Impacts of Laser Land Leveling in Rice-Wheat Rotations of the North-western Indo-Gangetic Plains of India

Jeetendra Prakash Aryal
Vegetable Farm

Ml Jat
International Maize and Wheat Improvement Center

Mr Harvinder Singh Sidhu
University of Hertfordshire

Impacts of Laser Land Leveling in Rice-Wheat Rotations of the North-western Indo-Gangetic Plains of India

Jeetendra P. Aryal[1*], Meera Bhatia[1], ML Jat[1], and HS Sidhu[1, 2]

[1]International Maize and Wheat Improvement Centre (CIMMYT), NASC Complex, Pusa, New Delhi-110 012, India

[2]Borlaug Institute for South Asia (BISA), Ludhiana, India

Abstract

We assessed the impact of laser land leveling (LLL) technology in rice-wheat systems of north-west India using data collected from household surveys in 2011. We compared crop yield and total irrigation time required per season between laser land leveling and traditional land leveling (TLL). The results show that laser leveling in rice fields reduced irrigation time by 47-69 h/ha per season and improved yield by approximately 7% compared with traditionally leveled fields. In wheat, irrigation time was reduced by 10-12 h/ha per season and yield increased by 6.7% in Haryana and 8.8% in Punjab by adopting LLL. Our analysis showed that LLL is a scale neutral technology i.e., not biased towards large farmers. The savings in irrigation time reduced the number of operation of tube wells for pumping water, and this reduction corresponded to a savings of 558-762 kWh of electricity ha^{-1} yr^{-1} or 300-410 litres of diesel ha^{-1} yr^{-1}. These savings in energies reduced farmer's cost and environmental foot prints. A farmer benefited additional USD 138 ha^{-1} yr^{-1} through increased rice and wheat yields once they laser leveled it. Therefore, adopting LLL, even in 50% of the area under RW system in the Haryana and Punjab states, can provide additional production of 699 million kg of rice and 987 million kg of wheat, amounting to USD 385 million/yr. Thus, LLL contributes to both food security and sustainable use of water resource.

Keywords: Laser land leveling, traditional land leveling, yield, rice-wheat system, irrigation

*Corresponding author: j.aryal@cgiar.org

1. Introduction

With increasing climate variability and rapid melting of glaciers, water resource scarcity is likely to threaten the future agricultural production and food security in South Asia (Cruz et al., 2007). Increasing temperature, which has been evidenced in most of the regions, accentuates the demand for irrigation water. Recent studies predict that there would be at least a 10% increase in irrigation water demand with a 1ºC rise in temperature in arid and semi-arid regions of Asia (Sivakumar and Stefanski, 2011). Water availability is expected to decline whereas global agricultural water demand is estimated to increase by approximately 19% by 2050 (UN-Water, 2013). In India, during the period from 2008 to 2012, the total fresh water withdrawal was approximately 761 billion cubic meters; 90% of this was used for agricultural production including both irrigation and livestock production (World Bank, 2013). The ground water table has been declining in India (Aggarwal et al., 2004; Joshi and Tyagi, 1994; Kerr, 2009; Kumar et al., 2007). Being the largest user of ground water for irrigation, declining ground water table will impend the sustainability of agriculture and overall food security in India (Kulkarni et al., 2011; Perveen et al., 2012). On the other hand, increased population and rapid urbanization will exert pressure to increase food production. To satisfy this demand, India will need to produce at least 37% more rice and wheat by 2025, with nearly 10% less water available for irrigation (Jat et al., 2006). Overall, there is a dire need of technologies that can both conserve water resource and enhance the agricultural productivity (Ambast et al., 2006; Hanjra and Qureshi, 2010).

Provision of subsidized electricity for agricultural irrigation, national food procurement and distribution system at a guaranteed price, and traditional land and water management practices are some of the major culprits for the rapid depletion of groundwater in India (Perveen et al., 2012). Despite increasing realization of negative impacts of these policies like subsidized electricity, substantial changes in these are not politically stress-free. Therefore, it is imperative to see better land and water management technologies to overcome the problem of groundwater depletion and to enhance farm productivity by increasing water use efficiency. Given that efficiency of irrigation at present is low in India, it is inevitable to look for alternatives to improve it (Lal, 2011). However, the alternative should be economically viable to the farmers. In addition, approximately 10-25% of irrigation water is lost during application because of poor water management and uneven fields (Kahlown et al., 2000). Improved land leveling technology can therefore save irrigation water and also reduce loss of agro-chemicals and nutrients (Jat et al., 2009; Jat et al., 2006; Jat et al., 2011).

Farmers in India now practice two technologies for leveling land: traditional land leveling (TLL) and laser land leveling (LLL). The TLL, which uses scrapers or leveling boards drawn by draft animals or tractors or even bulldozers in the case of highly undulated land, cannot achieve the desired accuracy and hence, is less likely to minimize uneven distribution of irrigation water (Jat et al., 2006). As the quality of land leveling impacts most of the farming operations along with input use efficiency and crop yield, there is a need for alternative method of land leveling. The LLL is an alternative to achieve desired level of accuracy as this uses laser equipped drag buckets in leveling land. Its use also facilitates uniformity in the placement of seeds/seedlings and better crop stands which eventually contributes to higher crop yield. A uniform field improves irrigation efficiency through ideal control of water distribution and reduces the potential for nutrient loss through improved runoff control, leading to better fertilizer use efficiency and higher yield (Jat et al., 2009; Jat et al., 2006; Jat et al., 2011). Therefore, application of LLL has a potential to increase crop yield with less use of water and fertilizer inputs compared with the traditional leveling practice. In India, where water scarcity is increasing over time, application of LLL holds tremendous potential for saving scarce water resources and increasing the stagnating yield. Despite this, there are still few empirical studies that examine the impact of LLL on crop yield, irrigation water requirements, and overall farm profitability.

Of the few studies in the IGP, Rickman (2002) claimed that rice yield in laser leveled field is 24% higher compared with traditionally leveled field. More recent study by Jat et al., (2009) evaluated various tillage and crop establishment methods under LLL and TLL in the western IGP. They found that irrespective of tillage and crop establishment methods, rice-wheat system productivity is approximately 7% higher under LLL compared with TLL and compared with TLL; LLL saves 10-12% irrigation water in rice and 10-13% in wheat. Their study shows that under LLL, RW system profitability was increased by US$113-175 ha^{-1} yr^{-1}. A study of cotton farmers in Tajikistan (Abdullaev et al., 2007) observed that the average annual net income from cotton farming in the laser leveled field was 22% higher than the control field and the gross margin from the laser leveled field was, on average, 92% higher than the control field.

