Food Sec.
DOI 10.1007/s12571-015-0460-y

ORIGINAL PAPER

Impacts of laser land leveling in rice–wheat systems of the north–western indo-gangetic plains of India

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Received: 14 April 2014 / Accepted: 30 March 2015
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Abstract We assessed the impact of laser land leveling technology in rice-wheat (RW) 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 leveled (LLL) and traditionally leveled (TLL) fields. Laser leveling in rice fields reduced irrigation time by 47–69 h/ha/season and improved yield by approximately 7 % compared with traditionally leveled fields. In wheat, irrigation time was reduced by 10–12 h/ha/season and yield increased by 7–9 % in laser leveled fields. Our analysis showed that laser land leveling is a scale neutral technology, not biased towards large farmers. Farmers benefited by an additional USD 143.5/ha/year through increased yields in RW systems and reduced electricity used in laser leveled fields compared to traditionally leveled fields when estimated by using the electricity tariff equivalent to the average subsidized tariff for agricultural use. This benefit became much larger when estimated by using an electricity tariff equivalent to the average cost of its supply. Hence, assuming an average electricity tariff equivalent to the average cost of its supply in the year 2010–11 in the country, the net benefit of shifting from TLL to LLL in RW systems in the study area was USD 194 per ha per year. This large difference in benefits indicates the loss due to market distortions by subsidy in electricity and hence, is a matter of policy concern requiring further scrutiny. The RW system in a hectare of laser leveled field required 754 kWh less electricity for irrigation per year compared to a traditionally leveled field. Furthermore, if 50 % of the area under the RW system in Haryana and Punjab states were laser leveled, this would provide an additional production of 699 million kg of rice and 987 million kg of wheat, amounting to USD 385 million/year. Thus, laser leveling contributes to food security and economical use of water and energy resources.

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Keywords Laser land leveling · Traditional land leveling · Yield · Rice-wheat system · Irrigation

Introduction

With increasing climate variability and rapid melting of glaciers, water scarcity is expected to be a major challenge to agricultural production and food security in South Asia (Hijioka et al. 2014). Increasing temperature, which has been evident in most of the region, accentuates the demand for irrigation water. Recent studies predict that there would be at least a 10 % increase in irrigation water demand with a 1 °C 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) and thus, water scarcity is becoming a more important determinant of food security than land scarcity (Brown and Funk 2008). 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 irrigated crops and livestock production (World Bank 2013). The groundwater table has been declining in India (Aggarwal et al. 2004; Joshi and Tyagi 1994; Kerr 2009; Kumar et al. 2007) and, as irrigation is the largest user of groundwater, a declining groundwater table will impact the sustainability of agriculture and the overall food security of the country (Kulkarni et al. 2011; Perveen et al. 2012). Furthermore, use of pumped groundwater for irrigation has substantially increased the consumption of energy by the agriculture sector in India (Kumar et al. 2011). Rising demand for food production due to increased population will further amplify the energy consumption by the agriculture sector. Given the existing consumption pattern, India will need to produce at least 37 % more rice and wheat by 2025 as compared to the year 2000, with nearly 10 % less water available for irrigation (Jat et al. 2006). Therefore, there is a dire need of technologies that can conserve water resources, increase the efficiency of energy use and enhance agricultural productivity (Ambast et al. 2006; Hanjra and Qureshi 2010).

In order to raise farm productivity, several state governments in India have provided electricity for farm use at a subsidized rate. Although this has contributed substantially to national food production, it is one of the major drivers for rapid depletion of groundwater in India (Perveen et al. 2012). Due to this provision, there is a wide gap between the average tariff realized and the average cost of power supply in India. In 2010–11, the average cost of power (including all sectors of the economy) was Indian rupees[1] (Rs.) 4.84 per kWh while the average tariff was only Rs. 3.57 per kWh (GOI 2011). This gap is further enlarged by supplying electricity to farmers at flat rates based on pump capacity rather than by the amount of water use measured through a meter (GOI 2011). For example, in 2010–11, the average tariff of electricity for the agriculture sector at the national level was only Rs. 1.01 per kWh; thus the gap between the average cost of power supply and average tariff realized was Rs. 3.83 per kWh (GOI 2011). Despite the increasing realization of negative impacts of policies such as subsidized electricity, substantial changes in these are politically difficult. Therefore, it is imperative to search for better technologies that reduce energy use in agriculture and, at the same time, overcome the problem of groundwater depletion without compromising farm productivity.

Low efficiency of irrigation and poor recovery of water charges are the major problems associated with agricultural water management in India (GOI 2013). In the rice–wheat (RW) system of the Indo-Gangetic Plains (IGP), about 10–25 % of irrigation water is lost due to poor water management and uneven fields (Kahlown et al. 2000). Laser land leveling (LLL) is an alternative land leveling technology that has the primary benefit of a reduction in the loss of irrigation water occurring due to highly undulating land. Therefore, applying LLL rather than traditional land leveling (TLL) can help reduce the use of irrigation water and save energy through reduced duration of irrigation (Jat et al. 2009; Jat et al. 2006; Jat et al. 2011).

