would happen at all levels and affect all types of irrigation systems. Better technologies do not necessarily mean new, expensive or sophisticated options, but ones that are appropriate to agricultural needs, the managerial capacity of system operators and farmers and institutional arrangements. Moreover, Qureshi (2011) asserts that the only way to achieve food security is to increase land and water productivity by introducing water conservation technologies such as precision land leveling, zero tillage and bed planting.

It is also argued that water savings at one place are likely to reduce return flows to other users downstream in the basin (Seckler, 1996; Perry, 1999; Ward and Pulido-Velazquez, 2008). However, if the field is located near the sea (Droogers and Kite, 1999) or the groundwater is saline, the return flows cannot be used by the downstream users (Ashraf *et al*. 2000; Khan *et al*. 2006). Molden (1997) concluded that at the field level, it is sometimes impossible, and often times unnecessary to know the fate of outflows. Only when moving up to the service and basin levels, one can determine whether to classify outflows as committed or uncommitted.

No doubt, water lost can be recovered by pumping groundwater but at what cost? In the country where more than 60% farmers hold less than 5 ha land (GOP, 2012), it may not be wise first to lose water and then pump it due to the following reasons: (i) Each farmer cannot install tubewells or cannot purchase water from the neighbouring farmer. (ii) Energy is required to pump water and use of energy to pump water has a direct impact on agriculture and on the net income of the farmers (Ashraf *et al*., 2000). The rising cost of energy (electricity and diesel) is becoming out of reach of the farmers. Ashraf *et al*. (2010) conducted a study in the command area of LBDC, Punjab-Pakistan and reported that the cost of pumped water was 3-7 times higher as compared to the canal water. Since then there is more than 50% increase in fuel prices whereas the cost of the canal water is the same. The canal water is being supplied at a flat rate of US$ 5.56/ha/year, whereas, the cost of one irrigation with groundwater ranges from US$ 16-40/ha. Similarly, Shah *et al*. (2008) reported that in India, per hectare cost of groundwater irrigation ranged from 1.5 times to 8 times the cost of irrigating with surface water. In an extreme case, the cost of supplemental irrigation with gensets could reach 100 times the cost of gravity supply. The farmers are spending about 4 billion rupees per year on maintenance and repair of private tubewells (Qureshi *et al*., 2003). The benefit cost ratio of the groundwater irrigation declines with an increase in the cost of irrigation, as the incremental income generated by investing in groundwater is eventually offset by the incremental cost (Khan *et al*., 2008). Moreover, the value of water varies across time and space and could be different to stakeholders at various scales (Hussain *et al*., 2007). (iii) The native groundwater in the Indus Basin is saline because of marine origin. Seepage from conveyance and irrigation networks has developed freshwater layers of varying thickness that overlay deeper saline groundwater. The thickness of fresh groundwater is high near the recharging sources and decreases with an increase in the distance from the recharging sources (Ashraf *et al*., 2012). Currently, over 1.0 million private tubewells are working in Pakistan (World Bank, 2007). As there is no proper groundwater regulatory framework in the Indus basin of Pakistan, anyone can install any number of tubewells, anywhere and can pump any amount of water at any time. These wells are installed without considering the saline-freshwater interface and most of these wells have one of these problems (Ashraf *et al*., 2012): (a) the strainers of the wells penetrate deep into the saline zone of the aquifer, resulting in the salinization of the productive agricultural lands. Qureshi and Barrett-Lennard (1998) reported that over 70% of tubewells in the Indus Basin were pumping sodic water. (b) Even when the wells are installed in the freshwater layer, over pumping results in upconing of the saline-freshwater interface resulting in the quality of the pumped water deteriorating over time. An estimated 28.2 Mg of salts are annually brought to the surface by the extensive tubewell pumping. As most of the groundwater contribution is in Punjab, therefore salt accumulation is also high in Punjab (24.7 Mg) as compared to Sindh province (3.5 Mg). As a result, slat accumulation in Sindh is much less than the Punjab province (Qureshi *et al*., 2008). It has been estimated that in Pakistan about 6.3 Mha are affected by different level and types of salinity, out of which nearly half are under irrigated agriculture (Qureshi *et al*., 2008). About 30% of this area lies in Punjab province (WAPDA, 2003).

Another 1.0 Mha is affected by water logging. Tarar (1995) reported that after monsoon, about 4.7 Mha (30% of the irrigated area) has groundwater level within 1.5 m of the soil surface. The Punjab and Sindh provinces have about 25% and 60% of their irrigated areas severely waterlogged. This rising groundwater table in turn may cause water logging and soil salinity within the irrigated area and an increased drainage flow into the downstream environment. This drainage water usually transports a variety of chemicals (salts, pesticides, etc.) (Bos, 2004; Hussain *et al.*, 2007).

Shallow groundwater salinity induced by irrigation can be managed by improving the irrigation efficiency and keeping irrigation applications below the net recharge (Ashraf *et al*., 2001; Khan *et al*., 2008; Qureshi *et al*., 2008). (iv) Most of the time, the water lost at a field is not recovered by the same farmers but by another farmer who sells water back to the same farmers from whose field the water was lost. The selling of pumped groundwater is at the discretion of the owner of the tubewell. He may not sell water to the neighboring farmers due to one or the other reasons, resulting in discrimination of groundwater use. (v) The loss of water is also associated with loss of nutrients as the percolated water leached the nutrients out of the root zone, decreasing crop yield and the net income (Ashraf *et al*., 2001).