Against this backdrop, this study uses household survey data collected in 2011 from two states of India to assess the impacts of using LLL on crop yields and water use. We also examined whether LLL is a scale neutral technology i.e., whether its impact varies with land sizes. This study also estimates the costs and benefits of using LLL and its economic profitability at the farm level.

The rest of the paper is organized as follows. Section 2 describes the study area, data and methodology. Section 3 provides the descriptive statistics of the survey. Section 4 presents the differences in crop yields and number of hours needed for irrigation with and without using LLL. Section 5 presents the economics of using LLL and its social benefits. Section 6 concludes the study.

2. Study area, Data and Methodology

2.1 Study area and data

This study was conducted in two Indian states: Haryana and Punjab. Three districts in Haryana viz. Karnal, Kurukshetra and Yamunanagar and three in Punjab viz. Bhatinda, Amritsar and Sangrur were selected for the household survey. The study sites captures contrasting soil types for example light soils (loamy sand to sandy loam) in Punjab and relatively medium to heavy soils in Haryana (sandy loam to clay loam). Also, the sites represents the diversity of production systems for example of the 3 districts of Punjab, 2 (Amritsar and Sangrur) are typically rice-wheat dominated and one (Bhatinda) is cotton-wheat dominated district. Similarly, in Haryana, 2 districts (Karnal, Kurukshetra) are typically rice-wheat dominated whereas Yamunanagar has diversified cropping systems such as sugarcane-wheat, potato, vegetables etc. A total of 192 farmers in each of the two states were surveyed. Table 1 presents the sample districts and the sample size.

Table 1: Study districts and sample size

Haryana state	Sample size	Punjab state	Sample size
Karnal	15	Amritsar	20
Kurukshetra	18	Bhatinda	63
Yamunanagar	63	Sangrur	13
Total	96		96

These states are considered to be the bread baskets of South Asia with primarily irrigated agriculture and rice-wheat as the dominant cropping system. Although the area is served by a developed canal irrigation system, groundwater is still a major source of irrigation (Krishna et al., 2011). In Haryana, the groundwater reserve has been depleted over time as the number of farmers using shallow and deep tube wells has increased. There are approximately 14 groundwater extraction structures per square kilometer (Kumar et al., 2007). Punjab has the similar situation, in which the rate of decline of the ground water level has been 4-5 meters during the period of 1984-94 (Joshi and Tyagi, 1994). Table 2 summarizes the status of the decline in ground water tables in the districts under study.

Table 2: Changes in water table in the districts under study

State	Period	District	Average fall of groundwater (m)
Haryana[1]	1974-2001	Karnal	3.09
		Kurukshetra	11.15
		Yamunanagar	1.10
Punjab[2]	1984-1994	Amritsar	2.3
		Bhatinda	1.9
		Sangrur	5.1

Notes: 1. Taken from (Kumar et al., 2007) and 2. Taken from (Joshi and Tyagi, 1994)

From Table 2, it is observed that among the districts under study, average fall of groundwater level is highest in Kurukshetra district and lowest in Yamunanagar district during a period of 1974-2001. In Punjab state, problem of ground water depletion is more severe in Sangrur district as compared with Amritsar and Bhatinda districts. The depletion in water table is directly co-related with the cropping systems as in general the districts with rice-wheat rotation have more serious issues of falling water tables than those with other cropping systems for example Bhatinda in Punjab and Yamunanagar in Haryana.

Data for this study were collected in 2011 from 192 households in Haryana and Punjab states of India. We collected the data using structured household-level questionnaire. The data include yields of rice and wheat, input use, input costs, land ownership, hiring cost of LLL service, time taken to laser level the land, farmers' perceptions regarding the impacts of LLL, number of irrigation per season and time required for irrigation. In order to assess the impact of using LLL on crop yield and irrigation water saving, we collected all the information from both laser leveled fields and traditionally leveled fields of the farm households. To select the sample households for the study, we used a previous village-level census survey of the sampled districts, which provided a preliminary list of farm households that had adopted LLL. The farm households were randomly selected from each district. As the number of farm households adopting LLL varied across the selected districts, random sample selection resulted in to the larger sample from the districts with large number of adopters. Replacement farmers were also selected in case some of the selected farmers were not present during the time of the survey or were unwilling or were mistakenly included in the list.

2.2 Empirical methods and measurement issues

To compare crop yields between laser leveled and traditionally leveled fields, we used mean comparison tests and stochastic dominance analysis. To assess whether the LLL is a scale neutral technology, we compared the average crop yields on laser leveled fields under different farm sizes using mean comparison tests. To analyze the economic benefits of laser land leveling, we calculated net present value of the income stream from 1 ha of laser leveled land, assuming that a one-time application of LLL lasts at least four years. Some of these methods are described below.

2.2.1 Stochastic Dominance Analysis

We used stochastic dominance analysis to compare the crop yield distribution between laser leveled land and traditionally leveled land. In this method, we compared the cumulative distribution functions (CDFs) of yield of each crop under alternative systems. There are two criteria for comparing the stochastic dominances: first-order stochastic dominance (FSD) and second-order stochastic dominance (SSD). Assume that *L(y)* and *T(y)* are cumulative distribution functions of rice (or wheat) yields for laser leveled land and traditionally leveled land respectively. Under the FSD criterion, the distribution *L(y)* dominates *T(y)* if $T(y) - L(y) \geq 0,\ \forall_y \in \Re$, with strict inequality for some $y \in \Re$. This means that the distribution with a lower density function dominates the distribution with a higher density function. In this case, *L(y)* dominates *T(y)* if the CDF of yield for traditionally leveled land *T(y)* is greater than the CDF of yields for laser leveled land *L(y)* for all level of yields (Mas-Colell et al., 1995). The FSD criterion fails if the graphs of the CDFs intersect each other. Under such a situation, we call for SSD. The SSD criterion compares the area under the CDFs. The decision rule appears similar to that of FSD. The distribution with larger area under the CDF is dominated by the distribution with smaller area under the CDF. Hence, under SSD criterion, the distribution *L(y)* dominates *T(y)* if $\int_{-\infty}^{y} \left(T(y) - L(y)\right) dy \geq 0,\ \forall_y \in \Re$, with strict inequality for some $y \in \Re$.

