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Smart precision agriculture but resource constrained farmers: Is service provision a potential solution? Farmer's willingness to pay for laser-land leveling services in Nepal

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A R T I C L E I N F O

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A B S T R A C T

Farmers commonly split large, undulating crop fields, even those at similar elevation range or contour, into a patchwork of small sub-plots in plane areas of Nepal. Specifically, to ensure irrigation or rainwater throughout their cultivated rice or wheat growing areas, structures like bunds, dikes, and ditches are commonly built. These structures not only require significant labor hours to build but also incur loss of some portion of productive crop areas. Laser-land leveling (LLL) is one of the precision technologies that can prevent these area losses, save labor costs, and enhance water utilization. However, purchase of LLL system requires significant capital which could be beyond the access of low resource farmers. In this study, we examined the potential of LLL adoption in a form of service provision or fee-for-service basis among farmers in Nepal. Using an appropriate contingent valuation that maintains efficient estimation and consistent response, we found that Nepali farmers' willingness to pay (WTP) for LLL services averages 1,550 Nepalese Rupees per hour. However, WTP is heterogeneous across farm size—top quantile farmers with relatively higher land acreages have 47% higher WTP for LLL than bottom quantile farmers. Additionally, our interval regression results show positive association of WTP with low irrigation access and with the opportunity cost of land area occupied by bunds and dikes. The results suggest for service provision support programs in LLL adoption to enhance market development of this precision technology in Nepal, specifically focusing land holders with low irrigation access in plane areas.

1. Introduction

Population growth and rising demands for natural resources are important challenges for global food security [24]. The agricultural sector is among the top sectors that consume natural resources and put considerable demands on ground and surface water [18]. In developing countries, agricultural water shortages – which are increasingly linked to climatic variability and climate change [72] – have been identified as a major limitation to enhance crop productivity [[52], [61]]. In intensively-farmed areas of South Asia, over 90% of freshwater resources are used for agricultural purposes [[8], [49], [74]]. However, nearly 25% of this water is wasted from inefficient use [32]. Declining groundwater table is an additional concern in areas that are intensively irrigated, as are the increasing price and energy required for pumping. These issues together undermine initiatives aimed at sustainable water management in the region [[8], [43]].

Rice-wheat cropping systems are the predominate irrigated agricultural production systems in South Asia, occupying most of northern India, Pakistan, Nepal's Terai region, and parts of Bangladesh. These regions together are often referred to as the Indo-Gangetic Basin (IGB).

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Fig 1. Figure shows a laser land leveler attached with four-wheel tractor. The transmitter emits the laser beam that is received by the receiver. The receiver is attached to the bucket or scrapper which is attached to the tractor's hydraulic system; this hydraulic system is controlled by the operator or tractor driver through control box. Source: Peter Lowe/CIMMYT.

The IGB occupies over 13.5 million hectares of land and contributes over 80% of South Asia's cereal production [[26], [70]]. Farmers are disincentivized from increasing production primarily due to relatively high costs of cultivation, difficulty in accessing groundwater, the costs associated with vertical water extraction and irrigation, and sub-optimal agronomic management practices [13]. Rice and wheat are typically grown under flood irrigation. Water is conveyed across the field surface until a desired depth is reached [[63], [65]] and farmers' plots have frequent dikes and ditches with high variation in micro-elevation, with slopes ranging from 1 to 5 degrees within fields [32]. Due to poor leveling and uneven soil surfaces, flood irrigation as described above results in inefficient water management and nutrient uptake by the crop. This limits the productivity of the rice-wheat system [13].

Nepalese agricultural systems are dominated by smallholders with an average land holding size of 0.8 ha and resource-poor farmers [19]. Farmers' land is commonly fragmented into numerous separate fields. Many of these fields are poorly leveled and have considerable slope and micro-elevation variability within them. As such, farmers frequently use bunds, dikes and ditches to control water movement and distribution. In areas where farmers poorly manage these bunds, dikes, and ditches, they face reduced land, water, and economic productivity [33]. Properly leveled plots with comparatively less difference in micro-elevation allow for uniform irrigation water distribution across the field. Leveling can increase nutrient use efficiency, save irrigation water [[2–4], [10]], and reduce energy and irrigation costs [4] in systems where farmers utilize rapidly-soluble fertilizers. This, in turn, can enhance water and crop productivity [31]. These benefits stand in contrast to the high price of cultivation due to water and energy costs in more intensively irrigated rice-wheat cultivation systems common in South Asia's Indo-Gangetic plains, where Nepal Terai is located [3].