[1] 1 US$ was equivalent to 50 Indian rupees in 2010–11.

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 the uneven distribution of irrigation water (Jat et al. 2006). As the quality of land leveling impacts most farming operations along with input use efficiency and crop yield, there is a need for a better method of land leveling. LLL is a method that achieves the desired level of accuracy as it uses laser equipped drag buckets. It also facilitates uniformity in the placement of seeds/seedlings and promotes better crop-stands, which eventually contributes to higher crop yields. A uniform field improves irrigation efficiency through better control of water distribution and reduces the potential for nutrient loss through improved runoff control, leading to greater efficiency of fertilizer use and higher yields (Jat et al. 2009; Jat et al. 2006; Jat et al. 2011). In the Indo-Gangetic Plain (IGP), Rickman (2002) claimed that rice yields in laser leveled fields was 24 % higher compared with traditionally leveled fields. Jat et al. (2009) evaluated various tillage and crop establishment methods under LLL and TLL in the western IGP and found that irrespective of tillage and crop establishment methods, the rice–wheat system productivity was approximately 7 % higher under LLL compared to TLL. As compared with TLL, LLL saved 10–12 % irrigation water in rice and 10–13 % in wheat. Their study showed that under LLL, the profitability of the rice–wheat system was increased by US\$113–175 ha^{-1} $year^{-1}$. A study of cotton farming in Tajikistan showed that the average annual net income from cotton farming in a laser leveled field was 22 % higher than that from the control field and the gross margin from the laser leveled field was, on an average, 92 % higher than that from the control field (Abdullaev et al. 2007). Therefore, application of LLL has the potential to increase crop yield with less use of water, energy and fertilizer inputs as compared with the traditional leveling practice. In India, where water and energy scarcities are increasing, application of LLL holds tremendous potential for saving these resources and increasing yields that are currently stagnating. Despite this, there has been no comprehensive study which examines the impact of LLL on crop yield, irrigation duration, energy saving, and overall farm profitability.

The major objective of this study is to assess the impact of LLL on crop yield, irrigation duration, energy saving, and farm profitability. In addition, this study also assesses whether LLL is a scale neutral technology, which is equally accessible to both large and small farms. To examine this, we used household survey data collected in 2011 from two Indian states, Haryana and Punjab. Therefore, this study not only contributes to the existing body of knowledge by providing further evidence that LLL increases yields, reduces water use and saves energy, but also presents new knowledge by showing that it is a scale neutral technology.

The rest of the paper is organized as follows. The second section describes the study area, data and methodology. This is followed by a third section dealing with the descriptive statistics of the data collected during the survey. The fourth section presents the impact of LLL on crop yield, duration of irrigation required per season and its implications for energy use. The economics of using LLL is discussed in the fifth section. Key results of the study, its policy implications and conclusions form the final two sections of the paper.

Study area, data and methodology

Study area and data

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

These states are considered to be the breadbaskets of South Asia with primarily irrigated agriculture and rice–wheat (RW) 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 is similar and here the rate of decline of groundwater level has been 4–5 m during the period 1984–94 (Joshi and Tyagi 1994). Table 2 summarizes the considerable variation in the lowering of groundwater tables in the districts under study. These were maximal in Kurukshetra district (11.15 m) of Haryana state in the period 1974–2001 and in Sangrur district (5.1 m) of Punjab state in the period 1984–1994.

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

The depletion of water tables is related to the cropping systems as, in general, the districts with rice–wheat rotation, e.g., Bhatinda in Punjab and Yamunanagar in Haryana have more serious issues of falling water tables than those with other cropping systems.

Data for this study were collected in 2011 from 192 households in Haryana and Punjab, using a structured household-level questionnaire. The data included yields of rice and wheat, input use, input costs, land ownership, hiring cost of LLL services, time taken to laser level the land, farmers' perceptions regarding the impacts of LLL, number of irrigations per season and time required for irrigation. In order to assess the impact of using LLL on crop yield and saving of irrigation water, we collected all the information from both laser leveled fields and traditionally leveled fields from 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 (Fig. 1). 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 larger samples from the districts with larger numbers of adopters. Replacement farmers were

Table 2 Changes in water table in the districts under study

State	Period	District	Average fall in level 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

[1] (Kumar et al. 2007)

[2] (Joshi and Tyagi 1994)

Fig. 1 Farmer in Ludhiana, Punjab using a laser land leveler

also selected in some cases where the selected farmers were not present during the time of the survey, were unwilling or were mistakenly included in the list.