2.2.2 Monetary benefits of laser land leveling

As a one-time application of laser land leveling lasts for 4 years, we consider 4 year time period for estimating the incremental benefit stream of the farm household. This is given by:

$$\sum_{i=1}^{4}[p_{Ri}\Delta y_{Ri} + p_{Wi}\Delta y_{Wi}] - C_L H_L$$

where Δy_{Ri} and Δy_{Wi} refer to the additional yield of rice and wheat in laser leveled field compared with traditionally leveled field in year *i*, respectively. Likewise, p_{Ri} and p_{Wi} are the prices of rice and wheat in year *i,* respectively. The C_L and H_L are the cost of hiring laser leveling service per hour and the time required to laser level the land.

2.2.3 Measurement of water saving

In the study area, tube well is the major source of irrigation. We observed that average size of tube wells and pump horse power are almost the same among the sampled farmers. Hence, water discharge rates are quite close. Therefore, reduction in total duration of irrigation in a season is considered as water saving in this study. So, we collected information on the number of irrigation in a season and average duration of irrigation events in a season for rice and wheat in laser leveled field and traditionally leveled field. We did not focus on crop water use. One can argue that reduction in number and duration of irrigation in laser leveled fields may not imply actual water saving when we consider consumptive water use. However, of the different fraction of water uses - E, T and leaching losses, the T component which is plant water uptake is very low and thus, it is less likely to have significant difference in consumptive water use. For this reason, we focus primarily on number of irrigations per season and the duration of each event. Overall, reduced time for irrigation implies saving of irrigation water in our case.

3. Findings of the survey

Farmers of all sizes ranging from small to large are observed to have adopted LLL, indicating that LLL is not only a large-farmer technology. Availability of the local custom service provider is the main reason behind the adoption of LLL by each category of farmers. As hiring services are delivered by the local service providers, farmers are not required to make a large investment in the machine. Table 3 provides the distribution of sampled farmers by land size.

Table 3: Distribution of sample farmers by land size

	Haryana		**Punjab**		**Total**	
Land size (in ha)	Number	Percent	Number	Percent	Number	Percent
Small (up to 2)	30	31.3	24	25.0	54	28.1
Medium (>2 and up to 4)	29	30.2	23	24.0	52	27.1
Large (> 4)	37	38.5	49	51.0	86	44.8
Total	96	100	96	100	192	100

From Table 4, we observed that of the total sample farmers using LLL, 28% are small farmers whereas about 45% are large farmers. Among the adopters, the percentage of large farmers is higher in Punjab (51%) than in Haryana (38.5%).

In the study area, the adoption of LLL is a relatively new phenomenon and has been steadily increasing over the years. Table 4 shows that majority of farmers (about 53%) had first adopted LLL in the year 2009 even though the technology was introduced in these states in 2005 and first adoptions at farm level started in 2007.

Table 4: First year of adoption of laser land leveling (LLL) among sample farmers

Year of first	Haryana		Punjab		Total	
LLL adoption	Number	Percent	Number	Percent	Number	Percent
2007	6	6.3	4	4.2	10	5.2
2008	9	9.4	25	26.0	34	17.7
2009	65	67.7	36	37.5	101	52.6
2010	16	16.7	31	32.3	47	24.5
Total	96	100	96	100	192	100

With regard to the rate of LLL adoption, a clear distinction was observed between Haryana and Punjab. In Haryana, there was a sharp decline in the percentage of new adopters of LLL in 2010 (about 17%) compared with the year 2009 (about 68%)

whereas this was not the case in Punjab where adoption declined from 37.5% in 2009 to about 32% in 2010.

Most of the farmers hired LLL services from private service providers as shown in Table 5. Only five out of 192 sample farmers owned LLL machines: two farmers in Haryana and three in Punjab. Unlike Haryana, about 19% farmers in Punjab received LLL services from agricultural cooperatives, implying that these cooperatives played significant role in providing LLL services in Punjab.

Table 5: Distribution of sample farmers by type of laser land leveling (LLL) service providers

Type of service provider	Haryana		Punjab		Total	
	Number	Percent	Number	Percent	Number	Percent
Private	89	92.7	71	74.0	160	83.3
Government	2	2.1	4	4.2	6	3.1
Self-owned LLL	2	2.1	3	3.1	5	2.6
Cooperative	0	0.0	18	18.8	18	9.4
Others*	3	3.1	0	0.0	3	1.6
Total	96	100	96	100	192	100

Note: * refers to LLL service provided by the specific project such as Cereal System Initiative in South Asia (CSISA)

The sample farmers varied in the proportions of their land they laser leveled. Some farmers laser leveled their entire land whereas others laser leveled only a portion. The farmers who had partially laser leveled their lands, often cultivated rice or wheat in both types of fields. Some farmers had laser leveled only the land that is used to cultivate rice or wheat while they had traditionally leveled the land that is used for cultivating other crops such as fodder. Therefore, we classified farmers into two categories: i) partial adopters i.e., those growing rice and wheat on both laser leveled and traditionally leveled land, and ii) full adopters i.e., growing rice and wheat only on laser leveled land. Table 6 presents the distribution of farmers by these two categories.

Table 6: Distribution of sample farmers by the status of adopting laser land leveling

	Haryana		Punjab		Total	
Crops	Number	Percent	Number	Percent	Number	Percent
Rice						
Partial adopter	59	61.5	40	50.6	99	56.6
Full adopter	37	38.5	39	49.4	76	43.4
Total	96	100	79	100	175	100
Wheat						
Partial adopter	58	60.4	65	67.7	123	64.1
Full adopter	38	39.6	31	32.3	69	35.9
Total	96	100	96	100	192	100

From Table 6, it is clear that almost 57% of farmers growing rice were partial adopters of LLL whereas 43% adopted it fully. Among the wheat growers, 64% have partially adopted LLL and 36% have adopted it fully. Overall, partial adoption is common in both the cases.

4. Impacts of laser land leveling

4.1 Overall impacts

The sampled farmers were asked to qualitatively and quantitatively describe the impact of using LLL. Table 7 presents the perceptions of sample farmers with regard to the impacts of LLL on water use, crop yield, fertilizer requirement and fuel saving.