Laser land leveling (LLL) is a precursor technology, meaning it is used before a crop is planted [[33], [59]]. Laser-guided leveling systems mounted on the back of four- or two-wheel tractors drag soil from one location to another, correcting for micro-elevation differences within fields (Fig. 1). Farmers can also use LLL to merge multiple fields separated by bunds, which are common in rice-wheat cropping systems. LLL technologies thus have the potential to consolidate fields and open areas formerly occupied by bunds to crop production [[27], [33], [59]]. The benefits of using LLL in different agricultural production systems are well documented [[3], [4], [6], [8], [9], [33], [34]]. The most prominent benefits include increased water productivity – particularly in flooded rice production systems [[31], [36]] – reduced irrigation water requirements and the reduced time needed to convey water across a field [[2–4], [8], [10], [13], [30]]. LLL has also been shown to increase crop productivity and farm returns [[4], [10]]. In flood-irrigated environments that require large quantities of water, LLL technologies can contribute to improved land and crop management decisions to produce more food with less water and energy.

Moreover, LLL is considered a climate-smart technology as it contributes to reduce greenhouse gas emission through its potential to decrease water pumping time by 10−12 h/ha/season for wheat and by 47−69 h/ha/season for rice cultivation, and decrease cultivation time and energy savings equivalent to US$ 143.5/ha [[8], [25]]. Farmers' adoption of LLL in the rice-wheat systems in India's Punjab – where groundwater depletion is a serious concern – have shown an increase in rice and wheat productivity by 7% and 7−9% [8], respectively. Some on-farm experimental research trials have shown a substantial gain in rice-wheat systems productivity and farm profits when LLL technology is coupled with conservation agriculture-based practices [[1], [12], [51]]. Coupling LLL with conservation agriculture, enhanced the water and nutrient use efficiency, while also reduced irrigation pumping costs [[31], [34], [35], [38], [51]]. Other benefits of LLL in the rice-wheat system include improved crop germination, reduced labor requirements for weeding, and improved long-term crop returns [[33], [59]]. However, despite the substantial benefits associated with LLL, farmers' adoption of this technology is limited to a few selected areas of rice-wheat systems in the western IGB. This paper addresses farmers' willingness to pay (WTP) for LLL services in Nepal, using novel *ex-ante* methods to provide information to development practitioners, policymakers, and researchers involved in efforts to conserve agricultural water and boost crop productivity in South Asia.

1.1. Laser land leveling in the rice-wheat systems of South Asia

LLL is a relatively new practice in the rice-wheat systems of South Asia. Research and development institutes first introduced LLL in 2001

Fig 2. Farmer in the study area using a lay flat pipe to irrigate wheat in small sub-plots separated by bunds. Source: authors.

in northwest India and promoted it through field demonstrations and participatory research trials [31]. Recognizing the emerging demand, local manufacturing companies in India started to design, re-assemble, and manufacture the LLL equipment. That lead to the adoption of more than 10,000 units of laser land levelers over a short period of time, primarily by the owners of four-wheel tractors who could add it to their existing equipment [[8], [9]]. Similar LLL adoption success has been reported in the rice-wheat systems of Punjab state of Pakistan [[4], [10]]. These successes are attributed to large land holdings, the high percentage of farmers owning high horsepower tractors, and through concentrated efforts like subsidy programs that targeted farm mechanization [[8], [9]]. Otherwise, farmers' adoption of LLL in the rice-wheat systems of eastern IGB has remained scant.

A number of studies conducted in the rice-wheat systems of the eastern IGB help understand how farmers value LLL technology. Lybbert et al. [45] found a heterogeneous demand for LLL services in the eastern part of India's Uttar Pradesh state and suggested targeted subsidies to increase adoption. Factors such as lack of information, credit constraints, and risk aversion contribute to the limited adoption, the research also found [45]. In another study, Magnan et al. [47] found demand for LLL in the eastern Uttar Pradesh increased when there are adopters in a farmers network. While these studies provide insight into LLL demand in the rice-wheat systems of eastern India, no such studies have been conducted in similar cropping systems in Nepal. Though the cropping systems are similar, the farmers' socio-economic context and agricultural policies in Nepal are different than in eastern India. Hence, this study explicitly focuses on smallholder farmers' WTP for LLL services in rice-wheat cropping systems in Nepal.