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 LLL is a scale neutral technology, we compared the average crop yields on laser leveled fields from farms of different 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 4 years. Some of these methods are described below.

Stochastic dominance analysis

This was used 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 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 levels 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 the SSD criterion, the distribution $L(y)$ dominates $T(y)$ if $\int_{-\infty}^{y} (T(y) - L(y))dy \geq 0, \forall_y \in \Re$, with strict inequality for some $y \in \Re$.

Monetary benefits of laser land leveling

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

$$\sum_{i=1}^{4} \left[p_{Ri} \Delta y_{Ri} + p_{Wi} \Delta y_{Wi} \right] + \sum_{i=1}^{4} \left[p_{EAi} \, \Delta IT_{TLL-LLL} \right] EU_h - C_L H_L$$

where Δy_{Ri} and Δy_{Wi} refer to the additional yield of rice and wheat in a hectare of laser leveled field compared with a hectare of traditionally leveled field in year i, respectively. Likewise, P_{Ri}, P_{Wi} and P_{EAi} are the prices of rice, wheat and the price of electricity for agricultural use in year i, respectively. The term $\Delta IT_{TLL-LLL}$ refers to the total difference in the duration of irrigation required for a hectare of land under a rice–wheat system (RW) between traditionally leveled fields and laser leveled fields. The expression EU_h denotes the average number of units of electricity consumption per hour of pumping water for irrigation while C_L and H_L are the cost of hiring laser leveling service per hour and the time required to laser level the land, respectively.

Measurement of water saving and energy saving

In the study area, tube wells are the major source of irrigation water. The average size of tube wells and pump horse power were almost the same among the farms sampled. Hence, water discharge rates were quite close. Therefore, reduction in total duration of irrigation in a season is considered as water saving in this study. We collected information on the number of irrigations and their average duration in a season for rice and wheat in laser leveled fields and traditionally leveled fields. We did not focus on crop water use. One can argue that reduction in number and duration of irrigations in laser leveled fields may not imply actual water saving when we consider consumptive water use. However, of the different fractions of water uses – evaporation (E), transpiration (T) and leaching losses - the T component, which is plant water uptake, is very low and is unlikely to play a significant role in any difference in consumptive water use between treatments. For this reason, we focused primarily on number of irrigations per season and the duration of each event. Overall, reduced time for irrigation implies saving of irrigation water. Energy saving was calculated based on the duration of irrigation, and the average number of units per hour of electricity used by the tube well motor to pump the water.

Descriptive findings of the survey

Farms of all sizes ranging from small to large had adopted LLL, indicating that it is not technology only for large farms. Availability of the local custom service provider is the main reason behind the adoption of LLL by each category of farm. As hiring services are delivered by the local service providers, farmers are not required to make a large investment in the machine.

Of the total number of farmers using LLL sampled, 28 % had small farms (up to 2 ha), 27 % medium sized farms and 45 % large farms (>4 ha). The number of farmers with large farms was greater in Punjab (86; 51 %) than in Haryana (49; 38.5 %; Table 3).

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

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 (to 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 (Table 5). Only five out of the 192 farmers sampled owned LLL machines - two farmers in Haryana and three in Punjab. About 19 % of farmers in Punjab received LLL services from agricultural cooperatives but none in Haryana.

Impacts of laser land leveling

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 yield, we included only those farmers who cultivated the two crops on both laser leveled and traditionally leveled plots in a given year. The farmers surveyed were more confident and motivated to estimate the yield increase for the year immediately after the adoption. In most cases, the produce from both laser leveled and traditionally leveled fields was harvested together in the following years. This makes it difficult to estimate the yield differences in the later years as farmers' reporting can be less accurate in such cases. The farmers in the study areas also reported that as the level of undulation in the study areas was low to medium, the cut and fill operation was unlikely to impact the fertility of the soils (Jat et al. 2006). Therefore, the increase in yields in the first, second and subsequent years were similar. For consistency, the yields for the first year after leveling were compared to assess the impact of LLL on crop yields (Table 6). We have also accounted for other factors such as level of mechanization and crop varieties in order to ensure that yield differences were primarily due to leveling.

From Table 6, it is clear that average yields of both wheat and rice were higher under LLL as compared to 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 the 1 % level. In Haryana, the average yields of rice under LLL and TLL were 5617 kg/ha and 5295 kg/ha, respectively; this difference is greater but it is not statistically significant as the variance in rice yield was much greater. This may be due to a knowledge gap among farmers who adopted LLL and could be overcome by designing appropriate policies to disseminate knowledge to farmers. Similarly in Punjab, the average wheat yield was 4083 kg/ha in TLL and 4444 kg/ha in LLL, an increase of 361 kg/ha which was statistically significant at the 1 % level. Although the yield difference in the case of rice in Punjab was also 361 kg/ha, this was not statistically significant. The difference in yields between laser leveling and traditional levelling was slightly higher in Punjab than Haryana. These findings were also confirmed by stochastic dominance analysis, which is presented in Fig. 2. 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 that the impact of LLL is positive on crop yields in both Haryana and Punjab.