Table 7: Distribution of sample farmers according to the overall impacts of laser land leveling

	Haryana			Punjab		
Impacts	Yes	Slightly	No	Yes	Slightly	No
Reduces water use	93	3	0	96	0	0
Increases Yield	23	66	7	50	42	4
Reduces fertilizer need	0	0	96	1	0	95
Saves fuel*	7	1	88	32	5	59

*Fuel savings if any reported were fuel saved in tractor use; diesel saved by running tube-wells less. Not many farmers run tube-wells using diesel so this number was low.

Table 7 shows that all sample farmers in Punjab and almost 97% farmers in Haryana perceived that use of LLL reduces the water required for irrigation. On the contrary, almost none of the sampled farmers responded that use of LLL reduces the fertilizer need for cropping. Nearly 52% farmers in Punjab and approximately 24% in Haryana reported an increase in yield due to the use of LLL. About 33% farmers in Punjab reported fuel savings under LLL compared with 7% reporting the same in Haryana.

4.2 Impact on crop yields

To assess the impact of LLL on crop yield, we compared the yield of rice and wheat under LLL and TLL. In comparing the yield, we included only those farmers who cultivated the two crops on both laser leveled and traditionally leveled plots in a given year. As a result, the number of observations for crop yield analysis is less than total sample size in both areas. The farmers surveyed were more confident when estimating the yield increase for the year immediately after the adoption as they were particularly motivated to estimate the impact at that point in time. However, in the following years the produce from both types of plots was usually harvested together making the differences in yield more difficult to estimate and the estimates are somewhat arbitrary. The farmers also emphasized that because the level of undulation in the study areas was low to medium, the cut and fill operation did not impact the fertility of the soils; therefore, the increase in yields in the first, second and subsequent years were similar. Therefore, for consistency, the yields for the first year after leveling are compared to assess the impact of LLL on crop yield. Table 8 presents the average difference in wheat and rice yields between LLL and TLL.

Table 8: Wheat and Rice yield difference under laser land leveling (LLL) and traditional land leveling (TLL) in Haryana and Punjab.

State and crop	Average yield (Kg/ha) LLL	Average yield (Kg/ha) TLL	Average yield difference (Kg/ha)	t-test
Haryana-Wheat	4576	4291	285	2.46***
	(84.94)	(79.42)		
Haryana-Rice	5617	5295	322	1.25
	(184.66)	(179.28)		
Punjab-Wheat	4444	4083	361	4.36***
	(57.252)	(57.71)		
Punjab-Rice	6168	5807	361	1.08
	(240.08)	(232.91)		

Note: *** significant at 99% confidence level; observations are combined observations; standard errors are reported in parentheses.

From Table 9, it is clear that average yields of both wheat and rice were higher under LLL as compared with TLL. The average yields of wheat in Haryana with laser leveling and traditional leveling were 4576 kg/ha and 4291 kg/ha respectively and this difference is statistically significant at 1% level of significance. In Haryana, the average yields of rice under LLL and TLL were 5617 kg/ha and 5295 kg/ha respectively; this difference is much higher but it is not statistically significant as the variance in rice yield was much higher. This can be due to the knowledge gap among farmers who adopted LLL and can be overcome by designing appropriate policies to disseminate knowledge to farmers. Similarly in Punjab, average wheat yield was 4083 kg/ha in TLL and 4444 kg/ha in LLL, implying that use of LLL increased wheat yield by 360 kg/ha and the difference is statistically significant at 1% level. Though the yield difference in the case of rice in Punjab is not statistically significant, the rice yield on average was 5807 kg/ha with TLL while it was 6168 kg/ha with LLL. Overall on average, the difference in yields between laser leveling and traditional was slightly higher in Punjab than Haryana. These findings are also confirmed by the result of stochastic dominance analysis, which is presented in Figure 1. In the figure, we see that in all cases, the cumulative distribution function representing LLL lies below the cumulative distribution functions representing TLL, indicating that LLL dominates TLL in all cases. This means impact of LLL is positive on crop yields in both Haryana and Punjab.

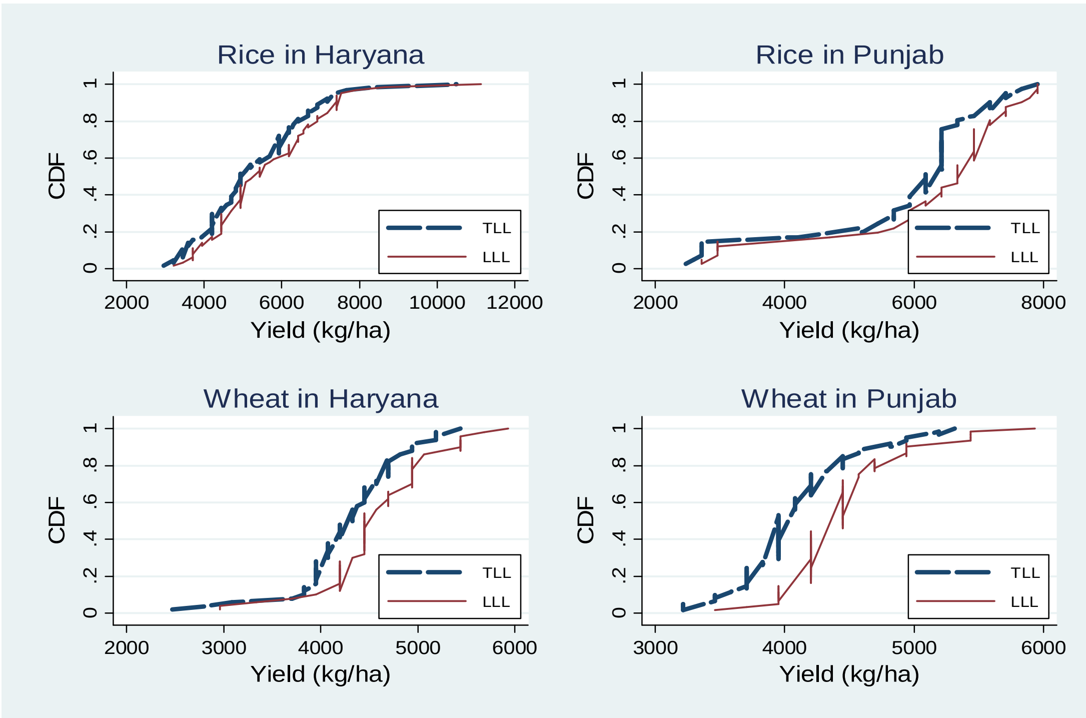

Figure 1: Yield difference between LLL and TLL using stochastic dominance analysis

A similar pattern of yield increase under LLL is observed when we compared crop yields across the districts under study. The results are summarised in Table 9. Kurukshetra and Yamunanagar districts of Haryana state achieved significantly higher average wheat yield whereas this was not the case in Karnal district. Although rice yield in laser leveled land was higher in all districts in Haryana compared with traditionally leveled land, none of these differences was statistically significant. In Amritsar and Bhatinda districts of Punjab state, the wheat yield was significantly higher in laser leveled land compared with traditionally leveled land. In case of rice, only in Bhatinda district of Punjab state we found significantly higher average yield in laser leveled land than in traditionally leveled land.

