CIMMYT-CCAFS

An Assessment of the Impact of Laser-Assisted Precision Land Levelling Technology as a Component of Climate-Smart Agriculture in the State of Haryana, India

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It hardly needs to be added that any errors and significant omissions are the sole responsibility of the author of this report.

Acronyms and Abbreviations

BARC	Bangladesh Agricultural Research Council
BMP	best management practice
BPL	below-poverty-line
CC	climate change
CCAFS	Climate Change, Agriculture and Food Security
CDF	cumulative distribution function
CH_4	methane
CIMMYT-CCAFS	CIMMYT component of the CCAFS program
CO_2	carbon dioxide
CO_2eq	carbon dioxide equivalent
CSA	Climate-Smart Agriculture
CSISA	Cereal Systems Initiative for South Asia
CSV	Climate-Smart Village
cumec	cubic metres per second
cusec	cubic feet per second
DTW	deep tubewell
EIGP	Eastern Indo-Gangetic Plain
FHH	female headed household
F-SP	Farmer-Service Provider
FY	Financial Year
GFAR	Global Forum for Agricultural Research
GHG	greenhouse gas
ha	hectare(s)
HP	horsepower
hr/ha	hours per hectare
HYV	high yielding variety
ICAR	Indian Council of Agricultural Research
IGP	Indo-Gangetic Plain
INR	Indian Rupees
IPCC	Intergovernmental Panel on Climate Change
IRR	internal rate of return
IRRI	International Rice Research Institute
kg	kilogram(s)
kW	kilowatt(s)
kWh	kilowatt-hour
LLL	laser-assisted precision land levelling
LLP	low-lift pump
lt/hr	litres per hour
MGNREGA	Mahatma Ghandi National Rural Employment Guarantee Act
MHH	male headed household
mm	millimetres
MT	metric tons
MW	megawatt
N_2O	nitrous oxide
NARC	National Agricultural Research Council (Nepal)
NPV	net present value
NRM	natural resource management

OBC	Other Backward Caste (India)
OECD	Organization for Economic Development and Coordination
OECD-DAC	OECD Development Assistance Committee
PPP	purchasing power parity
PPPCF	purchasing power parity conversion factor
PARC	Pakistan Agricultural Research Council
qtl	quintal (100 kg)
qtl/hr	quintal/hour
R&M	repair and maintenance
RWC	Rice-Wheat Consortium for the Indo-Gangetic Plains
SC	Scheduled Caste (India)
SOC	soil organic carbon
SSI	semi-structured interview
ST	Scheduled Tribe (India)
STW	shallow tubewell
TLL	traditional land levelling
UP	Uttar Pradesh
USD	US dollar
WTP	willingness to pay
σ	standard deviation

Conversion Factors

Although India officially uses the metric system, farmers and even machinery manufacturers often use (Imperial) measures introduced in British colonial times. Hence tractor engines, pumps and tubewell motors are rated in horsepower, rather than kilowatts and flow rates of pumps are stated in cusecs, rather than litres/second. Farmers even mix the two systems, as when they report areas in acres, but output in metric terms: in the 2014 survey they invariably reported yields in terms of 'quintals per acre'. The following listing of conversion factors may therefore be useful.

Traditional to Metric	Metric to Traditional
1 acre = 0.49469 hectares	1 hectare = 2.47105 acres
1 horsepower = 0.7457 kilowatts	1 kilowatt = 1.341 horsepower
1 Imperial ton[a] = 1.016047 metric tons	1 metric ton = 0.9842 Imperial tons[a]
1 US ton[b] = 0.90718 metric tons	1 metric ton = 1.10232 US tons[b]
1 pound = 0.45359 kilograms	1 kilogram = 2.2046 pounds
1 cusec = 0.028316846592 cumecs[c]	1 cumec[c] = 35.31466672 cusecs
1 cusec ≈ 28.3 litres/second	1 litre/second ≈ 0.03534 cusec
1 acre-foot = 1.23348184 megalitres	1 megalitre = 0.810713192 acre-feet

[a] Also known as the 'long ton' (= 20 hundredweight @ 112 pounds each)
[b] Also known as the 'short ton' (= 20 hundredweight @ 100 pounds each)
[c] 1 cubic metre = 1,000 litres

Executive Summary

This assessment covers a component of CIMMYT's Climate Change-relevant research activities that had their origins prior to 2011, but to which a CC dimension has been added by CCAFS interventions. It focuses on Laser-Assisted Precision Land Levelling (LLL) in the western Indo-Gangetic Plain. This technology which was first introduced into the region in 2011 under the auspices of the Rice-Wheat Consortium for the Indo-Gangetic Plains, an initiative that was convened jointly by CIMMYT, the International Rice Research Institute and a number of national and sub-national research institutes in the region.

When land is flood-irrigated, any degree of undulation in the soil surface can seriously reduce both water and land productivity. The LLL is a tractor-towed, laser-controlled device that achieves an exceptionally flat, even surface. It has three principal advantages:

- Potential for increased commercial profitability through: improved crop establishment, reduced weed infestation, improved uniformity of crop maturity, decreased time requirements, reduced volume of water for land preparation, improved crop yields, increased cultivated area (due to elimination of bunds), and reduced water requirements for irrigation
- Natural resource conservation and climate change adaptation, primarily through significantly reduced water requirements
- Climate change mitigation through emission reductions stemming from decreased pumping of irrigation water

The present study builds on a household survey conducted by CIMMYT-CCAFS in 2011 which covered 192 LLL adopters from different farm size groups in three districts each in the states of Haryana and Punjab (Aryal *et al* 2013). The Key findings were:

- In both states laser levelling of rice fields reduced irrigation time by 45-55 hrs per ha per season. In wheat, the reduction was10-12 hrs per ha per season
- The yield increases resulting from LLL were estimated at 340 kg/ha for rice and 320 kg/ha for wheat
- The resulting net present value of the increased income stream amounted to US$ 113 per hectare in the first year and by US$ 175 in the second year
- The reduction in the time for the use of tubewells for irrigation in the rice-wheat system amounted to 560-760 kilowatt hour of electricity per hectare per year on electric pumpsets and 300-410 litres of diesel/hectare/year on diesel pumpsets
- A flourishing market has developed in hiring out LLL services, and a significant number of smallholders are using the technology, so it can be described as scale-neutral

The findings of the above study supplies a very useful platform on which to build a further assessment of the impact of LLL. A 'key informant' study conducted in 2014 complements the 2011 survey in a number of ways, mainly because while earlier study was conducted from a demand perspective (LLL hirers), the later one used a supply perspective, with a sampling frame comprising owners of LLL equipment who both used this equipment on their own farms and provided LLL services to other farmers.

Methodology

The 2011 study covered six districts, three each in the states of Haryana and Punjab. However the 2014 study was conducted by a single researcher during a three week period in February. These constraints limited the study to one district in the State, namely Karnal (which was also one of those included in the 2011 study). Karnal was chosen purposefully because it is the area in the IGP in which CIMMYT-CCAFS first established its ‘Climate-Smart Village’ (CSV) model, and it also has the largest number of such villages, the earliest dating from the start of the Project in 2011. In these CSVs the Project is promoting a range of techniques and technologies, including LLL, that contribute to ‘Climate Smart Agriculture’ (CSA). This makes Karnal the most appropriate area in which to investigate the extent to which there are synergies and complementarities between LLL and the other elements of CSA as promoted in the CSVs. Twenty farmers within the CSVs in Karnal own LLLs, and all of them were interviewed. A major reason for limiting the study to these particular villages (apart from time constraints) was that they already have a close relationship with CIMMYT-CCAFS staff, and trust levels were high. The study was conducted through a series of semi-structured interviews with the owners. The SSI is based on a general framework of mainly open-ended questions, which permits new ideas to be brought in based on responses to questions. Although the sample size is small, it permits exploration of ‘why’ and ‘how’ questions, while larger questionnaire-based surveys are necessarily limited to ‘what’ and ‘how much’ questions.

Commercial Profitability of Investment in LLL

If the process of adoption of CSA is to be successful, it will be commercial profitability that will drive it forward. In this case, LLL investment was assessed using Internal Rate of Return (IRR), the discount rate that reduces the net present value of all cash flows from the investment to zero. The larger this discount rate, the more profitable the investment.

Details of the calculations are shown in Annex 2 for a number of different of investment assumptions. The IRR of an investment in LLL equipment ranges from 120 per cent with diesel low lift pumps to 115 per cent with tubewells. In both cases the payback time is less than a year, indicating an extremely profitable investment. Sensitivity analysis shows that even when the major restrictions are relaxed, the IRR is still exceptionally high. The attractiveness of this investment is borne out by the fact that growth in demand for LLLs has been exponential.

Area Under LLL Technology

No figures are available on the number of LLLs operating in the State. The best proxy is the amount disbursed in subsidies, which are paid by the State Department of Agriculture direct to the purchasers of these machines. This gives a cumulative figure of 1,535 machines. Although these are the most reliable proxies, they are almost certainly underestimates, for three reasons. First when the full subsidy has been utilized in a given financial year, so any further sales are not subsidized; given the profitability of this investment, further sales do take place. Second owners from the neighbouring states of Punjab and Uttar Pradesh also provide LLL services in Haryana. Third, the available figures do not include the current fiscal year, and given that sales have been increasing exponentially, these missing figures are likely to be large. The State Department of Agriculture informally estimates that the true figure must be in excess of 2,000.

Data from key informants in the 2014 study indicate an average of 212 hectares is levelled each year by each machine, so that the minimum area that has been levelled (including cases where land has been re-levelled) is around 544 thousand hectares. However, given the likely underestimation of the number of rigs, the true figure is likely to be closer to 650 thousand.

Impact on CC Mitigation

Laser land levelling mitigates climate change by reducing GHG emissions in three ways.

(a) Emission reduction through decreased pumping time

Irrigation in the study area is based on both ground- and surface water. The former is pumped by grid-connected electric tubewells, the latter by diesel-powered low-lift pumps (LLPs). A conservative estimate of the reduction in annual GHG emissions across the State as a result of levelling is 63,600 MT of CO_2eq.

(b) Emission reduction through decreased cultivation time

The estimated saving in tractor time is 3¼ hours/ha/annum, including the time required for LLL. Again using the most conservative estimate of aggregate area levelled, this translates into an annual fuel saving of 7.5 million litres of diesel, which lowers emissions by19,500 MT of CO_2 per annum.

(c) Emission reduction from fertilizer savings

A uniformly flat field reduces the potential for both N_2O emissions and nutrient loss by improving runoff control, thus leading to improved fertilizer use efficiency and higher yields. Most informants had not changed application rates, but none had increased them. A quarter of them reported having reduced urea application by between 10 and 25 per cent as a result of LLL. This was because there are now no areas in the field where crop stand is poor, whereas the usual response to this problem is to apply a top dressing of urea. Although the consequent emission reductions are real (and the contribution of N_2O to greenhouse gas effects is 310 times that of CO_2), it was not possible to quantify them in this particular case.

Impact on CC Adaptation

The general scientific view is that with CC areas which are currently wet will become wetter, while areas that are currently dry will become drier. Climate scientists expect the amount of land affected by drought to grow by mid 21st century semi-arid and desert areas are expected to expand.

All of this is of vital concern to arid and semi-arid parts of the world, such as Haryana, a State which is presently very agriculturally productive by national standards, but where 80 per cent of agriculture is irrigation-based and increasingly dependent on rapidly-depleting groundwater. If such areas do indeed receive less rain and face the increasing potential for droughts, any technology that reduces demand for groundwater while maintaining, or even increasing, agricultural production will play an exceptionally constructive role in assisting the sector and its farmers to adapt to CC.

From the data collected in the two studies, the most conservative estimate is that the amount of irrigation water presently saved by LLL is 933 million m^3/annum. A more realistic estimate would put the annual figure at a minimum of ≈ one billion m^3, or one cubic kilometre.

Impact on Agriculture and Food Security

Both the 2011 and 2014 studies focussed on the traditional rice-wheat cropping pattern that is dominant in Haryana (as across the IGP as a whole). The main impact of LLL on food supply is that it increases yields in this rotation, and this increases food security by augmenting its food availability component. However there is also a second effect in that in some areas of the State it has promoted crop diversification into nutrient-rich foodstuffs such as vegetables, which makes qualitative improvements in diet possible by supplying more micronutrients.

The 2011 estimates were post-LLL yield increases of 2.85 qtl/ha in wheat and 3.22 qtl/ha in rice. Taking the conservative estimated area of 544 thousand hectares laser levelled across the State, such yield increases translate into additional production of 155and 175 thousand MT per annum of wheat and rice respectively. This represents a significant increase in the food availability aspect of food security. As the 2008 food crisis showed most starkly, reductions in food availability quickly translate into rapidly increasing food prices, which have particularly effects the poor, who spend a relatively high proportion of income on food.

It is important that both the 2011 and 2014 studies show that these increases do not result from augmented application of agricultural inputs such as nitrogenous fertilizer, water and fuel. Rather the reverse. Hence, when translated from absolute terms into terms of mitigation and adaptation *per unit of food produced*, the climate change mitigation and adaptation effects are even greater than those reported above.

Impact on Socially Marginalized Groups

Socially marginalized groups are here taken to refer to (a) small and marginalized farmers, (b) women and (c) those who have traditionally suffered discrimination on grounds such as caste (scheduled tribes, scheduled castes) and religion. Any rigorous attempt to obtain information on these topics would require a separate intensive and extensive study involving a large cross-sectional sample, and available resources, particularly time resources, precluded this, so the evidence presently available is indirect. Moreover, initial attempts to collect information on group (c) in the 2014 study was causing friction, so the topic was dropped.

At the macro level it is worth making two general comments about the impact on such groups of a technology which both mitigates CC and improves adaptation to it. First, the socially marginalized benefit from reduction in GHG emissions disproportionately to their numbers, because they tend to live in marginal areas, which are especially prone to disasters, particularly drought and flood. Second, they also tend to benefit, again disproportionately, from any increase in food availability, because, in accordance with Engels' Law, the proportion of a household's income spent on food is inversely proportionate to that household's income level.

(a) Small and marginal farmers

The Government of India classifies farms into five size categories:

- Marginal (up to 1 ha): 47.7% of holdings, 9.7% of farmed area
- Small (1-2 ha): 19.4% of holdings, 12.5% of farmed area
- Semi-medium (2-4 ha): 17.6% of holdings, 22.3% of farmed area
- Medium (4-10 ha): 12.2% of holdings, 33.1% of farmed area
- Large (<10 ha): 3.0% of holdings, 22.4% of farmed area

The 2014 study found that the average size of holding operated by LLL owners was 11.4 ha, which puts them in the official category of large farmers; some have much smaller farms but other sources of income, particularly as owners of farm machinery hire firms. None of this is at all surprising, given that a laser leveller plus a tractor will cost close to a million rupees. What is more important is whether an efficient and competitive market has developed for the provision of LLL services and whether poorer farmers have access to it. The fact that there is a market is demonstrated by the fact 95 per cent of LLL time is hired out. Half of the owners reported that this market is becoming increasingly competitive and have lowered their (inflation-adjusted) hire charges in response. A quarter of the owners reported that their clients were large farmers, half that they were mainly small farmers and a quarter that they were from all categories, so that, as reported in the 2011 study, small farmers do have access. However the owners tended to define 'small' as 1-3 ha, which excludes the marginal category as officially defined. The reasons appear to be technical and economic, rather than discriminatory. The technical reason is that the smallest plot that can be levelled is 0.1-0.2 ha, and the economic reason is scale economies (reflected in the fact that hirers give a discount of around 10 per cent for those with larger plots). However competition among service providers is growing, as reflected by the fact that mean area levelled per farm has fallen from 6.9 to 4.0 hectares since 2008. Evidence is also beginning to emerge that in some cases the scale diseconomy may be overcome through social organization. One service provider reported that he had begun to hire out LLL services to groups of marginal farmers who had taken to demolishing the boundaries between adjacent plots in so as to create an area sufficiently large for economic levelling, before later re-establishing these boundaries.

(b) Women

It is unusual for landed female headed households (FFHs) in the area to farm themselves; they normally hire their land out to male farmers. However almost half of the respondents reported having hired out their machines to FHHs, but the number was small – in the range of 1-2 to 4-5 per season, compared with an average of more than 70 male farmers. However conditions of hire are the same in each case. The others reported that they had never been asked to supply LLL services to such households, but would have no objection to doing so if asked.

Some evidence has emerged of feminization of agriculture in areas where vegetables are replacing cereals in rice-wheat systems after LLL. Again the information came from a single respondent. It was noted that LLL enabled farmers to dispense with male labourers who were previously used for building and maintaining irrigation structures), but diversification into labour intensive crops like tomato and other vegetables makes it necessary to hire more labours for tasks such as constructing trellises, harvesting, grading and packing the crop. Women are hired for these tasks, because their wage rate is much lower than that of men. Such differences are not attributable to LLL technology, however: Indian government statistics show that significantly lower hourly wage rates for women are the norm in agriculture across all of the operations for which data are available.

General Impact on Employment and Earnings

Employment generation for LLL operators is highly seasonal, and all of the 2014 respondents reported that when they hired tractor drivers to operate the LLL rigs it was on a casual basis, and the season typically lasts 2-2½ months. The employment generation effect of LLL rigs was therefore no more than 80 person days/annum per machine. The reason for hiring at all is that the season is so short that the owners work their machines very intensively, typically around 18 hours/day. It would be wrong, however, to assume that these machinery operatives are from marginalized groups. They are semi-skilled workers, and they earn significantly more than casual labourers. The typical wage for an eight hour day is INR 500-550, compared to INR 300 for a male agricultural labourer.

Laser Levelling and other Climate-Smart Technologies

LLL is one of a range of climate-smart technologies being promoted by the CIMMYT-CCAFS project, although acceptance of this particular technology is now so widespread that in most places comparatively little effort is needed to promote it. There is, however, reason – backed by experimental data – to indicate that the performance of a number of other CS technologies improves significantly on laser-levelled fields, to the extent that it has been described as a 'precursor technology' for resource conservation.

Service providers interviewed in the 2014 study were asked whether they had adopted such technologies on their own farms, and if so, whether such technologies interacted in any way with LLL. Two thirds reported using other CS technologies promoted by the Project, while a further two have plans to use them in the forthcoming crop year. The main technologies in use were the turbo seeder, direct seeding of rice, raised bed planting and crop diversification. The following observations were volunteered:

- It is easier to use the turbo seeder and zero till planter on level fields, because of the elimination of field bunds.
- When the field has been levelled before a seed drill is used there is even moisture distribution across the field and therefore germination is much more uniform.
- Without a seed drill the seed is sown broadcast and then covered using a rotavator, which again disturbs the soil, thus counteracting some of the beneficial effects of LLL. However when a seed drill is used, the land remains flat, thus creating synergy
- LLL makes crop diversification into vegetables much easier because good water control is even more critical than with cereals.