In Nepal, LLL is a new technology and was introduced in 2011 through a project-based demonstration. LLL technology in Nepal is imported primarily from the neighboring country India. The rice-wheat systems of Nepal are similar to the other parts of IGB [26], but productivity in Nepal is the lowest among the South Asian countries [20]. The prevalence of subsistence farming, low levels of technology adoption, small and fragmented plots with numerous dikes and ditches and inappropriate crop, water, and nutrient management are identified as the major factors associated with low crop productivity in Nepal [[13], [44], [54], [70]]. Due to productivity stagnation, over 50% of districts in Nepal suffer from food shortages every year [35]. In this context, enhancing the productivity of rice-wheat systems has the potential to improve food security in Nepal. These systems in the Terai region are considered to have high potential for crop intensification due to better access to markets, inputs, financial resources and mechanization [[68], [69]]. Although less than 1% of Nepalese farmers own tractors, these tractor owners provide the tillage and land preparation services to other farmers by offering rental charges. Thus, over 50% of the area in rice-wheat cropping systems is cultivated through hired tractor services [68]. This study assumes that these tractor owners can potentially incorporate LLL attachments with existing tractors and they could provide LLL service to other farmers by offering rental changes and contribute to up scaling this technology.

Farmers in Terai regions of Nepal split their large plots into many small sub-plots using bunds, dikes, and ditches (Fig. 2). This process is labor-intensive, leading to increased production costs. Moreover, the irrigation cost for rice and wheat is higher than other crops, specifically associated with high fuel costs for pumping groundwater in the context of depleted groundwater tables. While crop production in sub-plots divided by bunds may benefit from better water management, a substantial portion of the productive area is occupied for non-productive use. In those areas, LLL adoption could consolidate under-utilized land by smoothing the top-soil, potentially minimizing water and energy costs and enhancing overall crop production, which was evident in northwestern India [[31], [59]].

Farm machinery manufacturing companies in Nepal are underdeveloped, so LLL technologies are imported from India. The price of a single LLL unit to attach to a four-wheel tractor is around 6,000 USD, based on the market assessment from machinery traders in the Terai region. Resource-constrained smallholder farmers may not be able to purchase such expensive technology without considerable support [[56], [75]]. Moreover, the operation of a LLL unit requires a four-wheel tractor, and only a limited number of farmers can afford tractors with sufficient horsepower to pull LLLs and drag soil. Additionally, the LLL tool is operated only during land preparation and then remains idle, which increases the payback period for the technology. Therefore,