Table 3 Distribution of farmers adopting LLL by land size

Land size (in ha)	Haryana		Punjab		Total	
	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

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

Year of first LLL adoption	Haryana		Punjab		Total	
	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

Similar patterns of yield increases under LLL were observed when crop yields across districts were compared. All three districts in Haryana State achieved higher average wheat yields and these were significant in Kurukshetra and Yamunanagar but, owing to variation, not significant in Karnal district (Table 7). 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. For rice, only in Bhatinda district of Punjab were yields significantly higher in laser leveled land than in traditionally leveled land.

Next we examined whether LLL is a scale neutral technology. For this, we compared crop yields in laser leveled land across the different categories of farmers, classified according to farm size (Table 8).

In Haryana state, there was no significant difference in average yield of rice across different categories of farms in the laser leveled land whereas in Punjab the yields from small farms was significantly higher than those from large farms. In contrast wheat yields from large farms in both Haryana and Punjab states were higher on laser leveled land than that of small farms though the difference was significant only at the 10 % level.

Impact of LLL on irrigation duration and energy used for irrigation

LLL provides evenness of farm fields and is thus expected to reduce the requirement for irrigation water. This depends not only on crop type but also on other factors such as the amount of rainfall and the temperature during the growing season. Taking these into consideration, we compared the duration of irrigation per season in the same year for laser leveled and traditionally leveled fields (Table 9).

For wheat in both States and for both LLL and TLL, the number of irrigations per season was almost the same but the total duration of irrigation was reduced by 7–12 h/ha. Similarly for rice, a highly water intensive crop, the number of hours of irrigation was significantly reduced by 47–69 h/ha. For small and medium farms in Haryana the average numbers of irrigations remained the same in both laser leveled and traditionally leveled land but for large farms the number of irrigations was reduced by one for LLL. In Punjab, however, farmers reduced their number of irrigations by 1–3, according to the size of farm.

Among wheat growers in the different districts studied, there was little difference in duration of irrigation per season between TLL and LLL (Table 10). For rice the differences were more marked, varying between 43 h/ha and 60 h/ha (Table 10).

In order to assess whether impact of LLL is scale neutral, we compared total duration of irrigation in wheat and rice per

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[a]	3	3.1	0	0.0	3	1.6
Total	96	100	96	100	192	100

[a] Refers to LLL service provided by the specific project such as Cereal System Initiative in South Asia (CSISA)

Table 6 Wheat and Rice yields under laser land leveling (LLL) and traditional land leveling (TLL) in Haryana and Punjab determined 1 year after leveling

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

[a] Significant at 99 % confidence level; observations are combined observations; standard errors are reported in parentheses

season in laser leveled land across the different categories of farmers (Table 11).

There was no clear bias towards large farms. For instance, in the case of wheat, large farms in Haryana had the shortest duration of irrigation in LLL fields whereas in Punjab small farms with LLL fields had the shortest duration. Similarly, in the case of rice, medium farms in Haryana required the shortest duration of irrigation in LLL fields while in Punjab this was the case with large farms (Table 11).

Given that the average capacity of tube well motors used in Haryana and Punjab is about 10 BHP (Break Horse Power), they require about 8 kWh of energy per operational hour (DHBVN 2014). In addition, the distribution loss is almost 31 % in India (GOI 2011). This means that to supply 1 kWh of electricity, India needs to generate 1.31 kWh. So the actual energy cost for the electricity authority becomes much higher in this case. In general a shift from traditional land leveling to laser land leveling reduces the duration of irrigation by 60 h/ha in rice production and 12 h/ha in wheat production. Hence, on average the electricity required to run a tube well motor for 72 h will be saved in the rice–wheat system in a hectare of land. Thus, the electricity saving is given by: 72 per ha * 8 kWh* 1.31 = 754.56 kWh per ha.

A recent report by Haryana Electricity Regulatory Commission stated that the tariff rate of Rs. 6.64 per kWh is required to cover the cost of electricity supply in agricultural water pumping (HERC 2014). Thus, the monetary value of saved electricity in the rice-wheat system of production in a hectare of a laser leveled field as compared to the traditionally leveled field is equivalent to about USD 100 per year.