- When rice is replaced with maize as part of the crop diversification, damage to the crop is much greater when the land has not been laser-levelled because the problem of high spots and low spots in the field affects maize more seriously.
- Raised beds are much easier to create on land that has been laser levelled
- Turbo seeding of wheat is more effective on levelled land, because low spots are eliminated, thus saving up to 20 per cent of the crop.

Conclusions

LLL contributes significantly to both CC mitigation and adaptation. This improvement can be regarded as sustainable because the amount of land levelled to date represents less than 20 per cent of the State's net irrigated area, so there is still ample scope for further growth.

The profitability of investment in LLL equipment is exceptionally high, so that the original justification for this subsidy in terms of encouraging uptake of the technology has served its purpose, and it could be withdrawn without adversely affecting uptake. The savings would be considerable – more than 11.5 million rupees – and could be diverted to supporting other proven forms of CS agriculture which have yet to achieve widespread uptake.

Time and methodological constraints precluded a rigorous examination of the impact of LLL on socially marginalized groups during the 2014 study, but such a study is a strong candidate for rigorous examination in any future impact assessment.

The study has produced evidence that many farmers see for themselves a number of synergies that exist between LLL and other CS agricultural practices being promoted by the Project (particularly in areas such a direct seeding), but they seem insufficiently unaware of other areas of synergy, such as increases in nutrient use efficiency resulting from better fertilizer placement. As the Project expands and intensifies its activities in the State and elsewhere on the IGP, it will become increasingly important for project staff and their partners in government and civil society to highlight these benefits.

LLL has been shown to be an exceptionally climate-smart technology in the western Indian IGP. However it remains to be seen whether the effects are similar in eastern areas of the Plain, where conditions are very different on agroecological, social and political fronts.

An Assessment of the Impact of Laser-Assisted Precision Land Levelling Technology as a Component of Climate-Smart Agriculture in the State of Haryana, India

1. Introduction

The Development Assistance Committee of the OECD defines impact as the "positive, negative, primary and secondary long-term effects produced by a development intervention, directly or indirectly, intended or unintended" (OECD-DAC 2010). Given the time required for such scaling out to occur, ex-post impact assessments are normally conducted some years after the completion of a development intervention. However, the agreement between CIMMYT and CCAFS requires the former to deliver an assessment of the impact of its work on the Project once in every three years, and since the Project officially began in 2011, the first such an assessment should be conducted in 2014. In order to meet this timetable, two key factors must be taken into account. On the negative side, three years is a very short time horizon in which to expect impact, especially given that there were the usual delays in Project initiation, and also the fact that the Project is still ongoing. On the positive side, a number of important Project activities build on previous CIMMYT interventions by focusing on and boosting the climate change (CC) dimension of this precursor work, so that in some cases it is possible to use a time horizon that is longer than that of CCAFS *per se*.

The approach adopted here will be to conduct an impact assessment of one component of CIMMYT's CC-relevant research activities that had their origins prior to 2011, but whose CC dimension has been boosted by CCAFS interventions. It will focus on Laser-Assisted Precision Land Levelling (LLL), a technology which was introduced into the region under the auspices of the Rice-Wheat Consortium for the Indo-Gangetic Plains (RWC) in 2001. The RWC was convened jointly by CIMMYT, the International Rice Research Institute (IRRI) and a number of national[1] and sub-national research institutes in the region.

2. The Setting

The Indo-Gangetic Plain (IGP) is a fertile alluvial plain in South Asia, which is home to an estimated one billion people – around a seventh of the world's population. The region curves in an arc from the Swat Valley in Pakistan, through the Indian states of Punjab, Haryana, Delhi, Uttar Pradesh, Bihar , West Bengal, parts of Rajasthan, across the Nepal Terai and into Bangladesh, where it typifies most of the country. The Plain is bounded by the floodplains of the rivers Indus to the west and Ganges to the east, the Himalayan foothills to the north and the Deccan plateau to the south. It is approximately 3,000 km from east to west and 250-300 km from north to south. It contains some of the Subcontinent's richest agricultural land. Rice and wheat are the two principal foodgrains in the region, crops which are grown in sequence on 13.5 million hectares of the Plain and contribute 80 per cent of its food production (Jat *et*

[1] The national research institutes are the Bangladesh Agricultural Research Council (BARC), the Indian Council of Agricultural Research (ICAR), the Pakistan Agricultural Research Council (PARC) and the National Agricultural Research Council (NARC) in Nepal.

al 2006). It also constitutes 85 per cent of South Asia's Rice-Wheat system (Gupta *et al* 2003). Other important crops are maize, sugarcane and cotton. Figure 1 shows a generalized map of the region, indicating its main subdivisions as well as the area covered by the dominant crop rotation.

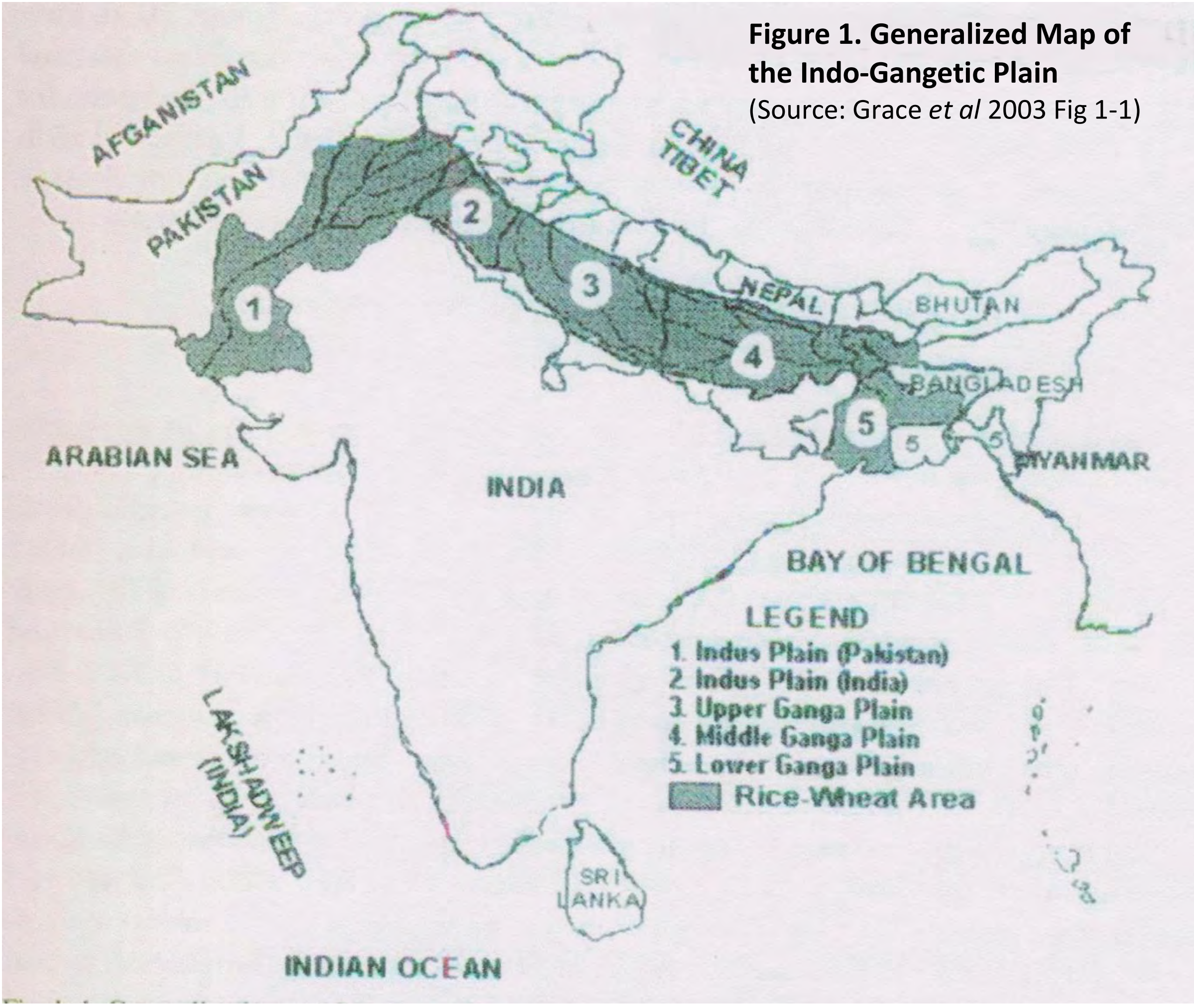


Figure 1. Generalized Map of the Indo-Gangetic Plain
(Source: Grace *et al* 2003 Fig 1-1)

In this region CIMMYT-CCAFS presently operates in three Indian states (Punjab, Haryana and Bihar), in the Terai region of Nepal and in Khulna subdivision of Bangladesh. It is focussed on achieving the following by 2015:

- Production of targeted recommendations for improved and more resource-efficient cereal-based systems at the farm level in different irrigated agro-ecologies in response to climate change (CCAFS Theme 1)
- Generation of recommendations for ICT-based information delivery system strategies to help manage household climate risk (CCAFS Theme 2)
- Production of policy recommendations on approaches to manage market risks and create strategies to reduce vulnerability of poor households (producers and consumers) arising due to price volatility (CCAFS Theme 2)

- Identification and dissemination of incentive systems and policy instruments for enhancing adoption of wheat-based climate smart agricultural practices (CCAFS Theme 3)

3. Laser-Assisted Precision Land Levelling

When land is flood-irrigated, any degree of undulation in the soil surface can seriously reduce both water and land productivity. Hence farmers in the IGP have traditionally spent considerable time and resources levelling the land, usually by passing a weighted tractor- or animal-drawn levelling plank or harrow repeatedly over the dry field. The field is then irrigated so that high spots can be identified and further levelled. There are obvious limits to the degree of accuracy that can be achieved by such rudimentary techniques.

LLL technology achieves a flat even surface, by using a rotating laser transmitter placed at the side of the field. This controls the degree of cut-and-fill to be made by the tractor-towed LLL. A levelling blade is used on wet fields and a drag bucket on dry fields. As the tractor moves the leveller across the field, the signal from the transmitter is picked up by a receiver mounted atop the LLL. This is then routed via a control box in the tractor cab which operates hydraulic valves, which raise and lower the bucket or blade so as to level out undulations in the field. The resulting degree of accuracy is extremely high.

Figure 2 shows such a machine in action. The tripod-mounted transmitter can be seen in the foreground, at the side of the field and the corresponding receiver is visible above the (yellow-painted) LLL. The soil can also be seen, piling up within the drag bucket as high spots are eliminated – including even the tyre tracks behind the machine.

This technology is widely used in developed countries such as Australia, Japan and the USA, where large scale irrigated agriculture is practised. It was first introduced into the IGP by the RWC in 2001, and spread rapidly, to the extent that a recent survey estimated that by 2012 there were more than 10,000 units in operation in the rice-wheat area of the IGP (Jat, 2012).

In order to obtain a complete picture, the impact of LLL on the aims of the CCAFS programme, this technology needs to be examined from four viewpoints: commercial profitability for the farmer, natural resource conservation and CC adaptation, CC mitigation, and the extent to which the technology affects the poor and marginalized (particularly women farmers and, in India and Nepal, members of particular castes and tribes). The first is essential, because private benefit is key to incentivizing the great majority of farmers to adopt the system. Although the public benefits of the other three are obviously be very significant, they can largely be regarded as by products from the viewpoint of the individual adopter.

3.1 Commercial Profitability for the Farmer

Commercially, the benefits of LLL tend to be stated in terms of raised resource productivity, and therefore increased profitability. An RWC document published shortly after the introduction of LLL (Rickman 2002) saw its advantages over conventional levelling techniques in terms of:

- Improved crop establishment
- Reduced weed infestation

- Improved uniformity of crop maturity
- Decreased time requirements
- Reduced volume of water required for land preparation
- Improved crop yields
- Increased field size due to elimination of bunds, and hence increased cultivated area
- Reduced water requirements for irrigation

Experiments in Cambodia between 1996 and 1999 showed that rice yields rose by an average of 24 per cent, or 530 kg ha^{-1} after land levelling (*ibid* p.2).[2] This document reports that in Cambodia much of the yield increase was attributable to improved weed control through better water coverage, which reduced weeds by up to 40 per cent. This in turn reduced labour requirements for weeding by an average of 16 person-days per hectare, or 75 per cent. More level land, it was noted, also facilitates replacement of transplanting by direct seeding, saving approximately 30 person-days per hectare. Field enlargement can increase farm area by 5 to 7 per cent, which can also reduce operating time by reshaping the farming area (*ibid* pp.2-3).

Field experiments conducted over two years in the western IGP under the auspices of the RWC evaluated various tillage and crop establishment methods under LLL and traditional land levelling (TLL) (Jat *et al* 2009). This compared water productivity, economic profitability and soil physical quality under the two land levelling regimes. Irrespective of

[2] It has also been claimed that crop quality can also be improved, although it is not clear what aspects of quality is meant (Chia 2013).

tillage and crop establishment methods, LLL was found to improve rice-wheat system productivity by 7.4 per cent by Year 2. Total irrigation water savings under LLL were 12 per cent in rice and 10-13 per cent in wheat. System profitability increased by US$ 113 per hectare in the first year and by US$ 175 in the second year. Reduced water use clearly increases profitability as well as contributing to resource conservation (see §3.2 below).

The evidence with respect to fertilizer requirements is mixed. Rickman (2002) noted that it is necessary to apply additional fertilizer, especially phosphate, in areas from which soil has been moved, particularly in the first year, but not after the second. However Jat *et al* 2009 observed that nutrient use efficiency is increased by LLL, because nutrient uptake is improved. On-farm investigations at 71 sites in western Uttar Pradesh recorded significant improvement in nitrogen use efficiency in rice-wheat cropping system after LLL due to improved nutrient-water interaction. In rice it was found that nutrient use efficiency increased from 45.11 to 48.37 kg grain kg^{-1} applied nitrogen. In wheat the equivalent figures were an increase from 34.71 to 36.9 kg grain kg^{-1} (Jat *et al* 2006). These improvements, it is argued, are achieved because better land levelling improves runoff control, so that fertilizer use efficiency is improved (*ibid*). It therefore may be that fertilizer requirements increase in the first two years, but decline thereafter.

3.2 Natural Resource Conservation and Climate Change Adaptation

The RWC's primary objective was not to adapt to CC, but to respond to increasing concerns about the sustainability of the rice-wheat rotation, which is of such fundamental importance to the food security, incomes and employment of hundreds of millions of people in the IGP and beyond (GFAR 2001). The Consortium therefore introduced LLL as a means of improving land productivity while conserving resources, particularly groundwater (Jat *et al* 2006). Other resources with which the RWC was concerned included soils, fuel and agroecosystem diversity. However, since the natural resource (NR) base upon which agriculture and food security depends is itself under threat from CC, any interventions that conserve this NR base will also assist in the process of sectoral adaptation to CC.

It is estimated that in order to meet her growing food needs, India will have to produce almost 40 per cent more food with almost 10 per cent less water by 2025 (*ibid*). Groundwater depletion is already a huge area of concern, particularly in the western IGP. The total water requirement for the rice-wheat system in the IGP is estimated at between 1,382 mm and 1,838 mm, 80 per cent of which is for irrigation in the rice component (*ibid*). As a result, water withdrawals from aquifers in north-west India are estimated at 13-17 cubic kilometres per annum, which greatly exceeds the recharge level, so that water tables have been falling. For example in the state of Haryana, the number of farmers using shallow tubewells (STWs) and deep tubewells (DTWs) has increased to the point that there are now approximately 14 groundwater extraction structures per square kilometre of cultivated area (Aryal *et al*, 2013). As a result the water table has been falling. According to the Government of Haryana:

> *Water table during the past 34 years (1974-2008) on an average declined to 5.75 metres across the State. However, during the subsequent period of three years (2008-2011), there has been a drastic decline in water table depth to 15.94 m across the State ... Declining water tables have serious implications by way of increased*

pumping costs as farmers have to shift to costly deep tubewells where in some areas there are indications of water quality decline due to possible intrusion of brackish water from adjoining saline groundwater regions (HKA 2013 p.19).

This switching to deep tubewells does not only impose extra financial costs on farmers: the extra power requirements of DTWs (compared with STWs) also increases GHG emissions per unit of water pumped.

In the neighbouring state of Punjab the situation is similar, with the water table falling in 90 per cent of the area of the State. This process started with the Green Revolution in the 1960s and 1970s, and has continued ever since, so that the area whose water table is lower than 30 feet (10 metres) below the land surface has increased from three per cent of the State in 1973 to 90 per cent in 2004 (Government of Punjab n.d.). These two states have traditionally been considered to be India’s ‘breadbasket’, so that falling productivity in these areas has nation-wide repercussions.

The water conservation contribution of LLL for both the land levelling process and for irrigation *per se* in the IGP was mentioned earlier. Water requirements for land levelling, let alone irrigation, are less than those for irrigation, and the potential savings are very significant. The average variation in height across fields in Asia is 160 mm, which increases water requirements by almost 10 per cent compared with level fields (Rickman *op. cit.*). This implies that up to 1,600 cubic metres of water per hectare is required using traditional methods of land levelling. The fact that with LLL the land can be worked under dry conditions using a drag bucket means that this volume of water can be saved each time the land is levelled or re-levelled.

Groundwater irrigation can also lead to deterioration in soil quality through salinization, so that reduction in irrigation counters this. Reduction in pumping equates to reduction in fuel requirements, so these resources are also conserved. At the moment, however, little information is available regarding agroecosystem conservation.

3.3 Climate Change Mitigation

A recent study of CC trends in Punjab State in the north-western IGP examined changes in weather patterns over the period 1970 to 2009 (Prabhjhot-Kaur *et al* 2013). This analysis revealed that there has been an overall decrease in annual rainfall levels in most districts of the State over roughly four decades. The situation is likely to be similar in Haryana, since the topographies of the two states are similar. Reduced rainfall implies that: (a) groundwater recharge rates are likely to be adversely affected, and (b) without significant progress towards reducing water requirements, water extraction rates are likely to rise to compensate for lower rainfall. The latter point is supported by research in the arid and semi-arid areas of Asia showing that every 1^{o}C increase in temperature is likely to be associated with at least a 10 per cent rise in demand for irrigation water (Shivakumar and Stefanski 2011).