Table 9: Difference in yields between laser land leveling (LLL) and traditional land leveling (TLL) by districts

State and crops	Average yield (Kg/ha) LLL	TLL	Average yield difference (Kg/ha)	t-test
Haryana-Wheat				
Karnal	4736.02	4464.21	271.81	1.09
	(179.51)	(172.58)		
Kurukshetra	4588.94	4377.14	211.79	2.01**
	(73.48)	(75.57)		
Yamunanagar	4487.45	4175.93	311.52	2.02**
	(115.45)	(103.43)		
Haryana-Rice				
Karnal	5158.14	4828.68	329.46	0.76
	(307.37)	(309.31)		
Kurukshetra	6023.45	5683.22	340.23	1.01
	(253.17)	(226.01)		
Yamunanagar	5829.65	5523.07	306.58	0.72
	(308.75)	(292.91)		
Punjab-Wheat				
Amritsar	4562.46	4165.34	397.12	1.89**
	(150.18)	(147.34)		
Bhatinda	4321.12	3956.64	364.47	5.20***
	(49.56)	(49.55)		
Sangrur	4906.63	4641.89	264.75	0.85
	(204.82)	(236.36)		
Punjab-Rice				
Amritsar	4783.08	4509.51	273.57	0.41
	(476.64)	(470.68)		
Bhatinda	6649.81	6221.02	428.79	2.38**
	(132.42)	(122.15)		
Sangrur	7289.35	6981.71	370.65	1.07
	(236.58)	(252.53)		

Note: significance level: ***: 1%, **: 5% and *: 10%; and standard errors are reported in parentheses.

Next we examine whether LLL is a scale neutral technology. For this, we compared crop yields in laser leveled land across the different categories of farmers, classified based on land size. The results are presented in Table 10.

Table 10: Difference in yields by farmers' categories in laser leveled field

State and crop	Average yield (Kg/ha) in laser leveled field: Small farmer (1)	Medium farmer (2)	Large farmer (3)	t-tests: 1 vs. 2	1 vs. 3	2 vs. 3
Haryana-Wheat	4460	4441	4753	0.017	- 1.83*	-1.52
	(87.26)	(155.38)	(134.43)			
Haryana-Rice	5302	5874	5780	- 1.29	- 1.17	0.192
	(245.18)	(367.02)	(324.71)			
Punjab-Wheat	4283	4415	4495	-1.01	-1.82*	-0.612
	(82.37)	(101.93)	(82.14)			
Punjab-Rice	6968	6851	5708	0.380	3.13***	2.70***
	(197.68)	(235.81)	(351.19)			

Note: significance level: ***: 1%, **: 5% and *: 10%; and standard errors are reported in parentheses.

From Table 10, we observed that in Haryana state, there is no significant difference in average yield of rice across different categories of farmers in the laser leveled land whereas in Punjab small farmers obtained significantly higher average yield of rice as compared with large farmers. Both in Haryana and Punjab states, large farmers obtained higher average yield of wheat in laser leveled land than that of small farmers though the difference is significant only at 10% level. Overall, LLL is not a technology that is biased towards large farmers.

4.3 Impact on irrigation water use

LLL provides the desired level of evenness of farm fields and thus, expected to reduce irrigation water requirements. Irrigation water requirements depend not only on crop type, but also on other factors such as the amount of rainfall and the temperature in the growing season. Taking this into consideration, we compared the irrigations applied in the same year by the farmer in laser leveled field and traditionally leveled field. This provides us accurate estimation of the average reductions in irrigation water use due to the use of LLL. Table 11 provides the number of irrigations in a season and the average duration per irrigation in wheat and rice in both types of land across farmers' categories.

Table 11: Impact on irrigation water use in wheat and rice across different farmer categories

State, crop and farm size	Traditionally leveled field			Laser leveled field			Difference in total duration (h/ha)
	No. of irrigations in a season	Average duration in each irrigation (h/ha)	Total duration of irrigation in a season (h/ha)	No. of irrigations in a season	Average duration of in each irrigation (h/ha)	Total duration of irrigation in a season (h/ha)	
Haryana-Wheat							
Small	4	12.97	49.42	4	9.86	37.51	11.91
Medium	4	11.12	43.51	4	8.75	34.17	9.34
Large	4	11.56	43.34	4	8.57	32.17	11.17
Punjab-Wheat							
Small	4	8.30	33.21	4	6.45	25.80	7.41
Medium	4	9.76	39.02	4	7.51	30.00	8.99
Large	5	9.81	47.29	4	7.86	35.71	13.29
Haryana-Rice							
Small	15	12.53	203.73	15	8.65	134.32	69.41
Medium	13	10.65	145.91	13	7.71	97.26	48.65
Large	15	10.53	156.61	14	7.59	106.50	50.11
Punjab-Rice							
Small	17	9.88	171.98	14	7.36	110.21	61.78
Medium	17	9.59	169.02	16	7.41	122.07	46.95
Large	15	8.45	135.56	13	6.45	88.21	50.90

From Table 11, we observed that in wheat, the number of irrigations per season remains almost the same; however the average duration per irrigation decreases by 2-3 h/ha. This reduces irrigation water requirements of a total of 7-13 h/ha in a season. A clear difference is observed in both Haryana and Punjab states with regard to the benefits of using LLL as compared to TLL. In Haryana, small farmers were able to reduce the total duration of irrigation in wheat per season by almost 12 h/ha when they laser leveled their field. Average number of hours for each irrigation was significantly reduced in rice, a highly water intensive crop. In this case, we also observed a reduction in the number of irrigations per season. For small and medium farmers in Haryana the average numbers of irrigations remained the same in both laser leveled and traditionally leveled land; however the large farmers reduced number of irrigations by one when they laser leveled their land. In Punjab, however, farmers reduced their number of irrigations by 1-3 times. The average duration per irrigation is reduced by 2-4 h/ha. Given the large number of irrigations required, this led to a significant reduction in the total irrigation duration of around 47-69 h/ha in a season. Overall, we observed reduction in the total duration required for irrigation in laser leveled land as compared to traditionally leveled land in all sample districts as shown in Table 12.