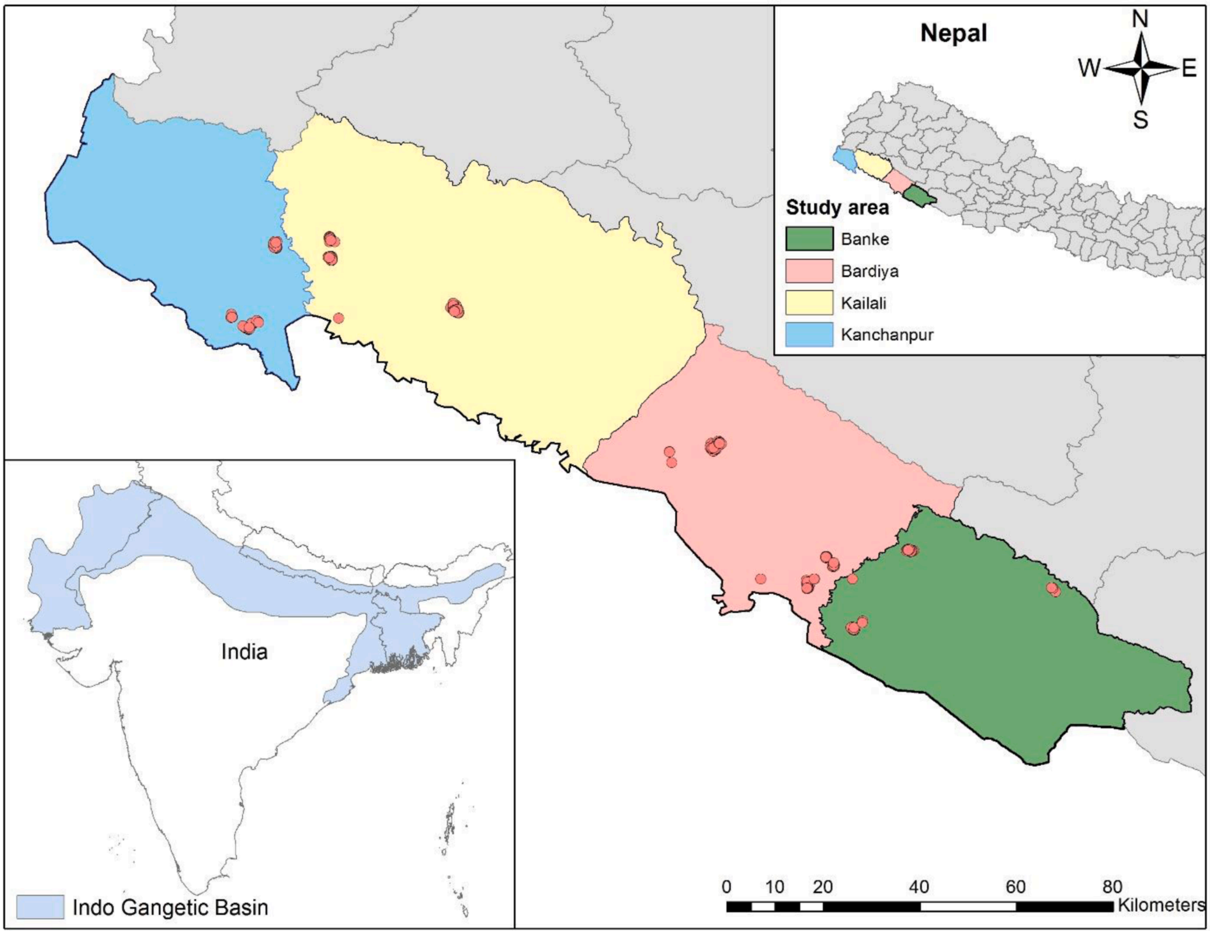

Fig 3. Map shows the study area, survey locations in Nepal, and rice-wheat systems of the Indo-Gangetic Basin.

farmers with more resources, who can withstand some risk and who own four-wheel tractors are more likely to purchase and adopt LLL technology, as evidenced from other parts of the IGB [39]. However, if existing tractor owners rented out LLL services, smallholder farmers could afford for rental charge. This study aimed to understand factors that determine the smallholder famers' WTP for such services and identify the potential demand for this technology.

This study assumes that providers are willing to offer LLL services. In Nepal, farmers who own four-wheel tractors are already providing tractor services to other farmers [68], so the assumption is fairly realistic. This research accounts for other challenges. Smallholder farmers may have very small plots of land that could limit the adoption of LLL, since operationalization requires fields that are at least 0.08 ha to accommodate four-wheel tractors [[31], [59]]. Since farmers tend to have parcels of land scattered across multiple locations [[40], [53], [55]], the potential for LLL may be limited in Nepal. Therefore, this study assessed farmers' WTP for LLL services by including farmers who cultivate rice and wheat on plots with areas $\geq$0.08 ha. The study also assessed the average market price of LLL services that existed in the central region, where a few four-wheel tractor owners and innovative farmers and/or service providers are renting out LLL services. This median service charge is used in the survey design to get some insight into farmers' WTP through contingent valuation. The study used one and a half-bound dichotomous choice model to assess farmers' WTP for LLL services, which is described in the next section.

2. Materials and methods

2.1. Data

The data used in this study comes from a survey designed to understand the scope of LLL services in four districts of Mid- and Far-western developmental regions of Nepal Terai that are part of the IGB and have the potential to scale-up LLL. Samples were collected from the districts *Banke, Bardiya, Kailali* and *Kanchanpur*. The International Maize and Wheat Improvement Center, Nepal, led the data collection in 2015. From each district, sub-districts (Village Developmental Committees, or VDCs) were purposively selected from Cereal Systems Initiatives for South Asia (CSISA) project (https://csisa.org/) working areas. The project was operational in 10 VDCs. The sampling strategy consisted of 50 percent of samples randomly selected from the list within CSISA project area and 50 percent of samples randomly selected beyond the CSISA project areas from the same VDCs. From each VDC, 40 sample households were selected randomly, resulting in an overall sample of 400 households (40 households from 10 sub-districts of four districts). An additional six samples were collected from one of the districts due to a higher proportion of rice-wheat systems in that district, bringing the overall sample size to 406.[1] The map of the study area, survey locations, and sample distributions are presented in Fig. 3.

[1] Additional six samples were included from Kailai distict of far western Nepal. Kaili district has the highest rice-wheat systems area, among the sampled districts.

Table 1
Economics of rice-wheat production in the study area.