Irrigation systems in the IGP are to a marked extent fossil fuel-dependent, because the water is pumped using either diesel-powered low-lift pumps (LLPs) for surface water, or electrically-powered tubewells for groundwater. A reduction in pumping hours implies a corresponding reduction in greenhouse gas (GHG) emissions, so that water-saving technology can also contribute to CC mitigation, whether the emissions occur at field level (diesel engines) or remotely (thermally-generated grid electricity). Moreover the fact that LLL technologies increase yields as well as reducing water requirements means that on a *per unit output* basis the decrease in GHG emissions will be even greater than the reduction in absolute terms.

3.4 Impact on the Disadvantaged and Marginalized

There is at present little empirical information on this type of impact. In §3.1 above time saving was noted as one of the advantages of LLL, at least in Cambodia – 16 and 30 person-days per hectare for weeding and transplanting respectively. However in Haryana, weed control is mostly herbicide-based, so that direct inferences should be avoided. Where weed control is manual, the degree to which this impacts negatively on the livelihoods of poor and marginalized groups depends on two factors.

The first is whether the labour saved is that of farm family members or casual labourers. In the former case the impact will not be negative, and may even be positive – as would be the case, for example, if women household members are spared such arduous tasks and their overall (and normally very heavy) workloads are correspondingly reduced.

The second factor, which applies in the case of casual labourers, depends on availability of alternative employment opportunities. If there are no such opportunities, the direct impact will clearly be negative, because casual labourers invariably come from the poorest and most marginalized segments of society. Although LLL may create a number of employment opportunities, notably in production, repair, maintenance and operation of the equipment, it is not very likely that the poorest and most marginalized will be in a position to grasp such opportunities, as there is likely to be competition from those who are less disadvantaged.

On the other hand, India has adopted a special social welfare measure, the *Mahatma Ghandi National Rural Employment Guarantee Act, 2005* (MGNREGA), which "aims at enhancing the livelihood security of people in rural areas by guaranteeing a hundred days wage employment in a financial year to rural households whose adult members volunteer to do unskilled manual work"[3]. This is the largest and best-resourced social welfare program in India. With a budget of US$8.91 billion, it is also the world's largest social security intervention in terms of household coverage (IDS 2012). The scheme applies in every district of the country, and in the present fiscal year it is operational in 778,134 villages, involving 285 million workers (48.7 per cent of whom are women) from 129 million households. The number employed includes 13.8 million from scheduled castes and 10.3 million from scheduled tribes (MRD, 2014).[4] A complaint very commonly heard from farmers is that there are labour bottlenecks at times of year such as transplanting and harvesting, and significant management problems associated with obtaining sufficient labour for these operations. In

[3] http://nrega.nic.in/netnrega/home.aspx

[4] Although the Indian caste system is very complex, for social welfare purposes the Government of India divides caste affiliation very broadly into 'general' and 'lower' caste, with the latter group being further sub-divided into 'scheduled caste' (SC), 'scheduled tribe' (ST) and 'other backward castes' (OBC) groupings.

India this is widely blamed on the alternative employment opportunities offered by the MGNREGA. The outcome, according to the farmers, is that farm tasks are delayed, with a resultant lowering of the productivity and profitability of the farm enterprise and a reduction in food production. Clearly if this last point is true, it will impact on the food availability component of food security, and quite possibly on the food access component also, if prices are higher than they would have been under conditions of greater food availability.

4. Evidence from Earlier Village-Level Surveys on the IGP

The data presented in §3 above was generated from on-farm or off-farm experiments in the IGP and elsewhere. Few studies have been conducted in the region on the impact of LLL under normal farm operation, but information is available from two recent studies, Aryal *et al* 2013 and Lybbert *et al* 2012. The first provides field level data on the commercial and natural resource management (including some relevant to climate change adaptation and mitigation), while the second provides information on potential social welfare aspects.

4.1 Aryal et al 2013

This study was based on a household survey of 192 adopters from different farm size groups (small to large) in three districts each in Haryana and Punjab states. It was conducted in 2011 using a stratified random sampling approach. The aim was to assess the impact of LLL on crop yields, and use of water and other inputs. Another aim was to investigate whether or not these impacts vary with size of land holding. The study also estimated the costs and benefits of using LLL and its economic profitability at the farm level. Data on impact of this technology on land under the dominant rice-wheat rotation were collected using a structured household questionnaire. Information was also collected on input use, costs, use and sources of LLL equipment. The sampling frame was based on a previous village-level census survey of the sample districts that included a preliminary list of farmers who had reportedly adopted LLL. The sample farmers were classified into two categories: (i) those growing rice and wheat on both laser-levelled and traditionally levelled land, and (ii) those growing rice and wheat only on laser-levelled land in a given year. The ratio of (i) to (ii) was 56.6:43.4. Hence in the majority of cases it was possible to control for a range of extraneous factors by comparing the two systems on the same farm in the same year. To assess whether input use was different comparing laser-levelled and traditionally levelled fields, mean comparison tests were used. Yield differences between the two land levelling technologies were assessed using mean comparison tests and stochastic dominance analysis.

Sample farmers were categorized as ‘small’, ‘medium’ and ‘large’. Table 1 shows the distribution.

Table 1. Distribution of sample farmers by holding size

	Haryana		Punjab		Total	
Holding size in hectares	**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

[a] Source: Aryal *et al* 2013 Table 3.

The sample farmers were asked to describe qualitative and quantitative the impact of using LLL. Table 2 presents the qualitative responses, as published on an earlier version of the study report (Mehrotra *et al* 2013). The quantitative assessment concluded that in both of the states laser levelling of rice fields reduced irrigation time by 45-55 hrs per ha per season. In wheat, the irrigation time was reduced by 10-12 hrs per ha per season. Yield improvement in wheat was 6.6 per cent in Haryana and 8.8 per cent in Punjab, and in both cases the difference was statistically significant at the 1 per cent level. In the case of rice, however, although the average yield was higher under LLL than under TLL in both states, the difference was not statistically significant in either case. The authors ascribe this to the fact that in both states the variance in rice yields was very much higher than was the case with wheat.[5]

Table 2. Distribution of Sample Farmers According to the Overall Impact of LLL

Impact of using LLL	Haryana			Punjab			Total		
	Yes	Slightly	No	Yes	Slightly	No	Yes	Slightly	No
Reduces water use	93	3	0	96	0	0	189	3	0
Increases yield	23	66	7	50	42	4	73	108	11
Reduces fertilizer requirements	0	0	96	1	0	95	1	0	191
Saves fuel*	7	1	88	32	5	59	39	6	147

Source: based on Mehrotra *et al* 2013 Table 8.
* "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."

The authors go on to note that:

> *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* (Aryal et al 2013, p. 13).

Figure 1 from this study is reproduced as Figure 3 overleaf. (In this diagram the vertical axis, CDF, represents the cumulative distribution function.)

The reduction in the time for the use of tubewells for irrigation in the RW system amounted to 560-760 kilowatt hour (kWh) of electricity per hectare per year on electric pumpsets and 300-410 litres of diesel/hectare/year on diesel pumpsets. Taking both states together, the yield increases resulting from LLL were estimated at 342 kg/ha for rice and 323 kg/ha for wheat. The resulting net present value (NPV) of the increased income stream amounted to US$ 138/hectare/year. Economic analysis of custom service providers of laser levelling revealed that use of laser leveller has become economically feasible and accessible, even to smallholders and other resource-poor farmers. The study estimated that direct employment generation per laser unit is 300 person days per year.[6] In terms of value added, the study

[5] An alternative explanation will be explored later in this report (see §10 below).

[6] This issue will be further explored later in this report (see §11.3 below).

estimated that adoption of this technology on 50 per cent of the area under rice and wheat in the two states would provide additional production averaging 0.28 metric tons (MT) per hectare of rice and 0.38 MT/ha of wheat, worth in the region of US$ 150 million per annum at the then prevailing exchange rate of USD1 = INR 50.

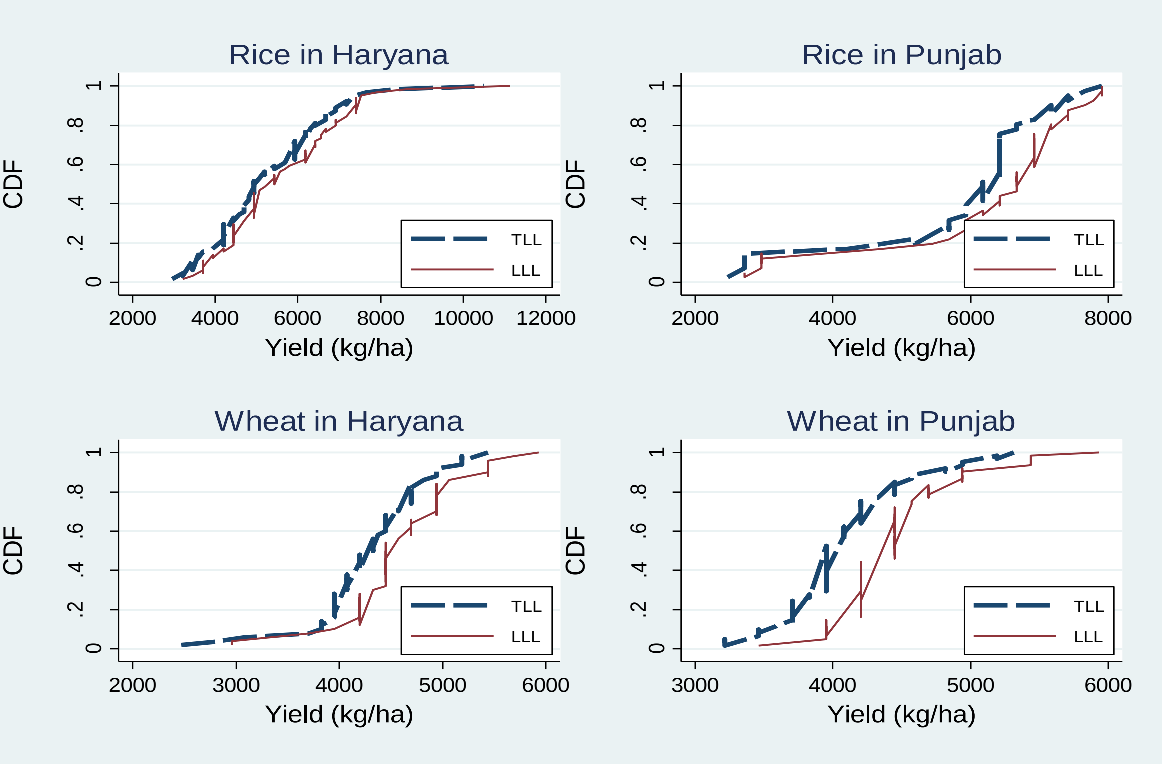


Figure 3: Yield difference between LLL and TLL using stochastic dominance analysis (Source: reproduced from Aryal *et al* 2013 Figure 1)

4.2 Lybbert *et al* 2012

The authors begin by noting that for many agricultural technologies the private sector lacks the incentives and information needed to serve the needs of poor farmers successfully, and that in these cases targeted subsidies are often proposed as a way to encourage broader technology dissemination. However, they argue, lack of information about poor farmers' valuation of new agricultural technologies typically remains a constraint. Consequently, even when there is a political will to target poor farmers with subsidy support, a vague and incomplete understanding of how different famers value a technology often prevents this political will and these subsidies from translating into agricultural productivity gains for the poor. The authors' aim was to fill this void in the case of in LLL eastern part of the Indian State of Uttar Pradesh (UP). They used experimental auctions to try to better understand heterogeneity of farmers' demand for LLL services in this region. Arguing that technology demand can be shaped by a variety of farm and farmer characteristics (such as farm size, risk preferences, education, experience, wealth, and access to markets, information, and credit), the authors' maintain that an understanding of how demand varies across observable variables is a necessary first step towards designing market segmentation strategies. While any public benefits associated with reduced groundwater pumping in a given region are shared, the private benefits of LLL can vary widely across different farmers and plots. The researchers argue that this mix of public benefits and heterogeneous private benefits associated with LLL makes novel market segmentation strategies and targeted subsidies a particularly potent means of improving social welfare.

The research was conducted in the Maharajganj, Gorakhpur and Deoria districts of eastern UP, which together represent the regional spectrum of productivity in rice-wheat cropping systems. During the summer *kharif* growing season, rice is grown on monsoonal rainwater, but the wheat crop, grown in the dry *rabi* season, relies primarily on irrigation from nearby rivers. Eight villages were randomly selected from each district, but any village that might have been exposed to LLL by technology hubs operating in the area was purposefully excluded from the sample. As a result, only six respondents reported ever having heard of LLL. Within each village 20-24 farmers from among those cultivating plots of at least 0.2 acres (which, according to the authors, is physically the minimum plot size for LLL)[7] were selected for interview. In each village households were randomly selected from a village census and an information session was convened with sample farmers to discuss the mechanics of LLL and its potential benefits and drawbacks. The information session consisted of a short video on LLL, the distribution of a picture brochure, and a question-and-answer session with a non-sample farmer who had previously received LLL services. The authors' aim was to provide complete and objective information without promoting the technology. Farmers were informed that recent LLL prices in other parts of India varied between INR 400-800 per hour. Farmers were told that they would get an opportunity to bid on LLL and that the bid options would range from INR 250-800 per hour, a price range that was printed on the picture brochure for reference.

The authors conducted a baseline survey on the economic activities, demographics and assets of the household, as well as key information about all the plots cultivated or owned by each farmer. Finally a 'binding experimental auction' was held in each village to elicit willingness-to-pay (WTP) for LLL custom hire services. Farmers were each assigned an enumerator to privately guide them through the auction process and record their responses. Since no one else was offering LLL services in this area, the auction was the only way farmers could obtain LLL services on their plots that season. In the auction, each farmer listed up to three plots he or she would most like levelled. For each, the farmer estimated how long it would take to level the plot using traditional techniques. This estimate would be a benchmark for understanding the amount of time LLL might take. Then, plot by plot, the enumerator recorded whether or not the farmer was willing to pay for laser levelling at ten different prices between 250 and 800 Rupees per hour.

The findings of this study give some useful insights for both evaluating the potential for uptake of LLL technology by the disadvantaged, and for suggesting possible policy instruments for translating this potential into practice. An important overall finding was that

[7] The 2014 study found that the minimum to be 0.25 acres but the difference is not huge, given that the two studies were conducted in different areas of the IGP (see §11.1 below).

'the demand curves were found to be very elastic below the market price of 500 Rs/hour, which implies that subsidies could dramatically expand LLL adoption. Less than 5 per cent of the land covered by our sample in any district would be levelled at the market price, but nearly 50 per cent would be levelled at half that price' (Lybbert *et al* 2012, p.3). Figure 4 disaggregates the data by six criteria, five of which are relevant to uptake by marginalized farmers. The first point of note emerging from these figures is that farmers in all categories would be willing to adopt this technology if the price was right. The authors note that 'some pronounced demand differences were found, when differentiating by district and caste' (p.3). While the district level findings are of little relevance to the present review, those on caste are of central importance. Figure 4 indicates that upper caste farmers are willing to level more of their land than lower caste farmers at nearly every price, which suggests that special measures would be needed to maximize prospects of farmers from the lower caste using LLL technology to its full potential.[8]

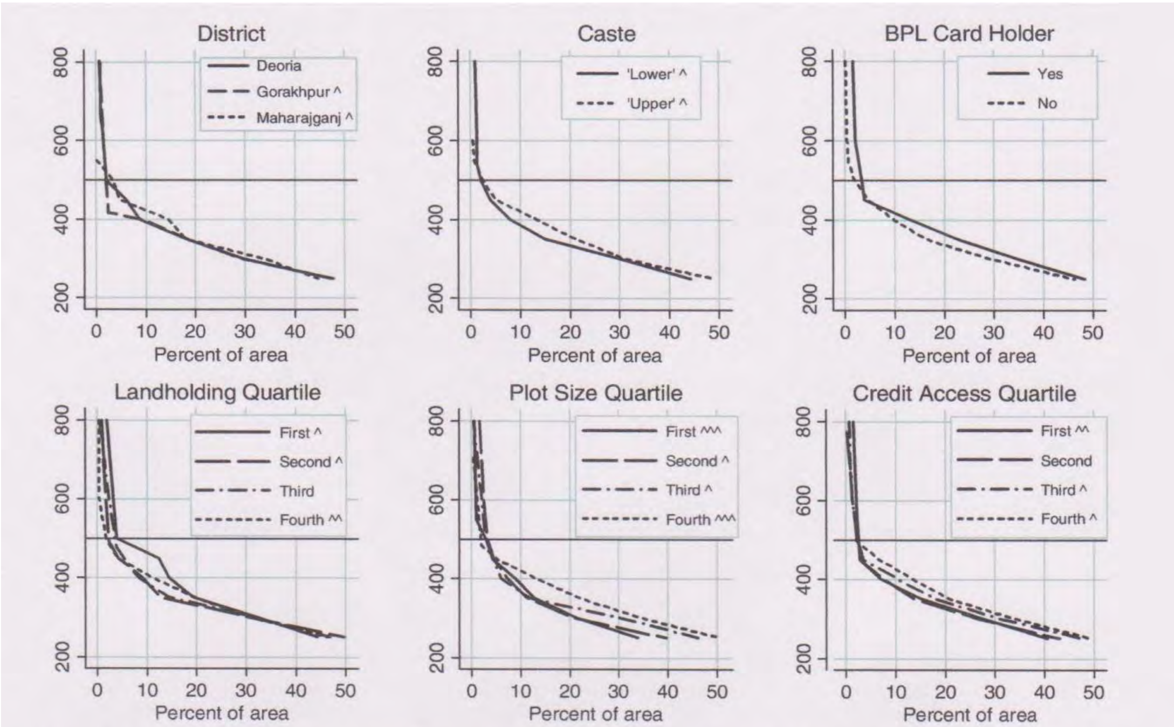


Figure 4. Disaggregated demand curves for LLL with WTP in INR/hour on y-axis (^, ^^ and ^^^ indicate the number of significantly different pairwise Kolmogorov-Smirnov comparisons of the underlying WTP distributions at the 10% level). The horizontal line represents the market price of INR 500/hour.

However, using poverty as a segmentation criterion, a very different picture emerges. In India poverty is defined in terms of the official poverty line, and the poor are issued with ration cards of various types which permit them to purchase essential commodities from *fair price* shops at subsidized prices. The largest entitlements are provided to those classed as living below the poverty line, people who are issued with special blue *below-poverty-line* (BPL)

[8] 'Within the sample, 26% of households classified themselves as SC, 2% as ST, and 50% as OBC. Only 14 farmers (3%) in the sample were Muslims, four of which classified themselves as upper caste, one as SC, and nine as OBC' (quoted from footnote 1 of the original document).

cards.[9] The authors of the study note that nearly half of the sample farmers carried a BPL card. Farmers who possessed such cards presented a sharp contrast to those classified as lower caste, in that they reported that they were willing to level *more* of their land than those without such cards at nearly every price.