Economics of using laser land leveling

Costs of laser land leveling

Total cost of laser leveling a hectare of land is calculated by multiplying the time required to laser level a hectare of

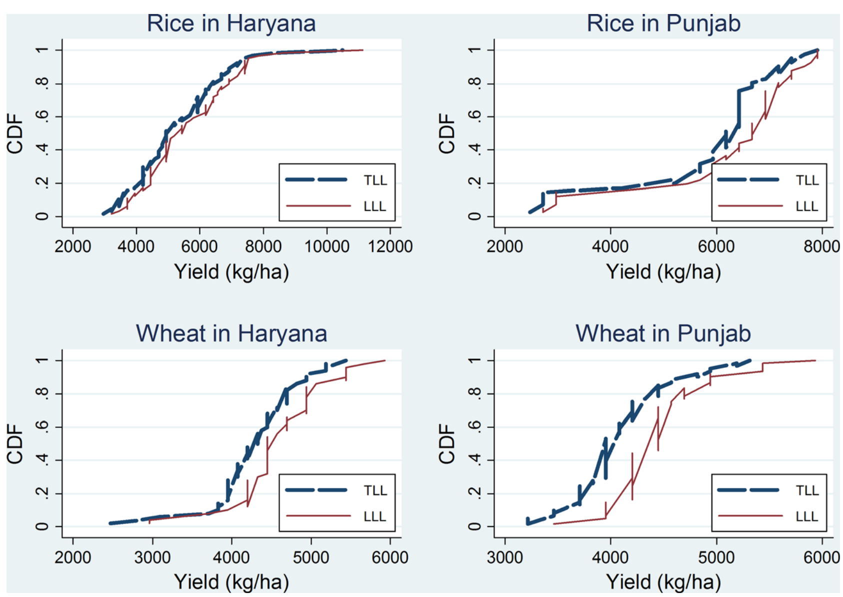

Fig. 2 Yield difference between LLL and TLL using stochastic dominance analysis

Table 7 Difference in yields between laser land leveling (LLL) and traditional land leveling (TLL) by districts

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

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

land and the rental price of hiring laser leveling service for an hour. Most of the farmers in Haryana reported that it took between 5 h and 6 h to laser level one hectare of land whereas it was between 4 h and 5 h in Punjab. Therefore, we used 5 h as the average time to laser level one hectare of land.

The majority of farmers hired in laser leveling services from service providers (Table 5). Therefore, cost of hiring the service is a more important factor in determining its adoption than the price of a laser leveling machine. In the study areas, the most common rate for use of a laser leveler was USD 10/h (one USD was equivalent to 50 Indian Rupees

Table 8 Differences in yields by size of farm in laser leveled fields

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

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

Table 9 Impact on irrigation water use in wheat and rice across different farm categories

State, crop and farm size	Traditionally leveled field		Laser leveled field		(A−B)[#]
	No. of irrigations in a season	Total duration of irrigation in a season (h/ha) (A)	No. of irrigations in a season	Total duration of irrigation in a season (h/ha) (B)	
Haryana-Wheat					
Small	4	49.4	4	37.5	11.9
Medium	4	43.5	4	34.2	9.3
Large	4	43.3	4	32.2	11.2
Punjab-Wheat					
Small	4	33.2	4	25.8	7.4
Medium	4	39.0	4	30.0	9.0
Large	5	47.3	4	35.7	11.6
Haryana-Rice					
Small	15	203.7	15	134.3	69.4
Medium	13	145.9	13	97.3	48.7
Large	15	156.6	14	106.5	50.1
Punjab-Rice					
Small	17	172.0	14	110.2	61.8
Medium	17	169.0	16	122.1	47.0
Large	15	135.6	13	88.2	47.4

Note: # all the differences are significant at 1 % level of significance

during the time of survey). This included the entire laser leveling package comprising the laser leveler, driver and fuel. Therefore the total cost of leveling one hectare of land was USD 50.

Monetary benefits of laser land leveling

When a farmer levels 1 ha of land using a laser land leveler, the effect typically lasts for at least 4 years. Thus, we assumed

Table 10 Impact on irrigation water use in wheat and rice under traditional land leveling and laser land leveling by districts

State, Crop and District	Traditionally leveled field		Laser leveled field		A–B
	No. of irrigations per season	Total duration of irrigation per season (h/ha) (A)	No. of irrigations per season	Total duration of irrigation per season (h/ha) (B)	
Haryana-Wheat					
Karnal	4	46.8	4	34.6	12.2
Kurukshetra	4	48.4	4	39.1	9.3
Yamunanagar	4	43.4	4	32.8	10.5
Punjab-Wheat					
Amritsar	5	47.3	5	35.6	11.7
Bhatinda	4	42.6	4	32.3	10.3
Sangrur	4	41.4	4	32.4	9.0
Haryana-Rice					
Karnal	13	135.5	13	85.5	50.0
Kurukshetra	14	127.9	12	84.1	43.8
Yamunanagar	15	185.8	14	127.6	58.2
Punjab-Rice					
Amritsar	14	107.6	10	56.5	51.1
Bhatinda	17	175.7	16	132.8	42.9
Sangrur	17	155.3	15	95.2	60.0

Table 11 Total duration of irrigation in wheat and rice by farmers' categories in laser leveled fields

State and crop	Total duration of irrigation in a season (h/ha) in laser leveled fields			Difference (h/ha)		
	Small farm (1)	Medium farm (2)	Large farm (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

the life of one leveling to be 4 years. We further assumed that the farmer practises the dominant cropping pattern of rice–wheat (RW) during the entire period - planting rice in the *kharif* season and wheat in the *rabi* season. We considered the yield differential in laser leveled land and traditionally leveled land to be 341.5 kg/ha for rice and 323 kg/ha for wheat (mean of values for the two states; Table 6).