Table 12: Impact on irrigation water use in wheat and rice under traditional land leveling and laser land leveling by districts

State, crop and Districts	Traditionally leveled field			Laser leveled field			Difference in total duration (h/ha)
	No. of irrigations in a season	Average duration of each irrigation (h/ha)	Total duration of irrigation in a season (h/ha)	No. of irrigations in a season	Average duration of each irrigation (h/ha)	Total duration of irrigation in a season (h/ha)	
Haryana-Wheat							
Karnal	4	11.71	46.83	4	8.65	34.59	12.23
Kurukshetra	4	12.11	48.38	4	9.79	39.12	9.27
Yamunanagar	4	11.64	43.37	4	8.80	32.84	10.53
Punjab-Wheat							
Amritsar	5	8.99	47.32	5	7.31	35.58	11.74
Bhatinda	4	9.59	42.58	4	7.51	32.27	12.01
Sangrur	4	10.35	41.41	4	8.10	32.37	9.04
Haryana-Rice							
Karnal	13	10.13	135.53	13	6.62	85.50	50.01
Kurukshetra	14	9.02	127.87	12	6.65	84.06	43.81
Yamunanagar	15	12.01	185.77	14	8.77	127.55	58.22
Punjab-Rice							
Amritsar	14	7.49	107.61	10	5.39	56.54	55.45
Bhatinda	17	9.98	175.74	16	8.13	132.84	42.87
Sangrur	17	8.95	155.25	15	6.25	95.21	60.05

According to Table 12, among the wheat growers in study districts, farmers in Karnal district were benefited more in terms of total irrigation time as it reduced by 12.23h/ha/season in laser leveled field. In case of rice, maximum reduction in total irrigation time (i.e., 60 h/ha in a season) was observed in Sangrur district in laser leveled field as compared with traditionally leveled.

In order to assess whether impact of LLL is scale neutral, we compared total duration of irrigation in wheat and rice per season in laser leveled land across the different categories of farmers. The results are presented in Table 13.

Table 13: Total duration of irrigation in wheat and rice by farmers' categories in laser leveled fields

	Total duration of irrigation in a season (h/ha) in laser leveled fields			Difference (h/ha)		
State and crop	Small farmer (1)	Medium farmer (2)	Large farmer (3)	(1- 2)	(1-3)	(2-3)
Haryana-Wheat	37.51	34.17	32.17	3.34	5.34	2
Punjab-Wheat	25.8	30	35.71	-4.2	-9.91	-5.71
Haryana-Rice	134.32	97.26	106.5	37.06	27.82	-9.24
Punjab-Rice	110.21	122.07	88.21	-11.86	22	36.86

From Table 13, it is observed that there is no clear biasedness towards large farmers. For instance, in the case of wheat, large farmers in Haryana were found to have shortest duration of irrigation in laser leveled field whereas in Punjab small farmers were found to have shortest duration of irrigation in their laser leveled field. Similarly, in the case of rice, medium farmers in Haryana required shortest duration of irrigation in laser leveled land while in Punjab this was the case with large farmers.

4.4 Impact on Use of fertilizer and other inputs

The farmers were questioned whether there is a difference in the fertilizer and other agricultural inputs used in the fields which are traditionally leveled vs. laser leveled. No difference was reported in the use of fertilizer and other inputs by any of the farmers in the sample. However, we can see that farmers are producing more with the same amount of fertilizer and other inputs. This means there is higher nutrient use efficiency, less nutrient loss and thus, is more environment friendly production with LLL.

5 Economics of using laser land leveling at farm

5.1 Costs of laser land leveling

5.1.1 Time required to laser level the land

Table 14 provides the information on time required to laser level a hectare of land in the study area. Majority of farmers in the study area reported that the average time taken to laser level a hectare of land was 5 hours. In Haryana, most of the farmers spent between 5 and 6 h/ha to laser level their field whereas in Punjab, they spent between 4 and 5 h/ha. Among other factors, this difference can be due to level of undulation before leveling the land. Majority of the sampled farmers reported low to medium level of undulation in their field before they laser leveled their fields.

Table 14: Time taken per hectare to laser level the land of sample farmers

	No. of farmers according to time taken to laser level the land	
Time (h)	Haryana	Punjab
2.5	2	1
3.7	5	21
5	61	72
6.2	17	2
> 6.2	11	0
Total sample	96	96

5.1.2 Costs required to laser level the land

Majority of the sampled farmers hired in laser leveling services from service providers (see Table 5). Therefore, cost of hiring the service is more important factor in determining its adoption than the cost of the laser leveling machine. Table 15 presents the rates paid per hour of use of the laser leveler by the sampled farmers. USD 10/h was the most common rate in the study area. The other common rates were between 9 and 12 USD/h which included the entire laser leveling package comprising the laser leveler, driver and fuel.

Table 15: Rates paid by the farmers per hour of use of laser leveling services

	Number of farmers paying the rate	
Rates (USD per hour)	Haryana	Punjab
4-6	3	0
6.1-7	1	1
8-9	2	1
9.1-10	62	72
10.1-11	9	4
11.1-12	19	14
12.1-13	0	4
	96	96

Note: USD 1= Rs 50

5.2. Monetary benefits of using laser land leveling

When a farmer levels 1 ha of land using laser land leveler, the effect typically lasts for at least 4 years. Thus, we assume the life of one leveling to be 4 years. We further assume that the farmer practices the dominant cropping pattern of rice-wheat during the entire period; planting rice in *kharif* and wheat in *rabi* season. Based on section 4.2 of this paper, we consider the yield differential in laser leveled land and traditionally leveled land to be 341.5 kg/ha for in rice and 323 kg/ha for wheat.