Using landholding as a classification, the authors found that 'farmers in the lowest total landholding quartile demand twice as much LLL at 450 Rs/hour than the other quartiles. Plot size differences are more systematic, with the highest quartile having the highest LLL demand below the market price. Differences in demand by credit access suggest that liquidity constraints may have constrained LLL demand: farmers with no self-reported access to credit (first quartile) demand less LLL at every price below the market price than farmers who, at a pinch, could get a loan of INR 20,000 or more (third and fourth quartiles).' The authors proceed to argue that, 'while credit access is not a potential segmentation dimension per se, these differences do suggest that relieving liquidity constraints with microfinancing options for LLL might be worth exploring as part of any segmentation strategy' (p.3).

4.3 Discussion

The Aryal *et al* study backs up much of the theoretical and experimental work on LLL that was reported in §3.1 above. The most definitive finding to emerge from it is that farmers see reduction in water use as by far the most important benefit of LLL, so it is equally clear that LLL does indeed reduce water consumption. At the macro level, LLL is a resource conservation technology that simultaneously contributes to CC adaptation by reducing demands on groundwater. Individual farmers may not be aware of CC, nor might they be particularly motivated to conserve a common property resource like this, so that a 'tragedy of the commons' situation (Hardin 1968) is likely to exist. Indeed such a situation has existed since the green revolution, because the private benefits of irrigation have exceeded the public cost of water depletion. However, increasing extraction costs has been shifting the balance of incentives in a way that fosters water conservation. Because LLL provides a way of reducing consumption, and therefore reducing costs, without imposing penalties in the shape of lower productivity or increased risk, it incentivizes water conservation, and hence CC adaptation. The fact that the majority of adopters also see yield advantages in LLL, even if they are only slight, further boosts the economic attractiveness of this technology, and therefore contributes further incentives for adoption.

The same study's finding that higher yields were achieved despite the fact that fertilizer use has not been affected appears to contradict the earlier-reported finding that more fertilizer is needed in the first two years after levelling. Quite possibly yields could have been further increased had farmers been aware of the need for more fertilizer in the seasons immediately following LLL. It would appear, however, that any yield increases that have been achieved in the three year period covered have resulted from better weed control, improved nutrient-water use or a combination of the two.

The finding that the use of laser levellers has become economically feasible and accessible, 'even to smallholders and other resource-poor farmers' (at least when small farmers are

[9] http://www.archive.india.gov.in/howdo/howdoi.php?service=7

defined as those cultivating less than two hectares), and that the technology is therefore scale-neutral, is encouraging, as is the fact that a significant number of smallholders are actually using the technology. This shows that this form of climate-smart agriculture has had beneficial impact on at least some of the more disadvantaged sections of the rural community. However, as indicated above, the marginalized in Indian rural society comprise a larger and more heterogeneous group than those farming less than two hectares, and include women, casual labourers and members of scheduled castes and tribes. Information was not collected on these variables in the Aryal *et al* study. However the study by Lybbert *et al* (2012) goes some way towards filling in these particular gaps.

Although the latter study was essentially a simulation exercise, and therefore of little relevance to measuring impact, it does complement Aryal *et al* study in that it subdivides sample farmers by caste, poverty, landholding, plot size and access to credit, so that it achieves a considerably greater degree of disaggregation of the data on marginalized farmers. However, although the study mentions female farmers in its introductory section (where it brackets them with the disadvantaged), gender is not mentioned thereafter. This may well be because few, if any, women farmers were found to be using LLL (or perhaps gender division of labour dictates that women are not responsible for land preparation in the study districts).

Perhaps the most surprising finding of the Lybbert *et al* study is the fact that although poor farmers (as defined as those with BPL cards) are more likely to demand LLL services than those who are not card-holders, the opposite seems to apply to members of lower caste farmers. This is counter-intuitive, given the widespread belief that members lower castes also tend to be the poorest farmers. One possible explanation is that there are deficiencies in the allocation of such cards in the area in question (e.g. IDS 2012 indicates that there is considerable disparity across the country in this regard), but the relationship is not explored in the Lybbert *et al* study.

5. The 2014 Study

5.1 Approach

The findings of the study by Aryal *et al* (which will now be referred to as the '2011 study', since that is when the field work was completed) provides strong evidence of positive impact of this technology, and provides a very useful platform on which to build a further assessment of the impact of LLL. The 2014 study complements this in a number of ways.

First, the earlier study used as its sampling frame farmers who had had at least some of their land laser-levelled, but the overwhelming majority of them hired in this service, so that it used a demand perspective, hence generating a wealth of impact data at the micro level.[10] The 2014 study, on the other hand, examined the issues from a supply perspective, with a sampling frame comprising owners of LLL equipment who both used this equipment on their own farms and provided LLL services to other farmers. Hence the two studies are highly complementary. The 2011 study noted that:

[10] Only five farmers of the sample of 192 were actual LLL owners, and no separate survey instrument was designed for them.

Reduced duration of irrigation corresponds to the 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.

The supply perspective of the 2014 study made it possible to quantify this mitigation effect, because it permitted calculation of the average area levelled by each machine in a year. Given that estimates of the savings in irrigation water per hectare levelled are available from the 2011 study (and validated in the 2014 study), it becomes possible to estimate the annual saving in pumping time attributable to each LLL. Irrigation in the survey area is both groundwater and surface water based. In the former case, grid-connected electric tubewells are used, and once the power rating of the pumps has been established, it becomes possible to calculate the amount of power saved in kilowatt-hours (kWh). This can then be adjusted to take into account: (a) the proportion of Indian grid electricity that is generated is from thermal sources, (b) the volume of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) emitted by this component of total supply, and (c) transmission losses in the grid, so as to make it possible to estimate the reduction in GHG emissions from electricity generation that can be attributed to each LLL. In the case of surface water, the volume of CO_2 emitted by diesel pumpsets per unit of fuel consumed is known, so that this source of reduction can also be quantified. Since the area under irrigation from surface and groundwater irrigation at the State-wide level is available from published data, and since it has been possible to obtain estimates of the number of LLLs operating in the State from unpublished data, it is possible to estimate the GHG mitigation effect on a Haryana-wide basis.

Reduction in irrigation water use is not the only source of reduction in GHG emissions attributable to LLLs. These machines also reduce the time required for cultivation, and since data on the power rating of commonly-used tractors, together with information on hourly fuel consumption were collected in the 2014 study, it is also possible to calculate the reduction in GHG emissions from this source also.

Reduction in water requirements for irrigation also have positive impact on CC adaptation and vulnerability to CC. As noted earlier, by conserving water resources, LLL contributes to CC adaptation by reducing demands on a scarce resource, groundwater, that is fast depleting, subject to reduced recharge levels because of falling rainfall trends, and which is facing growing demands from non-agricultural sectors. Although the 3-phase electricity supply required by tubewells is meant to be provided for eight hours per day, one of the most serious risks faced by farmers who rely on electrically-powered tubewells for irrigation is that of power outages to which they are regularly subjected. Reducing demand for groundwater, and therefore reducing pumping hours, will lower the level of risk associated with CC.

The CCAFS project is particularly concerned with the impact of CC on the poor and marginalized farmers, and is committed to ensuring that measures aimed at CC mitigation, adaptation and risk reduction should be pro-poor. Noting that small farmers are able to access LLL by contracting in this technology from service providers, the 2011 study concluded that it is scale-neutral and not biased towards large farmers. The 2014 study investigated this issue in rather greater depth and also assess the impact on women farmers.

5.2 Agriculture in Haryana

Figure 5 shows the State's position within India and the location of its 21 districts within the State and within its three agricultural zones. Haryana occupies just 1.34 of the country's land area, yet is the second largest contributor to the national foodgrain reserves. Average

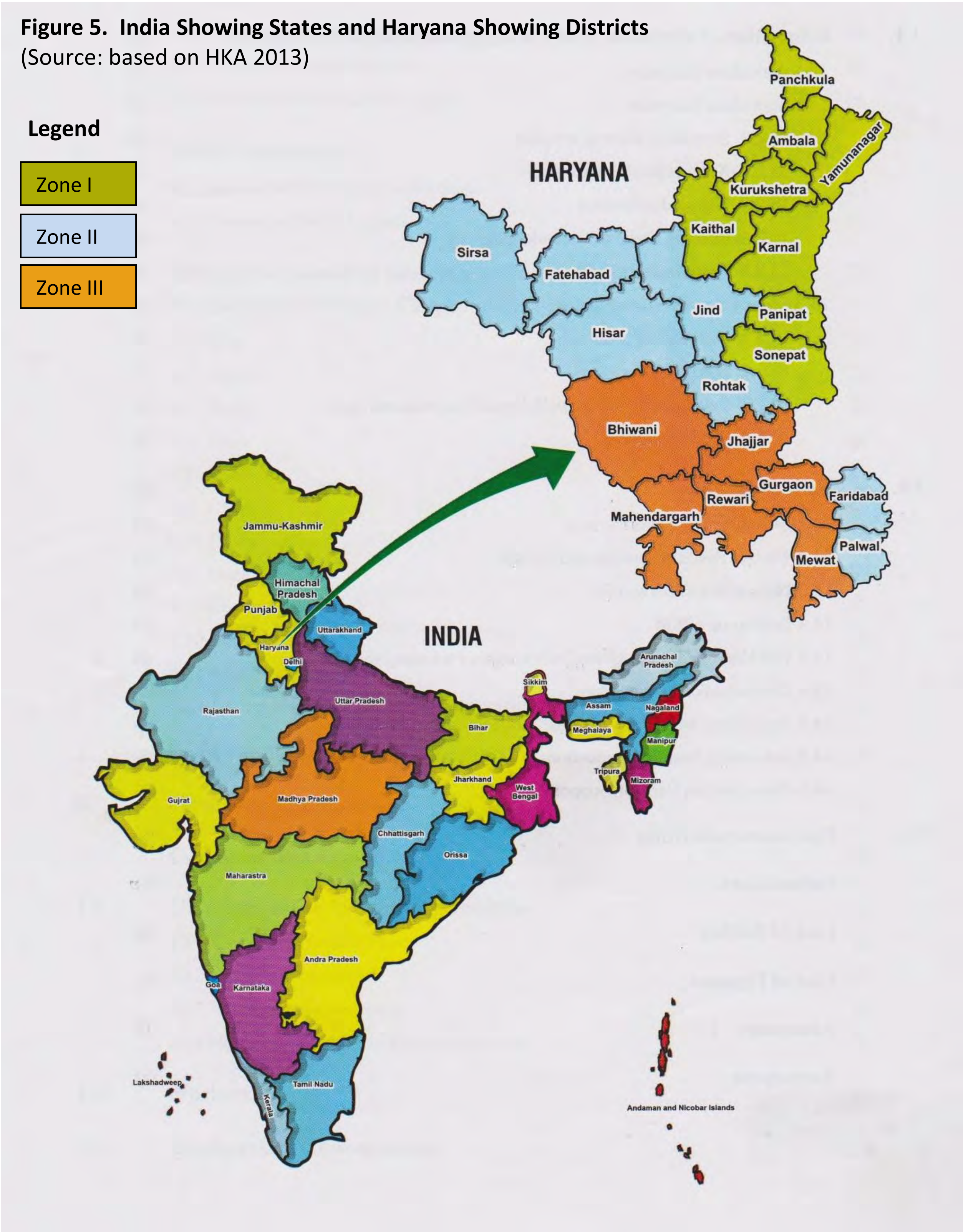


Figure 5. India Showing States and Haryana Showing Districts
(Source: based on HKA 2013)

productivity of foodgrains is 35.3 quintals/ha, compared with a national average of 19.2 quintals. The State is classed as *arid to semi-arid*, and has achieved the underlying high agricultural productivity by heavy reliance on irrigated agriculture. Surprisingly, given that foodgrain productivity is already nearly twice the national average, agricultural growth rates are also above average, at 3.9 per cent per annum compared with 3.7 per cent nationally (HKA 2013).

Table 3. Agricultural Zones of Haryana

Zone	Districts	Percent of Area	Dominant Cropping System
I	Ambala, Panchkula Kurukshetra, Yamunanagar, Karnal, Kaithal, Panipat, Sonepat	32	Wheat, rice, sugarcane and maize
II	Sirsa, Fatehabad, Hisar, Jind, Rohtak, Faridabad, Palwal	39	Wheat, coffee, rice, sugarcane and millet
III	Bhiwani, Mahendergarh, Rewari, Jhajjar Gurgoan, Mewat	29	Pearl millet, rapeseed and mustard

Source: Based on HKA 2013, Table 1.1
Note (from the source document): "Zones I and II have better irrigation facilities and overall infrastructure than Zone III."

Table 4. Agricultural development in Haryana since the green revolution

	1966-67	2010-11	Percentage change
Geographic area ('000 ha)	4,421	4,421	0.0
Cultivable area ('000 ha)	3,822	3,814	- 0.2
Cultivable area (as % of geographic area)	86.45	86.27	- 0.2
Net sown area ('000 ha)	3,423	3,576	4.5
Total cropped area ('000 ha)	4,599	6,484	41.0
Cropping intensity (%)	134.4	181.3	35.0
Net irrigated area ('000 ha)	1,293	2,879	122.7
of which canals ('000 ha)	991	1,277	28.9
of which minor irrigation ('000 ha)	302	1,602	430.5
Gross irrigated area ('000 ha)	1,736	5,528	218.4
Net irrigated area (%)	37.8	84.2	122.8
Gross irrigated area (%)	37.7	86.0	128.1

Source: based on HKA, n.d., Table 1

Table 3 lists the State's three agricultural zones indicating the dominant cropping system in each, while Table 4 shows some basis statistics on agricultural development in the State since the green revolution era.

Table 4 indicates a huge increase in irrigation development over the period, with net irrigated area more than doubling. More than 80 per cent of the State's cultivable area is now irrigated, and since irrigation is a necessary precondition for the productivity increasing effects of LLL, this clearly indicates the high level of potential for the latter technology throughout most of the State. Another remarkable development shown in this Table is the growing relative importance of minor irrigation (primarily tubewells), compared with canal irrigation. This has both positive and negative effects. The main positive effect is that with minor irrigation land does not have to be taken out of agriculture, as it does to provide for canals. The negative effects are (a) that it has permitted a massive and unsustainable drawdown on groundwater reserves, and (b) that groundwater irrigation requires more energy than surface irrigation, so that GHG emissions are higher (see §8.1 below).

5.3 Methodology

The 2011 study covered six districts, three each in the states of Haryana and Punjab. However the 2014 study was conducted by a single researcher during a three week period in February. These constraints limited the study to one district in the State, namely Karnal (which was also one of those included in the 2011 study). Karnal was chosen purposefully because it is the area in the IGP in which CIMMYT-CCAFS first established its 'Climate-Smart Village' (CSV) model, and it also has the largest number of such villages, the earliest dating from the start of the Project in 2011. In these CSVs the Project is promoting a range of techniques and technologies, including LLL, that contribute to 'Climate Smart Agriculture' (CSA). This makes Karnal the most appropriate area in which to investigate the extent to which there are synergies and complementarities between LLL and the other elements of CSA as promoted in the CSVs.

Twenty farmers within the CSVs in Karnal own LLLs, and it was decided to interview all of them. A major reason for limiting the study to these particular villages (apart from time constraints) was that they already have a close relationship with CIMMYT-CCAFS staff, and the study was able to build on this in the knowledge that they were much more likely to accept the explanation for the study, rather than suspect a hidden agenda, as is so often the case with large questionnaire-based surveys. In the event, one of the owners was absent from the District during the study, so a replacement owner was chosen from a neighbouring village.

The study was conducted through a series of semi structured interviews (SSIs) with the owners, and the pro forma for this is included as Annex 1 of this report. Unlike the highly structured form of a questionnaire-based survey which does not allow the enumerator to deviate significantly from a set of pre-determined questions, the SSI is based on a general framework of mainly open-ended questions, which permits new ideas to be brought in based on responses to questions. Although the sample size is small, it permits exploration of 'why' and 'how' questions, while larger questionnaire-based surveys are necessarily limited to 'what' and 'how much' questions. This adds a further dimension to the complementarity.

In the 2014 survey all of the interviews were conducted by the present author with the help of a translator, so that the familiar problem of questionnaire-based surveys, that of variation in interpretation and possible enumerator bias, did not arise. Clearly some of the questions on the SSI– such as the horsepower rating of the tractor – require only short simple answer, but others call for much more intensive investigation. This applies most strongly to question #13 on the advantages of LLL. Respondents were invited to list these unprompted, a procedure which often generated rich discussion. Once this process had been completed, any theoretical advantages (such as those listed in §3.1 above) that had not already emerged from the discussion were then explored. Question #30 on the interaction between LLL and other CSA practices also yielded a considerable level of insight. Throughout the process particular attention was paid to quantification of responses wherever appropriate. All of the respondents were both farmers and service providers, so that they were able to discuss issues from both perspectives. They are therefore referred to in the text as Farmer-Service Providers (F-SP).

6. Commercial Profitability of Investment in LLL

As noted earlier, if the process of adoption of CSA is to be successful, it will be commercial profitability that drives it forward. In the 2011 survey commercial profitability was explored from the viewpoint of the *users* of LLL services, and this analysis showed that system profitability increased by a very respectable US$ 113 per hectare in the first year and by US$ 175 in the second year (§3.1 above). In this section this information will be complemented by examining the profitability the combined enterprise of using an LLL rig on one's own land *and* hiring it out to others.

The standard tool for investment decision making is the Internal Rate of Return (IRR). This is the discount rate that reduces the NPV of all cash flows from the project to zero. The larger this discount rate, the more profitable the investment. IRR can be calculated from the following expression:

$$NPV = I + \frac{CF_1}{(1+r)^1} + \frac{CF_2}{(1+r)^2} \;.....+ \frac{CF_n}{(1+r)^n} = 0$$

Where: NPV = the net present value of the project (i.e. the value at present of a future income stream discounted at compound interest),
I = the initial investment,
n = the life of the investment,
$CF_{1,2,n}$ = cash flow (earnings minus expenditure) in a given year, and
r = the discount rate

The IRR is the value of r in the above expression, stated as a percentage. Because this expression is not an equation, the IRR is calculated through a series of progressive approximations. Details of the calculations are shown in Annex 2 for a number of different of investment assumptions.