The net incremental benefit stream of the farmer is:

$$\sum_{i=1}^{4}\left[p_{Ri}\Delta y_{Ri}+p_{Wi}\Delta y_{Wi}\right]+\sum_{i=1}^{4}\left[p_{EAi}\Delta IT_{TLL-LLL}\right]EU_{h}-C_{L}H_{L}$$

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 the discount rate can be assumed as one. Therefore, we calculated the benefit stream using minimum support prices of rice and wheat for the year 2011. The minimum support prices of rice and wheat were USD 0.22/kg and USD 0.234/kg, respectively. Likewise, we assumed the average break horse power (BHP) of water pumps as 10–15 BHP and thus, electricity use per hour of its operation is around 8 kWh. As LLL on average reduces duration of irrigation by 60 h for rice and 12 h for wheat, the total reduction is 72 h for the rice–wheat rotation. Given that electricity is provided at the flat rate in both of these states, there is no significant difference in farmers cost of electricity under LLL and TLL. For example in Punjab, the electricity tariff rate without government subsidy for agricultural use was Rs. 3.20 per kWh or Rs. 273 per BHP per month and with government subsidy, this reduced to Rs. 0.59 per kWh or Rs 50 per BHP per month (PSERC 2011). In Haryana, the electricity tariff for agriculture tube-well supply is Rs. 0.33 per kWh for metered supply and for unmetered supply this rate is Rs. 33 per BHP per month (DHBVN 2014). We used average subsidized electricity tariff (i.e., Rs. 0.46) to calculate cost saving by shifting from TLL to LLL for rice–wheat production. As there has been no significant change in the subsidized rates over the last four years starting from 2010, we used a constant rate to calculate the net present value in this study. This makes for simplicity in calculation and yet, provides realistic estimates. Considering the subsidized tariff of electricity for agricultural use, the net present value of the total revenue stream for the entire period of 4 years from the rice–wheat system in a hectare of laser leveled land is given by:

$$\begin{aligned}&4^{*}\{(0.22^{*}341.5)+(0.234^{*}323)\}\\&+\left[4^{*}\{(0.46)^{*}72^{*}8\}\Big/50\right]-50\\&=\text{USD }574.05\end{aligned}$$

Therefore, the net present value of the additional income stream resulting from 1 ha of laser leveled land under RW systems in a year is USD 143.52.

This additional benefits of shifting from TLL to LLL is much higher if it is estimated at the electricity tariff equivalent to the average cost of its supply. For example, in the year 2010–11, average cost of power was Rs. 4.84 per kWh (GOI 2011). Hence, the benefit stream

$$\begin{aligned}&4^{*}\{(0.22^{*}341.5)+(0.234^{*}323)\}\\&+\left[4^{*}\{(4.84)^{*}72^{*}8\}\Big/50\right]-50\\&=\text{USD }775.64\end{aligned}$$

Therefore, when estimated using the average cost of electricity supply rather than subsidized tariff of electricity for agricultural use, the net present value of the additional income stream resulting from 1 ha of laser leveled land under rice RW systems in a year is USD 194. Furthermore, this can be much larger if estimated using the average cost of electricity supply at the subsequent year.

Discussion

This study confirms that the adoption of laser land leveling has direct implications for food security through increased local food production, water resource conservation through reduced duration of irrigation, and also reduced energy use due to fewer hours of irrigation required in RW systems. As total duration of irrigation in laser leveled field is significantly lower, this reduces the electricity use for irrigation by 754.6 kWh per ha in the rice–wheat system in the IGP. This saving of electricity is equivalent to about USD 100 when electricity is priced at the average cost of its supply (i.e., around Indian Rupees[2] 6.64 per kWh). Such a decline in electricity use in agriculture would reduce fiscal burden to the government of India through reduced subsidy requirement for electricity used for irrigation. In a situation when the governments of these states are in quest of measures to conserve water and energy resources, LLL can be one of the most appropriate technologies to promote at national level.