The incremental benefit stream of the farmer is:

$$\sum_{i=1}^{4}[p_{Ri}\Delta y_{Ri} + p_{Wi}\Delta y_{Wi}] - C_L H_L$$

For simplicity, we assume that the increase in price of rice and wheat and the discount rate over time will balance each other so that prices stay constant at the current minimum support prices (MSPs) as fixed by the government of India and discount rate can be assumed as one. Therefore, we calculate the benefit stream using price of rice as USD 0.22 per kg and price of wheat as USD 0.234 per kg. Then the present value of the total revenue stream is:

4* {(0.22*341.5) + (0.234*323)} = USD 602.85

Based on Table 15, we assume the cost of hiring laser land leveling service is USD 10 per hour. Similarly, using information from Table 14, we consider 5 hours to be the average time required to laser leveled a hectare of land. Therefore the total cost of leveling 1 ha is USD 50. Using these estimates, the monetary benefit or net present value of the income stream resulting from 1 ha of laser leveled land then is:

(USD 602.85 – USD 50) / 4 = USD 138.2 per hectare per year

5.3 Social benefits of reduced irrigation water use

The entire water ecosystem is a complicated system; savings in one sector may not translate to real savings overall. However given increasing water scarcity and competing and increasing demands for water by domestic and industrial users, less water used by the agricultural sector makes more water available for the other sectors. In this context, we consider water saved due to laser leveling as 'water savings'.

According to our estimates, a shift from traditional land leveling to laser land leveling would on the average increase the yields of rice and wheat by 341.5 kg/ha and 323 kg/ha, respectively. This shift would also reduce the total irrigation time per season by 10 h/ha in wheat and 55 h/ha in rice. Major benefits of using LLL in RW system in north-western Indo-Gangetic plains of India are summarized in Table 16.

Table 16: Major benefits of adopting laser land leveling in rice-wheat systems

Area under RW system and benefits of LLL	Haryana	Punjab	Total
Area under wheat (million ha) in 2011-12	2.5	3.5	6
Area under rice (million ha) in 2011-12	1.2	2.8	4
Average increase in yield due to LLL			
Wheat (kg/ha)	285	361	323
Rice (kg/ha)	322	361	341.5
Additional output benefit if LLL is adopted in 50% of the area under RW system			
Wheat (million kg/year)	357.1	630.3	987.3
Rice (million kg/year)	193.2	506.2	699.4
Total value of additional output (million USD/year)[1]			384.9
Other benefits of LLL			
Direct employment generation (million person days/year)[2]			5.1
Electricity saving (kilowatt hour/ha/year)*	555-762	555-762	
Total value of Electricity saving (million USD/year)[3]			30
Diesel saving (litre/ha/year)*	300-410	300-410	
Total value of diesel saving (million USD/year)[4]			615
Irrigation time saving			
Wheat (hours/ha/season)	10.8	9.9	10.4
Rice (hours/ha/season)	56.1	53.2	55.0
Water saving potential in RW system of north-western IGP (1000 cubic meters/year)*			270

Notes: *Taken from Jat (2012). 1. Calculated using the minimum support prices (MSPs) of wheat (USD 0.234) and rice (USD 0.22) in 2011 in India. 2. Calculated by assuming that LLL generates employment equivalent to 300 person days per unit per year and at present there are 17000 Laser units in north-western IGP. 3. Calculated assuming that RW system in north-western IGP is 1.5 million hectares. 4. Estimated using the maximum amount of diesel saved i.e., 410 litre.

In Haryana, 2.5 million ha were under wheat and 1.2 million ha were under rice cultivation in 2011-12. Even if 50% of that area can be laser leveled, this would lead to an additional yield of approximately 357 million kg of wheat and 193 million kg of rice in Haryana. Similarly in Punjab, 3.5 million ha of wheat and 2.8 million ha of rice were cultivated in 2011-12. If 50% of that area can be laser leveled, this would lead to an additional yield of 630 million kg of wheat and 506 million kg of rice. The total value of additional outputs from adopting LLL in 50% of the land under RW system in Haryana and Punjab is equivalent to USD 385 million/year.

Based on our estimates and the current statistics for the study area, we see a large potential impact of laser land leveling technology in RW systems of the north-western Indo-Gangetic plains. In the north-western IGP, there are now nearly 17000 laser units in operation (estimates based on sale of laser levers by different agencies) with the adoption of approximately 1.5 million ha in RW systems alone. With an estimate that direct employment generation by a laser unit is 300 person days per year, the 17000 laser units at present would generate the employment of 5.1 million person days annually. In addition, expanding LLL also generates indirect employment in the economy through manufacturing, transport, and maintenance services. Saving electricity is another important benefit as LLL will save electricity used for irrigation in RW systems (1.5 million ha) of the IGP equivalent to USD 30 million annually. Consequently, this saves money for the government of India as the government now spends substantial amount on subsidizing electricity for farm use. Using LLL has a large potential to save approximately 270000 cubic meters of water per year in RW systems of north-western IGP. Along with these benefits, use of LLL rather than TLL also reduces emission of GHGs and improves fertilizer use efficiency.

6 Conclusions

Compared to traditional land leveling, the use of laser land leveling led to increased yield of wheat and rice and also reduced total irrigation time required for these crops. Survey results revealed that laser leveling in rice fields brought down the irrigation time by 47-69 h/ha per season along with the yield improvement of about 7% compared with TLL. Likewise in wheat, irrigation time was reduced by 10-12 h/ha per season with the yield improvement of about 7% in Haryana and 9% in Punjab. This implies that LLL considerably saves irrigation water and also improves crop yield.

Wheat and rice yields increased almost uniformly across different categories of farmers. The use of other inputs such as fertilizer was not reduced as the farmers applied the same amount of inputs in laser leveled field as they were used to apply in traditionally level field due to the fear of yield reduction. Thus, the possibility of increased nutrient efficiency due to LLL was not fully realized by the farmers.

Reduced duration of irrigation corresponds to other benefits of using LLL. For example, as LLL reduces the time of using tube wells for pumping water for irrigation, this will save approximately 558-762 kWh of electricity ha^{-1} yr^{-1} (electric pump sets) or 300-410 liters of diesel ha^{-1} yr^{-1} (diesel pump sets) depending on the source of energy. Reduced electricity and diesel consumption lowers costs and reduces greenhouse gas emission. Therefore, LLL can also contribute to climate change mitigation. The reduction in irrigation water use also provided a social benefit that the 'saved' water could be used in the other sectors of the economy.

The monetary benefits of LLL in terms of increased yields of rice and wheat was equivalent to USD 138 ha^{-1} yr^{-1}. This analysis shows that the use of laser leveler has become economically accessible, even to small holders and resource-poor farmers. Further, the adoption of LLL in 50% of the area under RW systems in the Haryana and Punjab states can provide additional rice and wheat production amounting to USD 385 million per year.