In this analysis, the cost of using the LLL rig on the owners' personal farm is treated as being equal to that of using it for service provision, because in the present situation,[11] where demand for services outstrips supply, the opportunity cost is the same.[12] The cost of the rig varies with the year of purchase, the effective range of the laser beam, the size of the drag bucket, the manufacturer, supplier and model, and whether the machine is new or second-hand. The age of the rigs in the sample ranged from 20 days to seven years; in this analysis

[11] See §11.1 below
[12] Opportunity cost is the real cost of satisfying a want, expressed in terms of the cost of the sacrifice of alternative activities. For example, if an LLL owner could earn INR 9,000/month driving a tractor for someone else, then INR 9,000/month is the opportunity cost of driving (but only driving, not other costs) his own machine on his own land.

the cost of new machines purchased in the past two years is used. There were four such machines, two costing INR 325,000 and two costing INR 365,000, so the mean level of investment is taken as INR 345,000. Apart from the initial investment in the LLL rig, investment in the tractor must also be taken into account. However, LLLs are used on average for only 2½ months per year, whereas tractors are used all year round, for tasks such as transport, tillage operations and as stationary power sources for other equipment. It is initially assumed that a quarter of tractor time should be ascribed to the LLL, but this assumption will later be relaxed. No LLL owner reported having had to spend time or money on repair and maintenance (R&M) of the rig, not even the one who had had his machine for seven years. However, an allowance has been made for R&M for the rig-plus-tractor rising by INR 1,000 per annum as the machine ages (the first year being free, because it is under guarantee). It is assumed that the useful life of the equipment is ten years, although this is probably very conservative. Other costs are based on owners' reports, with a five per cent annual allowance for inflation. It is, again conservatively, assumed that no revenue is earned in the year when the LLL is purchased – although in fact the rig could begin to earn almost immediately after purchase.

Unlike costs, the two revenue streams are treated differently. Revenue from service provision is calculated from: (a) the owners' reports of average area levelled for other farmers in a year, (b) the amount of time required to level one hectare of land and (c) the hourly hire rate. The estimated revenue stream from two sources: (a) fuel savings (negative costs) from reduced cultivation time and (in the case of LLPs) reduced irrigation time, and (b) increased yields, based on the findings of the 2011 Study, where it was reported that the NPV of the increased income stream amounted to US$ 138.2/hectare/year (INR 6,910/ha/annum). Again the figures have been adjusted to allow for inflation.

The reason that cost saving on irrigation time is considered differently for those who use tubewells and those who use LLPs is that in the former case, the charge for electrical power is based on the farm's total installed capacity for pumps connected to the grid, and is charged at the rate of INR 15/horsepower/month. The amount of time for which pumps are used is not taken into consideration, so that fuel can be treated as a fixed cost, and can be left out of the equation, since irrigation facilities are installed whether or not the land is levelled.[13] This does not apply in the case of diesel-powered cost of LLPs used for surface irrigation. Diesel used in agriculture is subsidized in Haryana, and costs INR 53.9 per litre. This is the scenario in which the highest IRR is obtained, namely 120 per cent (Annex 2, Table A2.1), which is exceptionally high. The same table shows that the cash flow in Year 1 is greater than the Year 0 investment, so that the 'payback time' is less than one year. It is difficult to imagine many investments in agriculture – or indeed outside of agriculture – yielding such a handsome return. Even in the case of electric tubewell irrigation, the absence of saving on fuel has only a minimal effect, reducing the IRR to 115 per cent (Table A2.2). Again the payback time is less than a year. The sensitivity analysis shows that even when the major restrictions are

[13] Nevertheless, reducing pumping time will reduce wear and tear on machines, so that the estimate of IRR will again be conservative. However these costs have not been included, because it would be very difficult to arrive at reasonably accurate estimates, and such is the profitability of the investment that they can conveniently be ignored

relaxed, the IRR is still exceptionally high. Thus when the subsidy is removed, the IRR is 97% (Table A2.3) and in the unlikely event of the tractor being used exclusively for towing the LLL (Table A2.4), the IRR becomes 61%. Even when both assumptions are relaxed (Table A2.5), the IRR is still a very attractive 55%, with a payback period of just over two years. The economic attractiveness of this investment is borne out by the fact that growth in demand for LLLs has been exponential (see §7 below).

7. Area Under LLL Technology

In order to estimate the area under laser levelling, a reasonably accurate estimate of the number of machines working in the area in question is needed. Unfortunately no statistics are published on this topic, so the estimating process offers some challenges. Originally it was planned to collect figures from importers and local manufacturers, but the logistical challenges of doing so, given time constraints, would have been considerable. An additional difficulty would be that of establishing the final destination of each machine at state – let alone district – level. However, during the course of field work it was established that in Haryana the subsidy on the machine (currently INR 75,000) is paid, not to the manufacturer or importer as was previously the case, but directly to the buyer on submission of proof of purchase. Thus the number of subsidies paid out serves as a proxy for the number of machines purchased. The State Department of Agriculture is responsible for subsidy payments, and the Director General generously agreed to provide the necessary figures by district and by year, for the period since the subsidy was introduced. These figures are reproduced in Table 5 overleaf.

Three caveats are necessary when interpreting these figures. First, not all purchases are subsidized. Each district is provided with funds for the subsidies in each financial year (FY), but when this fund has been exhausted, no more can be paid until the next financial year. Nevertheless, according to State officials, there are farmers who still purchase the machine, rather than wait until the next FY despite the fact that it is *de facto* unsubsidized. Second, a number of the respondents reported that service providers from the neighbouring states of Punjab to the west and Uttar Pradesh to the east, were beginning to offer LLL services to Haryana farmers, sometimes undercutting the prices charged by local F-SPs. Third, the figures in Table 5 cover the period to March 2013, and it is known that a significant number of LLLs were sold in the current financial year also. Thus the figures in Table 5 must be regarded as minimal, and the actual number, and hence the impact, is likely to be significantly higher than these figures suggest. It is informally estimated in the State Department of Agriculture that the actual number of rigs operating in the State could be closer to 2,000, rather than the figure of 1,535 reported in the Table. This is certainly credible, given the fact that even without the subsidy the IRR on such an investment is still a very impressive 96 per cent, and the payback period just over a year. It is assumed that all of the machines purchased since FY 2007-08 are still in use. This is because when SPs were asked about disadvantages of LLLs, none of them mentioned problems of breakdowns or difficulties with R&M. In addition, there are a number of agricultural machinery dealers in the area who are able to provide R&M services for these machines.

Figures 6 and 7 overleaf show the growth in subsidized sales since 2007-08, with exponential growth curves fitted in each case. At the State-wide level (Figure 6), the R^2 statistic is significant at the $p<0.001$ level, indicating a very high degree of statistical correlation. In Karnal Districtthe exponential fit is not quite so close (probably because there are much fewer machines and therefore more year-on-year variation), but the correlation is still statistically significant, in this case at the $p<0.05$ level. Such exponential growth rates are hardly surprising, given the very high IRRs reported earlier.

Table 5 shows a huge variation in the distribution of LLLs by district. Sales in the districts of Mohidergarh, Gugaon, Mewat, Rewari and Faridabad in Zone III are well below the average for the State, and even below the average for the zone. However, a glance back at Figure 5 will show that these four districts border on the desert state of Rajasthan. These districts are

Table 5. Year-wise sales of LLLs under subsidy in Haryana by zone and by district, 2007-08 to 2012-13

Zone	District	Financial Year [a] 2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	TOTAL	Mean number/ district
I	Ambala	2	5	8	22	34	35	106	95.3
	Panchkula	0	0	0	0	0	1	1	
	Yamunanagar	7	10	24	36	38	42	157	
	Kurukshetra	2	5	2	16	37	44	106	
	Kaithal	2	4	3	9	27	54	99	
	Karnal	5	4	2	13	38	52	114	
	Panipat	0	4	0	5	24	36	69	
	Sonipat	0	0	2	9	32	67	110	
II	Jind	0	0	1	11	33	80	125	95.9
	Rohtak	0	0	1	8	28	50	87	
	Hisar	2	1	3	3	43	102	154	
	Fatehabad	0	10	3	17	30	62	122	
	Sirsa	2	10	4	5	28	45	94	
	Faridabad	0	0	0	2	3	7	12	
	Palwal	0	0	0	4	16	57	77	
III	Jhajjar	0	0	1	1	8	30	40	17.0
	Bhiwani	0	0	0	2	9	36	47	
	Mahindergarh	0	0	0	0	0	0	0	
	Gurgaon	0	0	2	1	1	0	4	
	Mewat	0	0	1	1	1	4	7	
	Rewari	0	2	0	0	0	2	4	
STATE LEVEL		22	55	57	165	430	806	1,535	73.1

[a] The Indian Financial Year runs from 1st April.

Figure 6: Haryana State: Number of LLL units sold under subsidy, 2007-08 to 2012-13

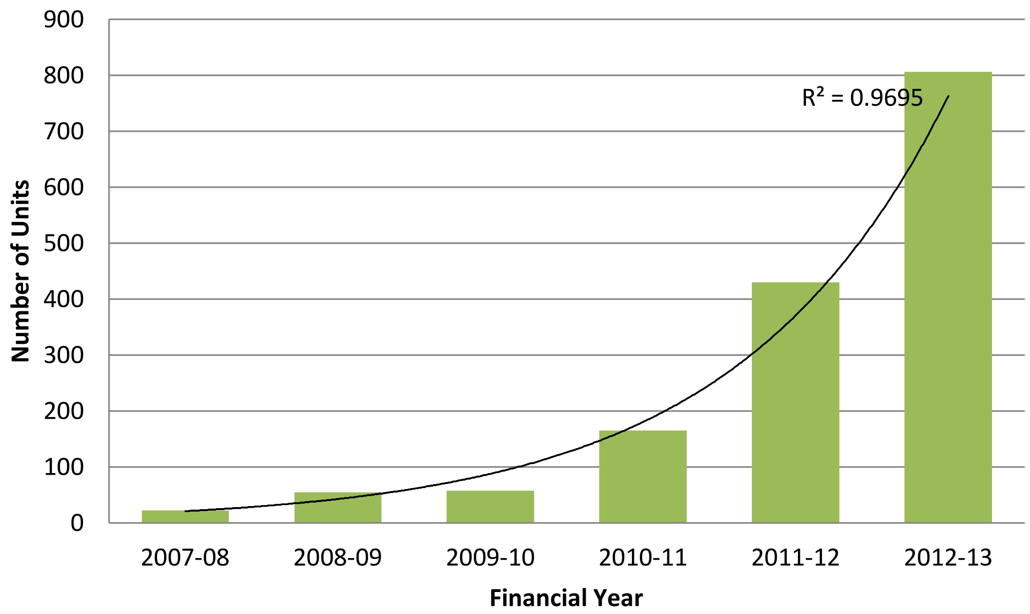
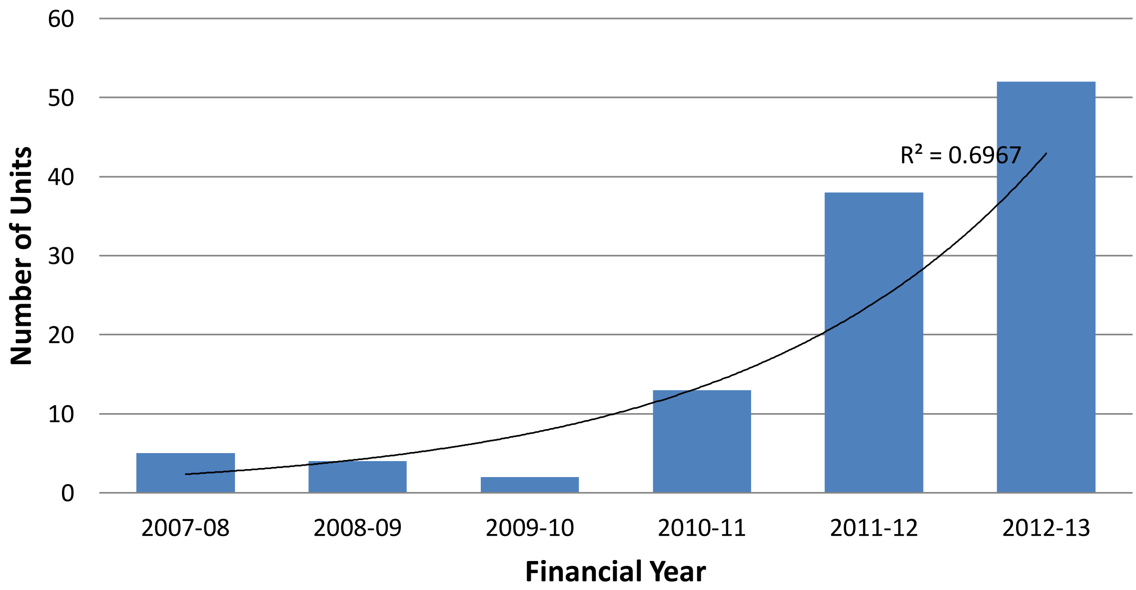


Figure 7: Karnal District: Number of LLL units sold under subsidy, 2007-08 to 2012-13



characterized by low intensity rainfed farming, sandy soils and very undulating land. The potential for irrigation is therefore very limited in these districts, and unless the land is irrigated, LLL technology has little to offer. Two other districts, Panchkula in Zone I and Faridabad in Zone II, also have low sales volumes. Panchkula borders on the Himalayan foothill and Faridabad on the Aravali foothills, and both are characterized by sloping topography, sandy soils and low intensity rainfed agriculture. Again these are not conditions in which land levelling would contribute significantly to increased agricultural productivity.

The average area levelled by respondents in the study, including both their own land and that of other farmers, was 212 hectares per annum. This figure, together with the number of levellers in the District as shown in Table 5, can be used to estimate the total area levelled in the district since 2007-08. The relevant figures are shown in Table 6 below.

Table 6. Estimates of laser-levelled land area in Karnal District, Haryana

	Financial Year						
	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	Cumu-lative
Number of machines[a]	5	9	11	24	62	114	n/a
Gross area levelled (hectares)[b]	1,060	1,908	2,332	5,088	13,144	24,168	47,700
Net area levelled (hectares)[c]	1,060	1,908	2,332	4,028	11,236	21,836	42,612

Notes:
[a] Cumulative number of machines operating in the District
[b] Levelling capacity assuming 212 ha levelled/machine/annum
[c] Net levelling capacity assuming fields re-levelled every three years
n/a = not applicable

The difference between the second and third rows is this table arises from the fact that land levelling is not a one-off task. During subsequent cultivation and harvesting operations the land is disturbed and becomes gradually more uneven, so that periodic re-levelling is required. When estimating the total area levelled, this re-levelling must be taken into account to avoid overestimation. The 2011 study reported that this happens every four years, but that study was based on reports from those who hired in LLL services. In the 2014 study the F-SPs reported levelling their own fields much more frequently, either doing so across the whole farm every year, or half of the farm in alternate years.[14] (It should be noted that once a field has been levelled, re-levelling it is much faster, with the per acre average falling from two hours to half an hour.) An average district-wide figure of re-levelling triennially has therefore been used in the calculations in Table 6, so that the true estimate for the total number of hectares levelled in the district over the six years is 42,600 (rounded).

[14] Whereas the 2011 study showed that farmers who hired in leveller rigs used them on only some of their land, the 2014 study found that, with only one exception, the rig owners levelled all of their own land. The exception was a very large farmer, who had 100 acres (41.5 ha), and who levelled only 60 acres, because the remainder was too undulating for laser levelling to be possible.

The district-wide figure of 212 ha/rig. annum may be used as a coefficient to estimate the area levelled per rig across the state, because areas where LLL is used in Haryana are topographically and climatically quite homogeneous. Even in the peripheral districts where conditions do not generally favour uptake, there will be pockets where irrigation is possible and LLL can be used. The State-level estimates are shown in Table 7 below.

From these figures it is estimated that a net area of 544 thousand hectares have been laser-levelled in the State since 2007-08. This represents a huge increase in just six years. However even so the net area levelled is under 20 per cent of the State's net irrigated area (see Table 4 above), so that there is clearly still very substantial scope for further expansion in scaling out of this technology.

Table 7. Estimates of laser-levelled land area in Haryana State

	Financial Year						
	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	Cumu-lative
Number of machines[a]	22	77	134	299	729	1,535	n/a
Gross area levelled (hectares)[b]	4,664	16,324	28,408	63,688	154,548	325,420	593,052
Net area levelled (hectares)[c]	4,664	16,324	28,408	59,024	138,224	297,012	543,656

Notes:
[a] Cumulative number of machines operating in the State
[b] Levelling capacity assuming 212 ha levelled/machine/annum
[c] Net levelling capacity assuming fields re-levelled on average every three years
n/a = not applicable

8. Impact on CC Mitigation

Laser land levelling mitigates climate change by reducing GHG emissions in several farm operations, but the main contribution is undoubtedly from the reduction in demand for irrigation water and the resultant reduction in power requirements for pumping water.

8.1 Emission Reduction through Decreased Pumping Time

Irrigation in the study area is based on both groundwater and surface water. The former is pumped by grid-connected electric tubewells,[15] the latter by diesel-powered LLPs. Electricity generation in India relies on a number of technologies, two of which are thermal. Coal-fired stations generate 59 per cent of total supply and natural gas-fired stations 9 per cent (Ramme *et al* 2011), meaning that just over two thirds of national generation capacity is thermal-powered and hence GHG-emitting. According to the latest-available figures from the Indian Government the total installed capacity for electricity generation from thermal power plants in the country (in 2007) was 89,275.84 megawatt (MW) (INCCA 2010). The electricity generation sector's GHG emissions in the same year are shown in Table 8 overleaf.[16]

[15] Electricity for tubewells is supplied on a 3-phase system, which is not used for other purposes, so that diversion to such purposes is not possible. Electricity for irrigation is supplied for four hours each morning and afternoon, although there are frequent outages.

[16] This sector produced no CO_2 removals (*ibid*).

Table 8. GHG Emissions by India's Electricity Generation Sector (2007)		
GHG	**Chemical Name**	**Total Emissions (MT)**
CO_2	Carbon dioxide	715,829,800
CH_4	Methane	8,140,000
N_2O	Nitrous oxide	10,666,000
CO_2 equivalent (CO_2eq)		719, 305,340
Source: INCCA 2010 (Table 5.3) [a] CO_2eq is calculated using coefficients of 21 for CH_4 and 310 for N_2O		

All of the respondents in the 2014 study reported irrigating with electric tubewells, and a total of 54 have been installed by them. Ninety three per cent of these are deep tubewells (DTWs), the rest shallow tubewells (STWs). DTWs have motors ranging in capacity from 7 to 25 horsepower (HP). The metric equivalents of these power ratings are 5.2 and 18.6 kilowatts (kW) respectively. The STWs have 3 HP (2.2 kW) to 7 HP (5.2 kW) electric motors. The most common rig in the area (42 per cent of DTWs) has a 15 HP (11.2 kW) motor.