Another question is that, what the farmers have to do with the water saved through reduced applications (Ahmad *et al*., 2014)? The Indus Basin Irrigation System (IBIS) was designed for an annual cropping intensity of 75% and the water is being supplied to the farm on weekly rotational basis called “warabandi”. The farmers receive their share of water once in a week for the period related to their lands and the cropping pattern. The amount of water during a turn is usually insufficient to irrigate the entire land. Famers who do not have access to groundwater either practice deficit irrigation or leave a fraction of the land uncultivated or un-irrigated. The saved water can be used to irrigate the uncultivated land or un-irrigated land (horizontal expansion) or to increase the cropping intensity (vertical expansion) (Ali *et al*., 2007). The farmers who have access to groundwater have increased cropping intensity to about 150%. Saving in water application will help reduce pressure on groundwater. Bhutta *et al*. (2000) reported that out of 43 canal commands, the water table was declining in 26 canal commands due to rapid increase in groundwater abstraction. Shah *et al*. (2006) also reported high energy cost and declining water tables are the two major issues for the groundwater economy of South Asia. The declining in water tables is not only because of reduction in recharge but also due to more abstractions of groundwater (Ashraf *et al*., 2012). There are two approaches for the sustainable management of the groundwater resources, i.e., increase groundwater recharge or reduce groundwater abstraction. Reduction in application of water helps reduce groundwater abstractions which has much more implications than recharge.

Out of 20 Mha cultivated areas of Pakistan, about 16 Mha are irrigated, of which 11 Mha (73% of the total) are situated in the Punjab (Khan *et al*. 2006). Laser land leveling technology was introduced in Punjab during 1985 by the OFWM, Punjab and since then is struggling to introduce this technology to the farmers. About 4000 laser units have been provided to the farmers in Punjab through OFWM Department (Technical Brief 3, Directorate General, Water Management Punjab) and 0.9 Mha of land has been laser leveled so far (Gill *et al*., 2013).

A key question is that, whether it is more cost effective to reduce seepage from canals (and fields) or to pump groundwater (Khan *et al*., 2006). A more cost effective option may be to increase water use efficiency and reduce the negative impacts on the environment associated with groundwater pumping (Ashraf and Saeed, 2006; Khan *et al*., 2006). Many studies have shown that better timing of irrigation and controlling amount of water applied can improve irrigation efficiency and water productivity with little additional cost (Jensen, 2007; Vazifedoust *et al*., 2008; Rockstrom *et al*., 2007; Qureshi, 2011). More recently, Suweis *et al*. (2013) showed that strategies aiming at increase in water productivity through agricultural practices that enhance crop yields while reducing water losses, improve the sustainability of trade-dependent societies with respect to a decrease in export rates from water-rich countries.

A question also arises that if laser leveling has so much benefit, then why it is not being adopted by the farmers, at large scale? There are certain misconceptions associated with the laser technology. Farmers and some professionals (particularly, Agric. Extension staff) think it imperative to level the fields every year thereby adding to the cost of production. There is also misconception that laser leveling increases the soil salinity and reduces the soil fertility. However, our study shows that there is no need to level the fields at least upto three years. Moreover, there is not significant effect of PLL on the soil salinity and fertility. Rather laser leveling helps uniform application of water thereby reducing the risk of salinity on crest of the fields where relatively less amount of water is applied as compared to trough. Similarly, as the fields are laser leveled to ± 2 cm only, it moves only small amount of soil from crest to trough. As farmers normally apply fertilizer with irrigation, therefore uniform application of water helps uniform application of fertilizers (Jat *et al*., 2006; Jat *et al*., 2011).

Non-availability of laser equipment at the time of need is another issue. There is only a short span available for laser leveling, particularly after harvest of rice and maize (from May to June) and after the monsoon (October and part of November before planting of wheat). Small land holdings also restrict the use of the available laser unit equipped with 60 HP or higher size tractors. There is a dire need to develop small size scrapers that can be operated with small size tractors. Laser leveling can be made more cost effective by proper training of the operators. Normally, the tractor operators, without survey just based on their experience, adjust the scraper to an average elevation level. Due to this reason, relatively more time is taken by the tractor to level a field than if a proper survey has been conducted and proper cut-fill ratio has been determined.

On Farm Water Management (a public sector organization) has been providing laser leveling service to the farmers on rent basis and were able to provide service to limited number of farmers. According to Turral *et al*. (2010), an investment in improving and adapting irrigation is likely to be more diffused and privately sourced. This technology could have taken off, if provided through Agricultural Service Providers (ASPs). The ASPs are a link between the technologist (i.e., researchers, OFWM staff and extension workers) and the farmers. They take technologies from the technologists and provide these to the farmers. As more than 60% of farmers in Pakistan are small land holders (less than 2.5 ha of land), they cannot afford to buy tractors, machines and implements. They are totally dependent on ASPs.

These service providers however, also lack knowledge and expertise for use of agricultural machinery. For example, it is imperative to survey the field before leveling. However, hardly any service provider knows how to do this. The use of laser equipment without knowledge of leveling and cut-fill ratio may result in a complete failure of the technology and may shake the confidence of the farmers to adopt this technology. The training of the service providers therefore, is very important for wide-scale adoption of the technology.

CONCLUSION

The laser-land leveling helped save water, improve WUE, crop yields and net income of the farmers. On average 51% water was saved under level fields as compared to unlevel fields in a cropping year. Rice, wheat and maize (fodder) yields from leveled fields were 6-10% more than those obtained from unleveled fields. The average WUE of rice, wheat and maize (fodder) of the level fields was 33-38% higher than those from unlevel fields. The net annual income obtained from level fields was 32% higher as compared to that from unlevel fields. With level fields, it is possible to apply small depth of water which is not possible in unlevel fields. The cost incurred on laser-land leveling was recovered within a season. After three years, the level fields need laser leveling again for better water applications. There was no systematic trend and significant effect of PLL on soil salinity and fertility.

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