Acknowledgements

The laser land leveling work in India was initiated through joint efforts of the Rice-Wheat Consortium for the Indo-Gangetic Plains (RWC), CIMMYT and the Indian Council of Agricultural Research (ICAR) and was out-scaled by the Indian NARES, private sector partners, manufacturers and service providers through the policy support of the Ministry of Agriculture, the Government of India and the State Governments of the respective states. We sincerely acknowledge the support of Dalip Bishnoi (CCSHAU, Hisar), field staffs of CIMMYT and farmers of Haryana and Punjab for helping in data collection for this study. Thanks also go to Dennis Wichelns, Menale Kassie and Joel Michalski (CIMMYT-India) for their valuable comments on previous version of this article. We also sincerely acknowledge the need based support from Cereal Systems Initiative for South Asia (CSISA) funded by BMGF and USAID. The support of CGIAR Research Programs (CRPs) on Climate Change, Agriculture and Food Security (CCAFS) and WHEAT (CRP 3.1) for synthesis and documentation of this study is thankfully acknowledged.

References

Abdullaev, I., Ul Hassan, M., Jumaboev, K., 2007. Water saving and economic impacts of land leveling: the case study of cotton production in Tajikistan. Irrig. Drain. Syst. 21, 251–263.

Aggarwal, P.K., Joshi, P.K., Ingram, J.S.I., Gupta, R.K., 2004. Adapting food systems of the Indo-Gangetic plains to global environmental change: key information needs to improve policy formulation. Environ. Sci. Policy 7, 487–498.

Ambast, S.K., Tyagi, N.K., Raul, S.K., 2006. Management of declining groundwater in the Trans Indo-Gangetic Plain (India): Some options. Agric. Water Manag. 82, 279–296.

Cruz, R., Harasawa, H., Lal, M., Wu, S., Anokhin, Y., Punsalmaa, B., Honda, Y., Jafari, M., Li, C., Huu Ninh, N., 2007. Asia Climate Change 2007: impacts, adaptations and vulnerability, in: Parry, M., Canziani, O., Palutikof, J., van der Linden, P., Hanson, C. (Eds.), Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, pp. 469–506.

Hanjra, M.A., Qureshi, M.E., 2010. Global water crisis and future food security in an era of climate change. Food Policy 35, 365–377.

Jat, M.L., 2012. Laser Land Leveling in India: A Success, in: Presentation Given at a Conference on "Lessons Learned from Postharvest and Mechanization Projects, and Ways Forward". Asian Development Bank's Postharvest Projects' Post-production Workgroup of the Irrigated Rice Research Consortium (IRRC), held at the International Rice Research Institute, Los Banos, Manila, Philippines, May 22-24.

Jat, M.L., Chandna, P., Gupta, R., Sharma, S.K., Gill, M.A., 2006. Laser Land Leveling: A Precursor Technology for Resource Conservation. Rice-Wheat Consortium Technical Bulletin Series 7. New Delhi, India, Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi, India.

Jat, M.L., Gathala, M.K., Ladha, J.K., Saharawat, Y.S., Jat, A.S., Kumar, Vipin, Sharma, S.K., Kumar, V, Gupta, R., 2009. Evaluation of precision land leveling and double zero-till systems in the rice–wheat rotation: Water use, productivity, profitability and soil physical properties. Soil Tillage Res. 105, 112–121.

Jat, M.L., Gupta, R., Saharawat, Y., Khosla, R., 2011. Layering precision landleveling and furrow irrigated raised bed planting: productivity and input use efficiency of irrigated bread wheat in Indo-Gangetic plains. Am. J. Plant Sci. 2, 578–588.

Joshi, P., Tyagi, N., 1994. Salt-affected and waterlogged soils in India: a review, in: Svendsen, M., Gulati, A. (Eds.), Strategic Change in Indian Irrigation. IFPRI/ICAR, New Delhi, India, pp. 237–252.

Kahlown, M.A., Raoof, A., Hanif, M., 2000. Rice yield as affected by plant densities. Mona Experimental Project Bhalwal, Report No. 238.

Kerr, R.A., 2009. Northern India's Groundwater Is Going, Going, Going .... Sci. 325 , 798.

Krishna, V., Bhatia, M., Teufel, N., 2011. Characterizing the Cereal Systems and Identifying the Potential of Conservation Agriculture in NW India, Nepal Terai and NW Bangladesh: Baseline Village Survey Report.

Kulkarni, H., Shankar, P.S.V., Krishnan, S., 2011. India's Groundwater Challenge and the Way Forward. Econ. Polit. Wkly. 46.

Kumar, V., Kumar, D., Kumar, P., 2007. Declining water table scenario in Haryana-A review. Water Energy Int. 64, 32–34.

Lal, R., 2011. Soil Degradatin and Food Security in South Asia, in: Lal, R., Sivakumar, M.V.K., Faiz, S.M.A., Rahman, A.H.M.M., Islam, K.R. (Eds.), Climate Change and Food Security in South Asia. Springer Science+Business Media B.V, pp. 137–151.

Mas-Colell, A., Whinston, M.D., Green, J.R., 1995. Microeconomic Theory. Oxford University Press, New York.

Perveen, S., Krishnamurthy, C.K., Sidhu, R.S., Vatta, K., Kaur, B., Modi, V., Fishman, R., Polycarpou, L., Lall, U., 2012. Restoring Groundwater in Punjab, India's

Breadbasket: Finding Agricultural Solutions for Water Sustainability. Columbia Water Center, Earth Institute, Columbia University, New York, USA.

Rickman, J.F., 2002. Manual for laser land leveling.

Sivakumar, M.V.K., Stefanski, R., 2011. Climate Change in South Asia, in: Lal, R., Sivakumar, M.V.K., Faiz, S.M.A., Rahman, A.H.M.M., Islam, K.R. (Eds.), Climate Change and Food Security in South Asia. Springer Science+Business Media B.V, pp. 13–28.

UN-Water, 2013. Water for Food [WWW Document]. URL http://www.unwater.org/fileadmin/user_upload/watercooperation2013/doc/Factsheets/water_for_food.pdf (accessed 8.15.13).

World Bank, 2013. Data [WWW Document]. URL http://data.worldbank.org/indicator/ER.H2O.FWAG.ZS (accessed 8.15.13).