If generating 89,275.84 MW of electricity produces 719.31 million MT of carbon CO_2eq per annum, generating one kilowatt-hour of electricity produces 10.19 kg of CO_2eq. This suggests that the most commonly-used tubewell motor in the area requires sufficient electricity to produce 8.7 kg of CO_2eq per hour. A weighed average of the power of all tubewells owned by F-SPs in the area is 10.7 kW (which is similar to that of a 15 HP motor), and equates to the generation of 7.0 kg of CO_2eq per hour of thermally-generated electricity. However this first approximation needs to be refined by taking two further factors into account.

The first is the earlier-noted point that only 68 per cent of India's electricity supply derives from thermal sources, so that the above tubewell-level emission estimate should be adjusted by a coefficient of 0.68 to convert them into GHG emissions at national level. The other factor is transmission losses. India's network losses are exceptionally high. In 2010 they were 32 per cent (including non-technical losses), compared to a global average of less than 15 per cent (Ramme *et al* 2011). Thus on average 132 kW must be generated in order to supply 100 kW at point of use. Factoring both of these parameters into the equation, and using the above weighted average of tubewell power ratings, produces an estimated mean of 6.3 kg of CO_2eq emissions per tubewell per hour.

Surface water irrigation is much less polluting than tubewell irrigation, because the total lift requirement is obviously much less. Canals in the area are gravity-flow systems and therefore do not of themselves produce GHGs. However diesel-powered low lift pumps (LLPs) must be used to raise the water to field channel level, so that emissions occur at this point. The irrigation canal network in Karnal District is less well-developed than elsewhere in the State, and only two of the respondents in the 2014 study had access to canal water for irrigation in addition to their tubewells. One had a 5 HP (3.7 kW) LLP that uses 2 litres of diesel per hour, while the other had two 10 HP (7.4 kW) LLPs that use 1.5 litres diesel/hour.[17] The three most common types of low lift pump used in India are shown in Table 9. On average their fuel consumption is fractionally below 1 litre per hour and the CO_2 emissions are therefore 2.5 kg/hour.

It was shown earlier (Table 4) that not only has irrigated agriculture expanded rapidly in Haryana since the 1960s, but that the sources of irrigation have also changed markedly. 'Minor irrigation' (which is virtually the same as groundwater irrigation) grew from less than a quarter of net irrigated area to 56 per cent of the total by 2010-11. Taking a weighted average of tubewell and canal-based irrigation together, average emissions from the system in the State are therefore estimated to be 4.7 kg CO_2eq per hour of irrigation time.

Table 9. Parameters of the three most commonly-used LLPs in Indian Agriculture

Type of pump[a]	HP (kW)[a]	Fuel Consumption (lt/hr)[a]	Emissions (CO_2/hr)[b]	Observations[a]
Older Indian-designed and manufactured pumps (Kirloskar, Bharat)	5 (3.7)	1.0-2.0	2.6-5.2	Green revolution model; very popular, and village mechanics can provide R&M
Newer Japanese-designed, Indian manufactured (Honda)	2-3 (1.5-2.2)	0.5-1.0	1.3-2.6	Also very popular and village mechanics can provide R&M
Newer Chinese-designed and manufactured (various)	2-3 (1.5-2.2)	0.4-0.9	1-2.3	Cheapest rig, but unreliable and have a short working life

Sources: [a] Greenpeace India 2013
[b] Based on a coefficient of 2.6 kg CO_2 released into the atmosphere per litre of diesel consumed (Grace *et al* 2003, p.33)

The 2011 study found that average savings in irrigation time following laser levelling was 12.2 hours/ha in wheat and 50.0 hours/ha in rice. (The savings with rice are much higher, because farmers irrigate on average 13 times per season with rice, but only four times per season with wheat.) However the 2014 study found the savings to be much higher: 24 hours/ha with wheat and 78 hours/ha with rice. The most likely explanation of the difference lies in the different sampling frames of the two studies. Whereas the 2011 study took as its sampling frame farmers who hired in levelling services, the 2014 study sampled from owners of LLLs. There are two major differences between these two groups. First, the owners level all of their land, whereas most of the hirers levelled only part of their land.[18] Second, the owners level their land either every year or every second year, whereas the hirers did so only

[17] The fact that the 10 HP pumps consume less diesel than the 5 HP model reflects the fact that the latter is older, and less fuel-efficient (see Table 9).
[18] Only one of the owners in the 2014 study reported levelling less than 100 per cent of his land, and this was because 40% of it was too undulating for LLL to be possible. However he did not included this unlevelled land in his report of time savings in irrigation.

every fourth year.[19] To obtain an estimate of the aggregate amount of time saved by LLL, it is necessary to take a weighted average of the above figures. On average owners levelled 10.6 hectares of their own land, but hired out levelling services on 201 hectares in 2013. Using this difference as a weighting factor, the weighted average of time saved is therefore 64 hours/ha per annum.

The estimated reduction in annual GHG emissions across the State as a result of levelling is:

$R_{ghg} = T_{hr/ha}$ x E_i x A_{lll}

where: R_{ghg} = Reduction in GHG emissions in CO_2eq

$T_{hr/ha}$ = Irrigation time saved per hectare/annum (64 hours)

Ei = GHG emissions per hour of irrigation (4.7 kg CO_2eq), and

A_{lll} = Area levelled across the State by LLLs (≈ 544,000 hectares)

The estimated reduction in GHG emissions in Haryana as a result of reduced irrigation time stemming from the expansion of LLL is therefore 163,600 MT of CO_2eq.

8.2 Emission Reduction through Decreased Cultivation Time

After diminished water requirements, reduction in time requirements for cultivation is the next most important advantage of LLL in terms of lowering GHG emissions. Before LLL farmers would typically plough or harrow the land 3-4 times and follow this by planking it once or twice. Each such operation took in the region of 20 minutes/acre (≈ 50 minutes/ha), so the total was in the area of 4¼ hours/ha for each of the two crops. Post levelling the need for harrowing is reduced to 2-3 and there is no need for planking, so the time required for cultivation falls to 50 minutes/acre (≈ 2 hours/ha) per crop. This translates into a time saving of 2¼ hours/ha/crop, or 4½ hours/ha/annum.

However the increase in emissions during LLL must be factored into these figures. The norm, as reported by the owners, is that it takes 2 hours/acre (≈ 5 hours/ha) the first time a field is levelled, but that subsequent levellings take 20 minutes/acre (≈ 50 minutes/ha). For the LLL owners, who level all of their land at the outset and re-level it either every year or every second year, the additional time requirements are, on average, 75 minutes/ha/annum, so that the net reduction in the time the tractor is on working land is 3¼ hours/ha.

In the case of hirers, the figure of 5 hours/ha must be spread over the norm of levelling only every fourth year (as reported in the 2011 study – see §8.1 above), so that the figure again averages 75 minutes/ha/annum, and again the net reduction in tractor time is 3¼ hours/ha. Using the earlier-calculated estimate of 544,000 hectares cultivated under LLL across the State, this translates into a total saving of 1.768 million hours. The hourly fuel consumption by the 50-55 HP tractors LLL owners use averages 4.25 litres, so that the fuel saved is 7.514 million litres. Based on the earlier-reported coefficient of 2.6 kg CO_2 released into the atmosphere per litre of diesel consumed (see Table 9, footnote b above), this translates into a reduction of 19,536 (say 19,500) MT of CO_2 emissions per annum.

[19] One owner reported levelling all of his land twice a year, once before each crop in the rice-wheat rotation.

8.3 Emission Reduction from Fertilizer Savings

One other source of savings noted by farmers was reduced fertilizer application levels. Although not all farmers reported reducing application levels, none reported increasing them. Although it has not been possible with available resources to quantify these, they cannot be ignored when assessing the impact of this technology.

The link between chemical fertilizer and GHG emissions, particularly N_20, is well established. Climate scientists have long understood that the cause of the increased nitrous oxide emissions was application of nitrogen-based fertilizer, because this stimulates microbes in the soil to convert N to N_2O at a faster-than-normal rate. However, only recently has it become possible accurately to identify the proportion of this GHG that is attributable to fertilizer use, distinguishing it from that arising naturally from forests and oceans (Park *et al* 2012).

One approach to mitigating such emissions is to time fertilizer application to avoid rain, because under wet conditions soil microbes produce large amounts of N_2O. Changes in the way fields are tilled, when they are fertilized and how much is used can also reduce N_2O production. It has been observed that by producing a uniformly flat field, LLL reduces the potential for both N_2O emissions and nutrient loss by improving runoff control, thus leading to improved fertilizer use efficiency and higher yields (Jat *et al*., 2006; Jat et al, 2009; Jat *et al* 2011).

It was noted earlier that empirical evidence presented in a number of papers on the subject, indicated that LLL improves fertilizer use efficiency (see §3.1, 4.1 and 4.3 above), yet only one of the 196 farmers interviewed in the 2011 study reported changing the level of fertilizer use. The subject was therefore revisited and probed in some depth in the 2014 study. As in the earlier study, the majority (in this case three quarters) of the respondents reported no change in the level of fertilizer use. However the remaining five all reported that they had reduced the amount of fertilizer applied as a direct result of LLL. Without exception, they reported that an important outcome of irrigating an undulating land surface is the quality of the crop is not uniform, and that they therefore tended to apply additional doses of urea where the crop looked patchy and unhealthy, which tended to be in low spots where there was waterlogging. They did this on the assumption that the problem was lack of nitrogen. This, they reported, did not happen with laser-levelled fields. The reduction was far from negligible. One respondent reported reducing urea application from 3 bags per acre (7.4 bags/ha) to 2-2.5 bags/acre as a result, while another stated that he had reduced application of this fertilizer by 10-15 per cent. Interestingly, one of the farmers who reported reducing fertilizer application specifically noted that other farmers were wrong when they assumed that poor growth in low spots could be cured by applying an extra dose of fertilizer. In his view the correct solution was to eliminate the low spots. Discontinuing the practice of applying urea in low spots where there is standing water will reduce N_2O emissions, because, as quipped by Park *et al* 2012, “wet and happy soil microbes can produce sudden bursts of nitrous oxide”.

9. Impact on CC Adaptation

The CC impact of water savings is not limited to the GHG emission reductions detailed above. Increased temperatures cause more evaporation, which in turn causes clouds to form faster and rain to increase. This means some places will receive greater concentrations of rain (and potentially floods) while other places will receive less rain (and potentially droughts). The general scientific view is that areas which are currently wet will become wetter, while areas that are currently dry will become drier. Climate scientists expect the amount of land affected by drought to grow by mid 21st century – and water resources in affected areas to decline as much as 30 percent. These changes occur partly because of an expanding atmospheric circulation pattern known as the Hadley Cell – in which warm air in the tropics rises, loses moisture to tropical thunderstorms, and descends in the subtropics as dry air. As jet streams continue to shift to higher latitudes, and storm patterns shift along with them, semi-arid and desert areas are expected to expand.[20]

All of this is of vital concern to arid and semi-arid parts of the world, such as Haryana. This is especially true of a State which is presently very agriculturally productive by national standards, but where 80 per cent of agriculture is irrigation-based and increasingly dependent on groundwater, which is already suffering from rapid depletion. If such areas do indeed receive less rain and face the increasing potential for droughts, any technology that reduces demand for groundwater while maintaining, or even increasing, agricultural production will play an exceptionally constructive role in assisting the sector and its farmers to adapt to CC.

The amount of water saved (W_s) by LLL can be estimated as:

$$W_s = \{[(D_{dtw} \times p_{dtw}) + (D_{stw} \times p_{stw}) + (D_{llp} \times p_c)] \times T_{hr/ha} \times A_{lll}\} \text{ litres/annum}$$

Where:

D_{dtw} = discharge rate of DTWs (33,120 lt/hour)
p_{dtw} = proportion of State's irrigated area under DTW irrigation (0.504)
D_{stw} = discharge rate of STWs (20,380 lt/hour)
p_{stw} = proportion of State's irrigated area under DTW irrigation (0.056)
D_{llp} = discharge rate of LLPs (20,380 lt/hour)
p_c = proportion of State's irrigated area under canal irrigation (0.44), and
$T_{hr/ha}$ = irrigation time saved (64 hours/ha/annum), and
A_{lll} = area levelled across the State by LLLs (544,000 ha)

The estimated amount of irrigation water saved is therefore 933 million cubic metres/annum. In fact, since it is known that the true number of LLLs operating in Haryana as shown in Table 5 above is an extremely conservative estimate (see §7 above for discussion), it can safely be assumed that the true figure for A_{lll} is significantly more than 544 thousand hectares, and that water saving in Haryana through LLL is therefore at least one billion m^3, or one cubic kilometre, per annum. This can be compared to the estimated saving of 13-17 km^3/annum for the whole of north-western India (see §3.2 above).

[20] Union of Concerned Scientists http://www.climatehotmap.org/global-warming-effects/drought.html

10. Impact on Agriculture and Food Security

Both the 2011 and 2014 studies focussed on the traditional rice-wheat cropping pattern that is dominant in Haryana (and indeed across the IGP as a whole). The main impact of LLL on food supply is that it increases yields in this rotation, and this increases food security by augmenting its food availability component. However there is also a second effect in that in some areas it promotes crop diversification into nutrient-rich foodstuffs such as vegetables, a process which not only increases the quantity of available food,[21] but also make qualitative improvements in diet possible by supplying micronutrients that are either absent from, or in short supply in, cereals.

This illustrated by the example shown in Box 1 overleaf.

The authors of the 2011 study found 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 (pp 12-13).*

Findings were similar in Punjab. The authors offered the following explanation for the lack of statistically significance in the differences in rice yields before and after LLL:

> *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* (*ibid*)

The 2014 study explored this issue further, and found that the respondents had a very plausible explanation for the wide variation found in rice yields, which is essentially that rice in Haryana (as in Punjab) may be regarded effectively as two different crops. One is HYV rice and the other is basmati. Compared to HYVs, basmati is an inherently low-yielding variety, but this is balanced by the fact that it is a long-grained aromatic variety, which commands a significant price premium on the market. Both basmati and HYV rice are widely grown across Haryana, and many respondents in the 2014 study reported that yields of basmati rice (a) respond positively to LLL, and (b) are lower than those of HYV rice (which also responds to this treatment). However, only one respondent felt confident enough to report the actual level of yield differences. He noted that with LLL basmati yields increased from 32.1 qtl/ha to 37.1 qtl/ha (15.4 per cent), while with HYV rice the gain yield increased

[21] Food security has four components: (i) food availability (i.e. is the sum of domestic production, imports (both commercial and food aid) and changes in national stock.; (ii) food access (which is a household's entitlement to food, which is the amount it can produce, purchase or otherwise receive (e.g. through public food distribution systems)); (iii) food utilization (the capacity of an individual to make use of the food to which s/he has access, which in turn relates to both food handling practices and physiology), and (iv) vulnerability to food insecurity, which can be either chronic or transient.

by 20 per cent, from 49.4 qtl/ha to 59.3 qtl/ha. Obviously it is not possible to calculate the statistical significance of mean yield differences with a sample of one, but it does back up the supposition that lack of statistical significance in comparing rice yields before and after LLL may well be attributable to treating basmati and HYV rice as a single crop.

Box 1. LLL, Crop Diversification and Food Security in Gangar Village, Karnal District: Illustrative Example I

Mr Mukesh Kumar is one of the LLL owners interviewed in the 2014 study. He reported that in the area around his village the introduction of this technology had triggered a widespread degree of crop diversification in the shape of a shift from the rice-wheat rotation into vegetable production, particularly in the *rabi* (winter) season, when wheat is grown. Mr Kumar cultivates 15 acres (6 ha) in total, all of which used to be under the rice-wheat rotation. However in the rabi season he now grows vegetables on 11-12 acres (4.5-4.9 ha), keeping the balance under wheat. During the *kharif* (summer) season he grows vegetables on 3 to 4 acres (1.2 to 1.6 ha) of and the rest under rice. The 2014 survey was conducted in the *rabi* season, and visual inspection of the area confirmed that vegetables were being widely grown in that particular part of the district.

The *rabi* vegetable crop in is dominated by tomato, which was being harvested at the time of the interview. Mr Kumar reported that after LLL (which he repeats on his whole farm every year) and without any increase in fertilizer application, there has been a 10-15 per cent gain in tomato yields, mainly because there is now no longer any need to maintain the three two-meter-wide field channels that were previously required to grow this crop, and this in turn releases land for production.

This farmer also noted that because of LLL it is now economic to grow onion. On non- levelled fields onion needs extremely small beds (because waterlogging causes huge losses in this crop) and this is very labour-intensive; without the LLL it would cost 2,000/acre for labour and this makes it completely uneconomic to grow this crop without LLL.

Mr Kumar has an arrangement with neighbouring farmers to hire a vehicle to transport their tomatoes directly to the Delhi market, so that there is no direct impact on local food security. However this type of crop diversification can be expected to contribute to food and nutritional security in two ways. First, a large number of women are employed to raise the trellises, on which the tomatoes are grown, and again to harvest, sort and pack the crop at harvest time. In total around 1,275 woman-days are employed per acre (3,150 per hectare) per annum for tomato production at a wage rate of INR 120 for a 7-hour day. The second effect is that when tomatoes are graded and packed a considerable number are rejected as being either fully ripe or having suffered some degree of physical damage that makes them unmarketable. A conservative (but admittedly subjective) estimate based on the author's observation of this operation, is that at least five per cent of the crop is rejected in this way. These tomatoes are simply abandoned by the roadside, and anyone who wants them can simply help themselves.

The 2014 study also investigated the reasons behind these yield gains, and the respondents identified two key factors. The first is the by-now familiar point that improved land levelling eradicates the problem of low and high spots in the field, eliminating the problem of waterlogging in the former and moisture stress in the latter. As a result the crop stand is more uniform, there is more tillering and the grain is better filled out, all of which are yield-increasing factors. The second reason is that field bunds, which are traditionally used as to terrace the field and hence keep it more level, are no longer required, so that the area actually under crops in each cultivated hectare is somewhat increased.

The figures from the much larger 2011 sample, which was also more representative in terms of farm size category, will be used here to estimate yield gains. Here stochastic dominance analysis was used to show that in all cases rice yields were higher after LLL, so that the effect on yields of rice as well as wheat could be calculated (see Figure 3 above). The 2011 estimates were a 2.85 qtl/ha increase in production of wheat subsequent to LLL, and a 3.22 qtl/ha increase in production of rice (Aryal *et al* Table 6). Given an estimated area of 544 thousand hectares laser levelled across the State, such yield increases translate into additional production as follows:
Wheat: (2.85 qtls/ha) x (544,000 ha levelled) = 155 thousand MT per annum, and
Rice: (3.22 qtls/ha) x (544,000 ha levelled) = 175 thousand MT per annum

This represents a significant increase in the food availability aspect of food security, and as the 2008 food crisis showed most starkly, reductions in food availability quickly translate into rapidly increasing food prices, which have particularly adverse effects on the poor.