Average time required to laser level the field for the first time is 5 h/ha. However, this can vary depending on the level of undulation of farm land. In some cases, insignificant differences between crop yields in laser leveled and traditionally leveled field can also be due to low undulation of farm land even before the application of laser leveling. In the study area, the majority of the sampled farmers reported low to medium level of undulation before they laser leveled their fields. Similarly in the study areas laser land leveling on dry fields is a common practice. As a result, rainfall during the period when laser leveling is usually carried out can affect the adoption of laser land leveling by farmers.

Improved crop yields with reduced amounts of irrigation water use is a crucial finding of this study. Our estimates exhibit that a shift from traditional to laser land leveling would, on average, increase yields of rice and wheat by 341.5 kg/ha and 323 kg/ha, respectively. In Haryana, 2.5 million ha were under wheat and 1.2 million ha were under rice 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 could 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 a rice wheat system in Haryana and Punjab is equivalent to USD 385 million/year. This additional output alone could feed approximately 7 million people per year (calculated assuming that 650 g of cereals per capita per day as a minimum consumption requirement). Though increased yield is only associated with the food availability aspect of food security, it is a very crucial aspect. This is mainly due to the fact that international cereal markets are thin and even a small shift in supply and demand can cause large shifts in price, thereby restricting the poor's access to food (Lampietti et al. 2011). Furthermore, local food availability is an important aspect of food security for rural farmers as there is evidence that major cereal exporters could ban exports in bad years due to fear of domestic shortage (Lampietti et al. 2011).

A shift from traditional land leveling to laser land leveling would also reduce the total irrigation time per season by around 10 h/ha in wheat and around 60 h/ha in rice. Thus LLL minimizes the water use for agriculture and also reduces the energy required to operate the water pumps. If the current economic growth and increase in population continue, future water demand in India will grow substantially. Though the exact figures are contested, all projections indicate a sharp increase in water demand from all sectors - domestic, agricultural and industrial. Amarasinghe et al. (2007) projected that average domestic water demand would increase from 85 l per capita per day (lpcd) in 2000 to 170 lpcd by 2050. Their study also estimated that livestock water demand in India would increase from 2.3 billion cubic meters (bcm) in 2000 to 3.2 bcm by 2050. Similarly, industrial water demand is projected to increase from 30 bcm in 2000 to approximately 151 bcm by 2050. On account of this situation, scaling up of LLL technology is crucial as it has the potential to save approximately 270,000 cubic meters of water per year in the rice–wheat system of the north–western IGP (Jat 2012). Though the water saving in agriculture may not substantially contribute to other sectors given the complexity of the entire water ecosystem, it would minimize the severity of the problem of increasing water scarcity. Given the competing and increasing demands for water by domestic and industrial users, less water used by the agricultural sector makes more water availability for other sectors. In this context, water saved in irrigation due to laser leveling of the farmer's field has a broad policy implication for the sustainability of agriculture and water resource management.

As India has rapidly shifted since the 1970s to groundwater for irrigation, its irrigation system relies more on energy security (Kumar et al. 2011). The share of energy consumed for agriculture, however, differs considerably among states. For instance, in 2009–10, the share of agricultural consumption of electricity to total consumption was 21 % at national level, whereas it was much higher in Haryana (40.3 %) and Punjab (33.5 %) (GOI 2013). This has substantially increased the amount spent on power subsidy for agriculture; for example in the year 2010–11, it was more than USD45 million for Punjab state alone (Perveen et al. 2012). Our estimate shows that the reduction in the time required for irrigation in laser leveled field corresponds to electricity saving of 754.6 kWh per ha per year for rice–wheat system. As a result, if 1.5 million ha of land under the rice–wheat system of the IGP is laser leveled, this would save electricity used for irrigation equivalent to USD 30 million/year. Consequently, this saves money for the government of India as it currently spends a substantial amount on subsidising electricity for farm use. These results therefore carry a vital message for policy makers in terms of setting an enabling environment so that improved

[2] Here USD 1=Indian rupees 50

technologies like LLL would be accessible to a greater number of farmers. Along with these benefits, a study in Haryana by Gill (2014) reported that use of LLL rather than TLL also reduces emission of greenhouse gases through decreased water pumping time, decreased cultivation time and increased efficiency of fertilizer use. His study showed that generation of electricity in India is based on GHG-emitting resources; almost 68 % of total electricity generation is based on thermal power including coal-fired stations (59 %) and natural gas-fired stations (9 %). Under the existing technology, generating one kWh of electricity in the country produces 10.2 kg of CO_2eq emission (INCCA 2010). Therefore, a reduction in the duration of irrigation avoids the GHG emission that would otherwise have incurred while generating the electricity required to operate tube-well motors for pumping water for irrigation. Gill (2014) showed that 2.6 kg CO_2 is emitted per litre of diesel consumed by the tractor used for cultivation of land. As the cultivation time is reduced by almost 2 h/ha in laser leveled fields as compared to traditionally leveled ones, this will largely reduce CO_2 emission due to tractor use for cultivating land (Gill 2014). Similarly, although farmers in the study area have applied the same amount of fertilizer per unit of land under both treatments, they obtained a much higher yield in the laser leveled field. This indicates that fertilizer use efficiency is much higher in laser leveled field as compared to traditionally leveled field. As use of fertilizer is associated with the emission of nitrous oxide (N_2O), a gas which has 310 times higher global warming potential than CO_2, efficiency of fertilizer use is crucial to reduce GHG emission from the agriculture sector.