It is important that both the 2011 and 2014 studies show that these increases do not result from augmented application of agricultural inputs such as nitrogenous fertilizer, water and the fuel needed to pump this water. Rather the reverse. Hence, when translated from absolute terms into terms of mitigation and adaptation *per unit of food produced*, the climate change mitigation and adaptation effects are even greater than those reported above.

11. Impact on Socially Marginalized Groups

Socially marginalized groups are here taken to refer to (a) small and marginalized farmers, (b) women and (c) those who have traditionally suffered discrimination on grounds such as caste (scheduled tribes, scheduled castes) and religion. During the 2014 Study attempts were made to uncover information on caste and religion, but the subject was clearly a very sensitive one and respondents were uncomfortable dealing with it. It was therefore decided early on to discontinue questioning on this part of the subject – partly because any information received could well be inaccurate, and partly to avoid the prospect of creating ill-feeling and hence possibly compromising the quality of information on other topics that are also key to this assessment. In any case, any rigorous attempt to obtain information on such a topic would require a separate intensive and extensive study involving a large cross-sectional sample, and available resources, particularly time resources, precluded this.

Before proceeding to look at the evidence on the direct effect of LLL on the socially marginalized, it is worth making two general comments about the impact on such groups of a technology which, as the preceding analysis shows, both mitigates CC and improves adaptation to it. First, the socially marginalized benefit from reduction in GHG emissions disproportionately to their numbers, because they tend to live in marginal areas, which are especially prone to disasters, particularly drought and flood. Second, they also tend to benefit, again disproportionately, from any increase in food availability, because, in accordance with Engels' Law, the proportion of a household's income spent on food is inversely proportionate to that household's income level.[22]

11.1 Small and Marginal Farmers

The Government of India classifies farms into five size categories, and the distribution across these categories in Haryana is shown in Table 10.

The 2011 study divided its sample into just three categories:

- *small* (up to 2 ha), [corresponding to the official *small* plus *marginal* categories]
- *medium* (>2 up to 4 ha), [corresponding to the official semi-medium category], and
- *large* (>4 ha) [corresponding to the official *medium* plus *large* categories]

The distribution of LLL users in the sample was: *small* 31.3 per cent; *medium* 30.2 per cent and *large* 38.5 per cent. The similarity in these three percentages led the authors to conclude:

> *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* (Aryal *et al* 2013, p.10).

While this is perfectly true, the percentages just quoted do not reflect the distribution of farmers across the State. Thus, while just over two thirds of the State's farmers fall into the small-to-marginal category (Table 10), the proportion of such farmers using LLL technology was less than one third. This suggests that, while smaller farmers can and do use this technology, its adoption is nevertheless biased towards larger farmers (in terms of the official definition).

Table 10. Haryana: Distribution of Farm Holdings and Area by Farm Category 2005/06

Farm Category	Definition (ha)	Number of holdings	Total Area (ha)	Mean area/ holding (ha)	Per cent of All holdings	Per cent of Total area
Marginal	up to 1	764,278	346,118	0.45	47.67	9.66
Small	1 to 2	311,397	448,104	1.44	19.42	12.51
Semi-medium	2 to 4	282,849	800,498	2.83	17.64	22.34
Medium	4 to 10	196,029	1,186,030	6.05	12.23	33.10
Large	> 10	48,714	802,548	16.47	3.04	22.40
Total	n/a	1,603,267	3,583,298	2.23	100.00	100.00

Source: Calculated from Government of India, *Agricultural Census 2005-06* Data Base

The 2014 study found that the average size of holding operated by LLL owners was 11.4 ha, which is in the official category of large farmers. However, not all of them could be so-described, as Table 11overleaf indicates. However, these smaller F-SPs all had alternative

[22] The Engels in question was the 19th century statistician, Ernst – no relation of Marx's more famous collaborator, Friedrich.

sources of income (in most cases they were owners of agricultural machinery hire firms), and farming represented a relatively small part of their range of business interests. This is hardly surprising, given that a laser leveller plus a tractor will cost close to a million rupees, so of course poor people cannot afford them. What is important is (a) whether an efficient market has developed for the provision of LLL services and (b) whether poorer farmers have access to it. The fact that there is a market is demonstrated by the fact 95 per cent of LLL time is hired out. Moreover, half of the owners reported that this market is becoming increasingly competitive and have lowered their real hire charges in response.

Table 11. Farm size category of LLL owners in the 2014 Study

	Owners	
Farm Category	**Number**	**%**
Marginal (less than 1 hectare)	0	0
Small (1 ≤ 2 hectares)	2	10
Semi-medium (2 ≤ 4 hectares)	3	15
Medium: 4 ≤ 10 hectares	8	40
Large: > 10 hectares	7	35

As a starting point towards establishing whether their clients were small, medium or large farmers, respondents in the 2014 study were asked to define what they understood by each of these terms. Their definition of a small farmer averaged 2.04 ha, with a range of 1 to 3 hectares, while their definition of a large farmer averaged 5.30 ha, with a range of 4 to 8 hectares. Definitions of medium farmers varied greatly, but lay between the above means. Respondents were then asked whether their clients were large, medium or small farmers in terms of their own definitions. The distribution was as follows:

- Small or mainly small: 50%
- Small to medium: 12.5%
- Mixture of all three types: 12.5%
- Large farmers: 25%

These finding support the view expressed in Aryal *et al* 2013, that the technology is scale-neutral – at least down to the level of small (as distinct from marginal) farmers. Respondents with a preference for large farmers explained this in terms of the scale economies of dealing with large units, and all service providers stated that they give a discount, typically Rs 50/hour (7.7 per cent) to large farmers, because it is easier to level larger fields and there is no need to constantly adjust the rig, as is the case with small plots. This is evidence of scale economies, rather than of discrimination against small farmers.

Two other pieces of evidence from the 2014 study are relevant here. First respondents were asked the smallest size of plot that could be levelled with this equipment. By far the most common response was 0.25 acres (0.1 ha), but with the caveat that it is more economic to level larger plots. It is of course necessary to distinguish between size of plot (which is the more relevant from the viewpoint of feasibility of LLL) and size of farm (which is more relevant in terms of impact on small and marginal farmers), but the above finding does reinforce the view that any bias towards larger farmers is driven by economics rather than discrimination.

Second, respondents were also asked the number of farmers to whom they provided LLL services and the area levelled, and the 2013 mean transpired to be 4 ha, with a standard deviation (σ) of 3.2 ha. This suggests that while small farmers may dominate in terms of number of clients, larger farmers dominate in terms of area levelled. However the mean figure has been steadily falling since 2008, when was 6.9 ha (σ = 4.0 ha).

Finally respondents were asked if there was competition in the LLL hire market. The split between yes and no was around 50-50, but those who said yes, tended to add that competition was growing as the number of machines increased – hardly surprising given the profitability of this investment and the consequent exponential growth of the number of rigs in operation in the area. The number of rigs can therefore be expected to continue to grow rapidly, and it is likely that owners may be forced to lower their rates – as many report they are already doing. Such a trend will lower unite area profits, but presently there is ample scope for this. This seems to be the area of greatest growth potential – especially since larger farmers, having seen the potential of this machine, are now tending to purchase their own rigs after having hired them from service providers for a few years. This means that, as far as present F-SPs are concerned, these new market entrants will switch from being customers to becoming competitors.

All of the above indicates that a competitive and economically-rational market for LLLs has already developed and that the only factor that might reduce the scope for marginal farmers to access it is the technical problem that some of their fields may be too small. Even in this case, evidence is beginning to emerge that in some cases this particular scale diseconomy may be overcome through social organization. One F-SP reported that he had begun to hire out LLL services to groups of marginal farmers who had taken to demolishing the boundaries between adjacent plots in order to create an area sufficiently large for economic levelling, before later re-establishing these boundaries.

Irrigation is a precursor technology for LLL, since without it there is no rationale for precision land levelling. It was therefore hypothesised that, because less than 100 per cent of the State's farm land is under irrigation, small and marginal farmers, being unable to afford the investment, may have less of their land under irrigation, and will therefore be excluded from the benefits LLL. This hypothesis was tested using data from India's most recent Agricultural Census of India (GoI 2007) and the findings are attached as Annex 3 of this report. These figures show an average the proportion of holdings under irrigation as 99.01 per cent with an extremely low σ (0.49 percentage points). There is no statistically significant trend across classes and sub-classes. In the case of proportion of farmed area under irrigation, again the proportion is extremely high (97.78%) and the standard deviation even lower (σ = 0.28 percentage points). Again there is no statistically significant trend across classes and sub-classes.

On the basis of this analysis the above hypothesis should be rejected, but there are strong reasons for questioning the validity of the underlying figures. As described earlier (§7), six of Haryana's 21 districts are mainly characterized by rainfed farming, and this is reflected in the State-level statistics which show that by 2010-11, net irrigated area was 84.2 per cent of cultivated area. The agricultural census figure, however, imply that the proportion of cultivated area was almost 98 per cent, and this must be questioned. Thus the above hypothesis cannot be tested on the basis of these figures. Since no other data are available, this issue cannot presently be resolved.

Some fragmentary evidence emerged from the 2014 study of a very positive income generation effect following crop diversification from the rice-wheat rotation into vegetables. The details are presented in Box 2 below.

Box 2. LLL, Crop Diversification and Poverty Reduction Gangar Village, Karnal District: Illustrative Example II

Mr. Mukesh Kumar, whose views on crop diversification were presented in Box 1, also noted that diversification into vegetable production is especially popular among small farmers (who dominate the area), because the crops are labour-intensive, but generate high returns to labour investment. He estimated that small farmers could gross as much as INR 100,000 per acre (INR 240,000 per hectare) when growing vegetables. Using the current exchange rate of USD 1 = INR 60.9, this translates into USD 3,940 per hectare.

This latter figure may well be a serious underestimate. The common practice of using the official exchange rate to make international comparisons of prices, earnings, etc. is unsatisfactory, because it does not take differences in purchasing power into account, which in turn makes international comparisons misleading. This is especially true when comparing developing and developed economies, because of the high levels of disparity in many of the relevant variables. A more widely-accepted measure today is to adjust the exchange rate measure by a use a purchasing power parity conversion factor (PPPCF). For India the PPPCF is 20 (2011) and the ratio of the PPPCF to the market exchange rate is 0.4.[a] Using this latter measure, the PPP value of the INR 247,000 would be USD 9,850.

[a] The purchasing power parity (PPP) of a currency is the number of units of a that currency required to buy the same amount of goods and services in the domestic market as a US dollar would buy in the United States. In India, the PPP conversion factor is 20, and the effective rate of exchange is the PPPCF/the official exchange rate http://data.worldbank.org/indicator/PA.NUS.PPPC.RF). This means that in 2011 terms, USD 3,940 equates 3,940 x (50/20) = 9,850 PPP dollars.

11.2 Gender Aspects

All of the respondents – as well as a great number of other resource persons in the district – reported that it was unusual for female headed households (FHHs) with agricultural land to farm it themselves. The normal practice is to hire it out to male farmers. However women farmers are far from unknown in the district. Almost half of the respondents reported having hired out their machines to FHHs, but the number was small – in the range of 1-2 to 4-5 per season, compared with an average of more than 70 male farmers. However conditions of hire were the same in each case. The others reported that they had never been asked to supply LLL services to such households, but would have no objection to doing so if asked. The only difference – and it is instructive – is that all of the farmers who hired out their machines to FHHs reported that a woman would never approach a male LLL owner either in person or by mobile phone (the normal modes of communication), but would make contact either through one of her children or through a male relative. Since demand for LLL services presently exceeds supply, the following hypothetical question was put to the respondents: suppose time was scarce and both a male and a female farmer asked for the machine; other things being equal to which one would you give preference? Some said the woman farmer (‘because that is our custom’), some said they had no preference, but it was clear that the question was causing embarrassment, so it was decided it to drop it.

Some fragmentary evidence has emerged of feminization of agriculture in areas where vegetables are replacing cereals in rice-wheat systems. Again the information came from a single respondent (see Box 1). It was noted that LLL enabled farmers to dispense with male labourers who were previously used for building and maintaining irrigation structures), because LLL land eliminated the need for these structures. On the other hand, diversification into labour intensive crops like tomato and other vegetables makes it necessary to hire more labours for tasks such as constructing trellises, harvesting, grading and packing the crop. Women are hired for these tasks, because their wage rate is much lower than that of men. Women are paid INR 120 for a 7-hour day, while men receive INR 300 for an 8-hour day. This wage differential is obviously a powerful incentive to hire female labour. It would be wrong, however, to assume that this pay differential is attributable to LLL technology. Table 12 overleaf shows that significantly lower hourly wage rates for women are the norm in Indian agriculture across all of the operations for which data are available.

11.3 General Impact on Employment and Earnings

Employment generation for LLL operators is highly seasonal, since such operations cannot be carried out when there are crops in the field. All of the 2014 respondents reported that when they hired tractor drivers to operate the LLL rigs it was on a casual basis, and the season typically lasts 2-2½ months. The employment generation effect of LLL rigs was therefore just around 80 person days/annum per machine. The reason for hiring at all is that the season is so short that the owners work their machines very intensively – on average 17½ hours/day – which is why they typically hire one or two tractor drivers. This extra labour is needed because of LLL service provision, rather than ‘own farm’ work, because the ratio of work done on a contract basis to work done on the owner’s farm is 19:1. Contracting out is not the practice with traditional levelling techniques, so there is no direct labour displacement effect. It would be wrong to assume that these machinery operatives are from marginalized groups. They are semi-skilled workers with some degree of training, and they earn more than casual labourers. The typical wage for an eight hour day is INR 500-550, compared to INR 300 for a male agricultural labourer (see §11.2 above and Table 12).

There may, however, be indirect labour displacement effects. It was noted earlier (§3.1) that experiments in Cambodia indicated that labour requirements for weeding were reduced by an average of 16 person-days per hectare, and that more level land also facilitates replacement of transplanting by direct seeding, saving approximately 30 person-days per hectare. None of the informants mentioned saving in weeding time and cost as significant, because they use herbicides for weed control. It was noted, however, that herbicides are not entirely effective on high spots in the fields, and that some degree of manual ‘spot weeding’ is therefore

Table 12. All India Annual Average Daily Wage Rate for Various Agricultural Operations (Rupees)

Crop Year	Ploughing			Sowing			Weeding			Transplanting			Harvesting		
	Men	Women	Ratio	Men	Women	Ratio	Men	Women	Ratio	Men	Women	Ratio	Men	Women	Ratio
2006-07	81.79	43.37	0.53	73.29	41.41	0.57	64.97	52.82	0.81	69.17	56.44	0.82	68.45	55.69	0.81
2007-08	91.38	49.96	0.55	79.28	57.18	0.72	70.07	58.27	0.83	73.79	61.93	0.84	75.24	62.31	0.83
2008-09	102.90	55.43	0.54	90.00	65.00	0.72	80.15	68.02	0.85	83.28	71.43	0.86	87.05	71.58	0.82
2009-10	120.85	70.43	0.58	104.52	79.47	0.76	92.78	78.94	0.85	98.29	86.71	0.88	102.82	84.95	0.83
2010-11	144.50	87.68	0.61	124.84	97.69	0.78	110.64	95.70	0.86	119.51	103.72	0.87	121.93	101.69	0.83
2011-12	190.91	n/a	n/a	173.00	115.82	0.67	146.75	120.20	0.82	144.86	128.36	0.89	163.12	128.93	0.79

Source: Calculated from GoI 2013 Table 8.9
Notes:
n/a = not available
Ratio = women's rate ÷ men's rate;
In no case is the observed rate of growth in this ratio significantly different from zero, even at the $p<0.1$ level

required when the land is not level. However none of the respondents regarded this as a significant saving resulting from LLL.

It should be noted, however, that farmers do not tend to hire labour directly in this Karnal. Instead they engage labour contractors who will bring in labourers to perform the work. The LLL owners are not therefore the best sampling frame to use to investigate these issues. In the case of direct seeding in rice vis-à-vis transplanting, this is a technology which has been introduced only very recently, and there are as yet no reports concerning resulting labour displacement.

12. Laser Levelling and other Climate-Smart Technologies

LLL is one of a range of climate-smart technologies being promoted by the CIMMYT-CCAFS project, although acceptance of this particular technology is now so widespread that in most places comparatively little effort is needed to promote it. There are theoretical reasons, backed by experiments to indicate that the performance of a number of other CS technologies improves significantly on laser-levelled fields, to the extent that it has been described as a 'precursor technology' for resource conservation (Jat *et al* 2013a). The technologies in question are:

- Retention of organic matter in such forms as crop residues and cover crops in order to eliminate the common and harmful practice of burning of residues, while simultaneously improving soil health, conserving water and contributing to both mitigation of and adaptation to climate change (Jat *et al* 2013b).
- Introduction of seeding machines ('Turbo Happy Seeder' and the 'Multi-crop zero till planter') to facilitate planting directly into the stubble of the previous crop seed while simultaneously applying a basal dose of fertilizer.
- The 'Greenseeker' and 'Nutrient expert' tools to improve targeting of fertilizers
- Raised bed planting to improve water control
- Crop diversification to both reduce the damage to soil health caused by perpetual repetition of the rice-wheat rotation and to replace some of the area under rice with crops that are less water-demanding

F-SPs interviewed in the 2014 study were asked whether they had adopted such technologies on their own farms, and if so, whether such technologies interacted in any way with LLL. Thirteen of the nineteen F-SPs in CS villages reported using other CS technologies promoted by the Project, while a further two have plans to use them in the forthcoming crop year. The main technologies in use were the turbo seeder, direct seeding of rice, raised bed planting and crop diversification. The following observations were volunteered:

- It is easier to use the turbo seeder and zero till planter on level fields, because of the elimination of field bunds that results from laser levelling.
- When seeding machines are used in fields that have not been levelled there is uneven distribution of moisture, so that seed germination is somewhat patchy. However, when the field has been levelled before a seed drill is used there is even moisture distribution across the field and therefore germination is much more uniform.

- Without a seed drill the seed is sown broadcast and then covered using a rotavator, which again disturbs the soil, thus counteracting some of the beneficial effects of LLL. However when a seed drill is used, the land remains flat, so that the two technologies used together create a synergistic effect.
- LLL makes crop diversification into vegetables much easier because good water control is even more critical than with cereals. Onion is a very profitable crop, but it is uneconomic to grow it unless the field is level, because of the very high level of labour requirements for irrigation on fields that have had only TLL.[23]
- When rice is replaced with maize as part of the crop diversification drive promoted by the Project, damage to the crop is much greater when the land has not been laser-levelled because the problem of high spots and low spots in the field affects maize more seriously.
- Raised beds are much easier to create on land that has been laser levelled
- One F-SP noted that the previous year he had used a turbo seeder to plant his wheat on an unlevelled field and that due to heavy rain he has lost 20 per cent of the crop. In the current year the same field was levelled before turbo-seeding. Again there was heavy rain, but this time there was no crop damage, because the low spots had been eliminated.
- Two F-SPs were using the Greenseeker tool as an aid to guide application of nitrogen, but did not seem to see any connection with LLL
- In total ten farmers saw no connection between LLL and the other CS technologies promoted by the Project
- One respondent stated that laser levelling is not compatible with stubble retention, so the latter must be burned off before the land is levelled.

13. Conclusions

The area under LLL in Haryana is conservatively estimated at just over half a million hectares, and the number of machines in the State is up to 2,000 and growing exponentially, driven by an exceptionally high rate of return on the investment. This increase can be regarded as sustainable, at least in the medium term, because the amount of land levelled to date represents less than 20 per cent of the State's net irrigated area, so there is still ample scope for further growth.

LLL contributes significantly to both CC mitigation and adaptation. The contribution to CC mitigation is two-fold. The reduction in irrigation requirements and consequent reduction in fuel consumption and GHG emissions, conservatively estimated at 163,600 MT of CO_2eq per annum, and reduced requirements for tillage operations estimated at an additional19,500 MT CO_2e/annum. The CC adaptation effect also derives from reduced requirements for irrigation water, estimated at a minimum of one billion m^3 of water/annum. Although it was not possible to measure the degree of reduction in N_2O emissions, they certainly exist, as some farmers have reduced their use of nitrogenous fertilizer.

The report that laser levelling is not compatible with crop residue retention because the stubble must be burned off before the land is levelled (§12 above), is highly creditable, but in

[23] Note that this is not a labour displacement effect, because without LLL onion is not grown.

terms of contribution to GHG emission three mitigating factors should be taken into account. First, stubble burning is standard practice in Haryana, so that LLL per se makes no contribution to the ill effects. Second, although this practice presents a health and safety hazard, it does not contribute significantly to net CO_2 emissions because, in the words of the expert group on agriculture at the Intergovernmental Panel on Climate Change (IPCC):

> *Agricultural lands generate very large CO2 fluxes both to and from the atmosphere (IPCC, 2001a), but the net flux is small. US-EPA, 2006b) estimated a net CO2 emission of 40 Mt CO2-eq from agricultural soils in 2000, less than 1% of global anthropogenic CO2 emissions* (Smith *et al* 2007).

Finally, CA in the form of residue retention should reduce the need for regular re-levelling of the land, because a basic principle of CA is minimum or zero disturbance of the soil, so that it should remain level.

An important conclusion that has emerged from the 2014 study is that the profitability of investment in LLL equipment is exceptionally high, even without the subsidy that is presently provided by the Government of Haryana. Hence the original justification for this subsidy in terms of encouraging uptake of the technology has served its purpose, and it could be withdrawn without adversely affecting uptake. The savings would be considerable – more than 11.5 million rupees – and the resources saved could be diverted to supporting other proven forms of CS agriculture which have yet to achieve widespread uptake.

Time and methodological constraints precluded a rigorous examination of the impact of LLL on socially marginalized groups during the 2014 study, but it is a strong candidate for rigorous examination in any future impact assessment. At the macro level it can be stated with a reasonable degree of confidence that the socially marginalized will not only benefit, but will benefit disproportionately, from interventions such as LLL that both mitigate and facilitate adaption to CC.

Two facets of social marginalization that *could* be specifically explored in the 2011 and 2014 studies were the direct impact on small farmers (in both studies) and on women farmers (in the 2014 study). Although poor and marginal farmers suffer from technical diseconomies of scale, no evidence was found of systematic discrimination against them on social grounds. Although investment in LLL requires is affordable only by the well-to-do, a well-functioning market in hiring out LLL services has developed in Haryana, so that poorer farmers can still access the technology. LLL yields high financial returns for users, and exceptionally high rates of return for owners, and this is what drives an adoption rate that is growing exponentially. Since the number of LLLs in operation is increasing so rapidly, competition for customers has begun to emerge and can be expected to grow. As this happens, hire charges are likely to fall, so that this technology will become increasingly affordable for small and marginal farmers.

In the case of women farmers, although they do have access to LLL services, ample evidence emerged of prejudice against women in the shape of wage discrimination. Although the evidence from the 2014 study is fragmentary, it does appear that where LLL leads to crop diversification into vegetables, it can also facilitate the feminisation of the casual agricultural labour market, as women are paid very significantly less than men. However this is not so much an impact of LLL, as a reflection of Indian society in general.

The study has produced evidence that many farmers see for themselves a number of synergies that exist between LLL and other CS agricultural practices being promoted by the project (particularly in areas such a direct seeding), but they seem insufficiently unaware of other areas of synergy, such as increases in plant nutrient efficiency resulting from better nutrient placement. As the Project expands and intensifies its activities in the State and elsewhere on the IGP, it will become increasingly important for project staff and their partners in government and civil society to highlight these benefits.

Finally, LLL has been shown to be an exceptionally climate-smart technology in the western Indian IGP. However it remains to be seen whether the effects are similar in eastern areas of the Plain, where conditions are very different on agroecological, social and political fronts.

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Annexes

Annex 1. Semi-structured Interview Format: LLL Service Providers

Name: (#)

Place: Village

Date: February 2014

1. How many laser land levellers do you have?
   -
2. Where did you obtain it/them?
   -
3. When did you obtain it/them?
   -
4. What was the cost?
   -
5. How many horsepower is your tractor?
   -
6. How much diesel does it consume per hour?
   -
7. How many hours per day does the machine work during the season?
   -
8. How did you learn that this technology existed?
   -
9. Did you receive any training on how to use it?
   -
10. Do you use it on your own farm?
    -
11. If so, how many acres have you levelled on your own farm?
    -
12. Is any area on own farm left unlevelled, and if so why?
    -
13. What are the main advantages of LLL?
    - (F-SP own reponses)

    Further probing (as required)
    - Improved crop establishment?

- Reduced weed infestation?
- Improved uniformity of crop maturity?
- Decreased time requirements?
- Reduced volume of water required for land preparation?
- Improved crop yields?
- Increased field size due to elimination of bunds, and hence increased cultivated area?
- Reduced water requirements for irrigation?

14. What are the disadvantages, if any?

-

15. Do you hire out your laser land leveller to other farmers?

-

16. If so, to how many other farmers in each year since you bought it?

Year	No of farmers	Total number of acres
2007		
2008		
2009		
2010		
2011		
2012		
2013		

17. What was the total average acreage levelled for other farmers in each year since you bought it?

-

18. How much is the charge?

-

19. Do you also charge for travelling time?

- No

20. Is the rate lower if a farmer wants a large area levelled?

-

21. At what time of year do you use your laser equipment, and how many days per year?

-

22. Do you employ anyone to operate the equipment, and if so how many?

-

23. How would you define a small, medium and large farmer (in acres)?

- S =
- M =
- L =

24. Are the farmers who hire your equipment regarded as big farmers, small farmers, medium sized?

-

25. What is the smallest field on which the equipment can be used?

-

26. Do any women farmers hire your levelling equipment, and if so how many?

-

27. Is there increasing competition among those who hire out laser levelling equipment?

-

28. Do you go out looking for business, or do farmers contact you when they want their fields levelled?

-

29. Do you use other climate smart practices as promoted by CIMMYT?

-

30. How do these practices interact with laser land levelling?

-

Annex 2: Cost-Benefit and IRR Calculations for LLL with Tractor

Table A2.1 Low-Lift Pump Irrigation: Assuming full LLL subsidy and 25% cost of tractor

COST-BENEFIT ANALYSIS (all figures in INR)													
	COSTS						**REVENUE**				**NET**		
	LLL		Tractor			Both	Own Farm						
								Fuel Savings					
Year	Purchase	Subsidy	Purchase	Fuel	Driver	R&M	Yield Gain	Irrigation	Cultivation	Hiring Out	Cost	Revenue	Cash Flow
0	345,000	-75,000	125,000	0	0	0	0	0	0	0	395,000	0	-395,000
1	0	0	0	286,512	8,505	0	73,000	19,760	7,862	650,000	295,017	750,622	455,605
2	0	0	0	300,838	8,930	1,000	76,650	20,748	8,255	682,500	310,768	788,153	477,385
3	0	0	0	315,880	9,377	2,000	80,483	21,785	8,668	716,625	327,256	827,561	500,304
4	0	0	0	331,674	9,846	3,000	84,507	22,875	9,101	752,456	344,519	868,939	524,419
5	0	0	0	348,257	10,338	4,000	88,732	24,018	9,556	790,079	362,595	912,386	549,790
6	0	0	0	365,670	10,855	5,000	93,169	25,219	10,034	829,583	381,525	958,005	576,480
7	0	0	0	383,954	11,398	6,000	97,827	26,480	10,536	871,062	401,351	1,005,905	604,554
8	0	0	0	403,151	11,967	7,000	102,718	27,804	11,062	914,615	422,119	1,056,200	634,082
9	0	0	0	423,309	12,566	8,000	107,854	29,195	11,616	960,346	443,875	1,109,010	665,136
10	0	0	0	444,474	13,194	9,000	113,247	30,654	12,196	1,008,363	466,668	1,164,461	697,792
													IRR
													120%

Annex 2: (Continued)

Table A2.2 Tubewell Irrigation: Assuming full LLL subsidy and 25% cost of tractor

COST-BENEFIT ANALYSIS (all figures in INR)														
COSTS							**REVENUE**				**NET**			
Year	LLL		Tractor			Both	Own Farm			Hiring Out	Cost	Revenue	Cash Flow	
	Purchase	Subsidy	Purchase	Fuel	Driver	R&M	Yield Gain	Fuel Savings: Irrigation	Fuel Savings: Cultivation					
0	345,000	-75,000	125,000	0	0	0	0	0	0	0	395,000	0	-395,000	
1	0	0	0	286,512	8,505	0	73,000	0	7,862	650,000	295,017	730,862	435,845	
2	0	0	0	300,838	8,930	1,000	76,650	0	8,255	682,500	310,768	767,405	456,637	
3	0	0	0	315,880	9,377	2,000	80,483	0	8,668	716,625	327,256	805,775	478,519	
4	0	0	0	331,674	9,846	3,000	84,507	0	9,101	752,456	344,519	846,064	501,545	
5	0	0	0	348,257	10,338	4,000	88,732	0	9,556	790,079	362,595	888,367	525,772	
6	0	0	0	365,670	10,855	5,000	93,169	0	10,034	829,583	381,525	932,786	551,261	
7	0	0	0	383,954	11,398	6,000	97,827	0	10,536	871,062	401,351	979,425	578,074	
8	0	0	0	403,151	11,967	7,000	102,718	0	11,062	914,615	422,119	1,028,396	606,277	
9	0	0	0	423,309	12,566	8,000	107,854	0	11,616	960,346	443,875	1,079,816	635,941	
10	0	0	0	444,474	13,194	9,000	113,247	0	12,196	1,008,363	466,668	1,133,807	667,138	
													IRR	
													115%	

Annex 2: (Continued)

Table A2.3 Tubewell Irrigation: Assuming no LLL subsidy and 25% cost of tractor

COST-BENEFIT ANALYSIS (all figures in INR)														
COSTS							**REVENUE**				**NET**			
Year	LLL		Tractor			Both	Own Farm			Hiring Out	Cost	Revenue	Cash Flow
							Yield	Fuel Savings					
	Purchase	Subsidy	Purchase	Fuel	Driver	R&M	Gain	Irrigation	Cultivation				
0	345,000	0	125,000	0	0	0	0	0	0	0	470,000	0	-470,000
1	0	0	0	286,512	8,505	0	73,000	0	7,862	650,000	295,017	730,862	435,845
2	0	0	0	300,838	8,930	1,000	76,650	0	8,255	682,500	310,768	767,405	456,637
3	0	0	0	315,880	9,377	2,000	80,483	0	8,668	716,625	327,256	805,775	478,519
4	0	0	0	331,674	9,846	3,000	84,507	0	9,101	752,456	344,519	846,064	501,545
5	0	0	0	348,257	10,338	4,000	88,732	0	9,556	790,079	362,595	888,367	525,772
6	0	0	0	365,670	10,855	5,000	93,169	0	10,034	829,583	381,525	932,786	551,261
7	0	0	0	383,954	11,398	6,000	97,827	0	10,536	871,062	401,351	979,425	578,074
8	0	0	0	403,151	11,967	7,000	102,718	0	11,062	914,615	422,119	1,028,396	606,277
9	0	0	0	423,309	12,566	8,000	107,854	0	11,616	960,346	443,875	1,079,816	635,941
10	0	0	0	444,474	13,194	9,000	113,247	0	12,196	1,008,363	466,668	1,133,807	667,138
													IRR
													97%

Annex 2: (Continued)

Table A2.4 Tubewell Irrigation: Assuming full LLL subsidy and 100% cost of tractor

COST-BENEFIT ANALYSIS (all figures in INR)													
COSTS							**REVENUE**				**NET**		
Year	LLL		Tractor			Both	Own Farm			Hiring Out	Cost	Revenue	Cash Flow
	Purchase	Subsidy	Purchase	Fuel	Driver	R&M	Yield Gain	Fuel Savings					
								Irrigation	Cultivation				
0	345,000	-75,000	500,000	0	0	0	0	0	0	0	770,000	0	-770,000
1	0	0	0	286,512	8,505	0	73,000	0	7,862	650,000	295,017	730,862	435,845
2	0	0	0	300,838	8,930	1,000	76,650	0	8,255	682,500	310,768	767,405	456,637
3	0	0	0	315,880	9,377	2,000	80,483	0	8,668	716,625	327,256	805,775	478,519
4	0	0	0	331,674	9,846	3,000	84,507	0	9,101	752,456	344,519	846,064	501,545
5	0	0	0	348,257	10,338	4,000	88,732	0	9,556	790,079	362,595	888,367	525,772
6	0	0	0	365,670	10,855	5,000	93,169	0	10,034	829,583	381,525	932,786	551,261
7	0	0	0	383,954	11,398	6,000	97,827	0	10,536	871,062	401,351	979,425	578,074
8	0	0	0	403,151	11,967	7,000	102,718	0	11,062	914,615	422,119	1,028,396	606,277
9	0	0	0	423,309	12,566	8,000	107,854	0	11,616	960,346	443,875	1,079,816	635,941
10	0	0	0	444,474	13,194	9,000	113,247	0	12,196	1,008,363	466,668	1,133,807	667,138
													IRR
													61%

Annex 2: (Continued)

Table A2.5 Tubewell Irrigation: Assuming no LLL subsidy and 100% cost of tractor

COST-BENEFIT ANALYSIS (all figures in INR)													
COSTS							**REVENUE**				**NET**		
Year	LLL		Tractor			Both	Own Farm			Hiring Out	Cost	Revenue	Cash Flow
								Fuel Savings					
	Purchase	Subsidy	Purchase	Fuel	Driver	R&M		Irrigation	Cultivation				
0	345,000	0	500,000	0	0	0	0	0	0	0	845,000	0	-845,000
1	0	0	0	286,512	8,505	0	73,000	0	7,862	650,000	295,017	730,862	435,845
2	0	0	0	300,838	8,930	1,000	76,650	0	8,255	682,500	310,768	767,405	456,637
3	0	0	0	315,880	9,377	2,000	80,483	0	8,668	716,625	327,256	805,775	478,519
4	0	0	0	331,674	9,846	3,000	84,507	0	9,101	752,456	344,519	846,064	501,545
5	0	0	0	348,257	10,338	4,000	88,732	0	9,556	790,079	362,595	888,367	525,772
6	0	0	0	365,670	10,855	5,000	93,169	0	10,034	829,583	381,525	932,786	551,261
7	0	0	0	383,954	11,398	6,000	97,827	0	10,536	871,062	401,351	979,425	578,074
8	0	0	0	403,151	11,967	7,000	102,718	0	11,062	914,615	422,119	1,028,396	606,277
9	0	0	0	423,309	12,566	8,000	107,854	0	11,616	960,346	443,875	1,079,816	635,941
10	0	0	0	444,474	13,194	9,000	113,247	0	12,196	1,008,363	466,668	1,133,807	667,138
													IRR
													55%

Annex 3. Haryana: Estimated Number of Operational Holdings by Size Classes and Irrigation Status

(Source: Calculated from figures in the Agricultural Census 2005-06 Data Base (GoI 2007) Table 4)

Farm Category	Total Holdings			Area Irrigated (ha)			Area Irrigated (%)	
	Number	Area	ha/holding	Number	Area	ha/holding	No.	Area
MARGINAL	764,278	346,118	0.45	752,732	340,036	0.45	98.49	98.24
< 0.5	479,651	132,313	0.28	471,145	129,972	0.28	98.23	98.23
0.5-1.0	284,627	213,805	0.75	281,587	210,064	0.75	98.93	98.25
SMALL	311,397	448,104	1.44	308,904	439,332	1.42	99.20	98.04
1.0-2.0	311,397	448,104	1.44	308,904	439,332	1.42	99.20	98.04
SEMI-MEDIUM	282,849	800,498	2.83	281,701	780,971	2.77	99.59	97.56
2.0-3.0	171,837	415,975	2.42	171,044	406,946	2.38	99.54	97.83
3.0-4.0	111,012	384,523	3.46	110,657	374,025	3.38	99.68	97.27
MEDIUM	196,029	1,186,030	6.05	195,397	1,158,897	5.93	99.68	97.71
4.0-5.0	69,817	313,777	4.49	69,504	306,266	4.41	99.55	97.61
5.0-7.5	85,465	524,363	6.14	85,226	512,269	6.01	99.72	97.69
7.5-10.0	40,747	347,890	8.54	40,667	340,362	8.37	99.80	97.84
LARGE	48,714	802,548	16.47	48,594	784,645	16.15	99.75	97.77
10.0-20.0	39,095	504,715	12.91	38,993	492,607	12.63	99.74	97.60
> 20.0	9,619	297,833	30.96	9,601	292,038	30.42	99.81	98.05
TOTAL	1,603,267	3,583,298	2.23	1,587,328	3,503,881	2.21	99.01	97.78

No of holdings irrigated: 98.2-99.8%
Area of farm irrigated: 97.6-98.3%