Another potential impact of laser land leveling technology in RW systems of the north–western Indo-Gangetic plains is on employment generation. Based on the recent statistics on sales of laser land levelers by different agencies, there are now nearly 17,000 laser units in operation in the area. With an estimate that direct employment generation by a laser unit is 300 person days per year, the 17,000 laser units at present would generate the employment of 5.1 million person days annually (Jat 2012). In addition, expanding LLL also generates indirect employment in the economy through manufacturing, transport, and maintenance services.

LLL is not a technology that is biased towards large farms. However, in order to increase its uptake, socio-cultural barriers, especially gender inequalities need to be addressed. Our discussion with LLL service providers in the study areas revealed that a woman farmer would never approach a male LLL owner or service provider in order to make a hiring contract. She often does the deal through one of her children or through a male relative. This is mainly due to existing gender norms in the society which constrain their participation in the public domain. As a result, access to information about new technologies by female headed households is limited. Thus, removing such constraints could raise the uptake of resource conserving technologies including LLL (Aryal et al. 2014). A recent study in the IGP showed that economic benefits from resource conserving technologies may not be sufficient to motivate smallholder farmers for its adoption and thus indicates a need for proper design of promotional incentives (Aryal et al. 2015).

Conclusion

Laser land leveling reduces the use of water for irrigation and increases crop yields. Irrigation time in laser leveled fields was reduced by 47–69 h/ha/season in rice and by 10–12 h/ha/season in wheat and yields of wheat and rice were 7–9 % and 7 % higher, respectively, in laser leveled fields as compared to traditionally leveled ones. Reduced duration of irrigation corresponds to decrease in energy use for agriculture and thus lowers greenhouse gas emission from agricultural activities. Therefore, increasing the use of LLL contributes to climate change mitigation. In addition, less use of water for irrigation also provides scope for the water saved to be used in other sectors of the economy e.g., to satisfy the needs of increasing populations, industrialization and urbanization.

The net monetary benefits from 1 ha of laser leveled field in terms of increased yields of rice and wheat and reduced electricity consumption was equivalent to USD 143.5/year when we used an electricity tariff equivalent to the average subsidized electricity tariff for agricultural use. This benefit becomes much larger if we use an electricity tariff equivalent to the average cost of its supply. Hence, assuming average electricity tariff equivalent to average cost of its supply in year 2010–11 in the country, the net benefit of shifting from TLL to LLL in RW systems in the study area is USD 194 per ha per year. This large difference in benefits indicates the loss due to market price distortions by subsidizing electricity and hence is a matter for further scrutiny.

Despite being a relatively new technology in the study areas, LLL has been steadily adopted by farmers and is economically manageable, even by smallholders and resource-poor farmers. Most farmers hire LLL services from private service providers and this has contributed to scale neutrality. Based on our estimations the adoption of LLL in 50 % of the area under RW systems in the Haryana and Punjab states could provide additional rice and wheat production amounting to USD 385 million per year. Adopting LLL also saves electricity amounting to about 755 kWh per ha for the rice–wheat system; this is equivalent to USD 100, estimated using the average cost of supply. Overall, adoption of LLL technology promotes agricultural productivity, energy use efficiency and water use sustainability.

Acknowledgements The laser land leveling work in India was initiated through joint efforts of the Rice–Wheat Consortium (RWC) for the Indo-

Gangetic Plains, the International Maize and Wheat Improvement Center (CIMMYT) and the Indian Council of Agricultural Research (ICAR) and was out-scaled by the National Agricultural Research System (NARS), 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 from Chaudhary Charan Singh Haryana Agricultural University (CCSHAU) at Hisar in Haryana, 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, Joel Michalski, Christian Boeber and Sofina Maharjan for their valuable comments on previous versions of this article. We acknowledge the support from Cereal Systems Initiative for South Asia (CSISA)-Phase I, funded by the Bill and Melinda Gates Foundation (BMGF) and the United States Agency for International Development (USAID). The support of Consultative Group in International Agricultural Research (CGIAR) Research Programs (CRPs) on Climate Change, Agriculture and Food Security (CCAFS) and Wheat (CRP 3.1) for analysis, synthesis and documentation of this study is thankfully acknowledged. Finally we thank two anonymous reviewers and the editors of this journal for their valuable comments and suggestions to improve this paper.

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