	Overall farms (*N*=406)		Bottom quantile farms (*N* =113)		Top quantile farms (*N* =94)		Sig.
	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev	
Rice-wheat area[#] (ha)	1.20	1.02	0.72	0.65	2.27	1.42	***
Tillage cost ('000 NPR/ha)	14.60	6.92	16.34	7.61	13.38	5.61	***
Cost of traditional leveling ('000 NPR/ha)	3.85	2.84	4.26	3.40	3.63	2.70	
Cost of bunds construction ('000 NPR/ha)	3.19	2.77	3.08	2.28	2.81	2.25	
Cost of irrigation ('000 NPR/ha)	5.81	7.71	5.57	6.82	4.43	5.88	
Total cost of irrigation, leveling, bunds construction and tillage (NPR/ha)	27.45	11.87	29.25	11.78	24.25	9.79	***
Area occupied by bunds (square meters/ha)	702.25	593.44	747.57	611.37	674.32	0.46	
Forgone profit from the bunds area[†] ('000 NPR/ha)	1.46	4.15	0.51	2.34	4.15	7.06	***
Total labor cost ('000 NPR/ha)	50.11	21.44	58.00	23.48	40.51	17.39	***
Grain yield[##] (tons/ha)	6.42	2.07	6.08	2.06	6.73	2.09	**
Total variable cost ('000 NPR/ha)	116.15	38.82	128.29	38.47	98.84	31.68	***
Gross revenue ('000 NPR/ha)	141.24	45.46	133.73	45.28	148.09	45.99	**
Gross margin ('000 NPR/ha)	25.08	49.19	5.44	51.87	49.25	42.62	***

Notes: *** and ** indicate significant at 1% and 5% level, respectively. Exchange rate: USD 1= NPR 100 during the survey year. [#]Rice-wheat area includes area under rice-wheat, rice-fallow, and fallow-wheat cropping systems. [##]Grain yield is the combined yield of rice and wheat, presented to represent the rice-wheat system productivity. [†]Forgone profit is calculated as [(current profit/ rice-wheat area without bunds) × area occupied by bunds].

Table 2
Descriptive statistics of the variables used for WTP elicitation.

Variables	Overall farms (*N*=406)		Bottom quantile farms (*N* =113)		Top quantile farms (*N* =94)		Sig.
	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev	
Farm size of household (ha)	0.81	0.72	0.24	0.08	1.82	0.85	***
No. of parcels of land (no)	2.23	1.46	1.69	0.96	3.15	2.01	***
Household size (number)	7.03	3.69	5.70	2.44	9.23	5.51	***
Forgone profit from the bunds area ('000 NPR/ha)	1.46	4.15	0.51	2.34	4.15	7.06	***
Access to groundwater irrigation (1=low access)	0.35		0.42		0.32		*
Total cost of irrigation, leveling, bunds construction and tillage (NPR/ha)	27.45	11.87	29.25	11.78	24.25	9.79	***
No. of years of farming (years)	25.68	14.50	22.44	14.00	27.34	13.24	***
Sex of household head (1=male, 0=others)	0.91		0.90		0.93		
Caste of household (1=upper caste, 0=others)	0.35		0.47		0.19		***
Education of household head (years)	4.84	4.40	4.77	4.27	5.20	4.58	
No. of household members migrated (no)	0.43	0.91	0.50	0.87	0.24	0.54	***
No. of bullocks raised for agriculture purposes (no)	1.36	1.33	1.01	1.09	1.77	1.46	***
Land tenure (1=leased, 0=others)	0.04		0.07		0.03		
Sharecropping (1=shared-in, 0=others)	0.14		0.29		0.02		***
Percentage parcels of land irrigated (%)	37.27	46.03	44.22	48.20	34.55	45.01	
Farms using four-wheel tractors (1=yes, 0=no)	0.76		0.66		0.89		***
Off-farm income ('000 NPR/year)	146.14	295.78	111.96	126.03	128.31	177.28	
Percentage share from on-farm income (%)	41.42	39.11	22.75	32.96	64.89	35.05	***
Location (1=if farms are located in far-west region, 0=mid-west region)	0.51		0.54		0.52		

Notes: *** and ** indicate significant at 1% and 5% level, respectively. Exchange rate: USD 1= NPR 100.

2.2. Analytical framework

Farmer responses and the potential adoption of technology like LLL maynot be exactly assessed without providing farmers with detailed information on the benefits of the technology [[11], [42]]. In the case of LLL service in Nepal, farmers do not have sufficient information and incentives to thoroughly evaluate the values associated with technology because there is low or no existence of an established service provision market. We adopted contingent valuation approaches to elicit farmer's WTP where survey enumerators explained benefits through different hypothetical scenarios for the LLL services [[7], [15], [23]]. With this method, two different econometrics approaches are generally used for assessing farmers' WTP for the technology: (i) single bound approach (SB) [29] and (ii) double bound approach (DB) [28]. In SB format, farmers are able to provide "yes" or "no" responses to their desire for LLL services at a single price point. This approach is incentive-compatible but may be limited in efficiency [28]. On the other hand, DB format has higher efficiency in benefit estimates but is criticized to have inconsistent responses in second bid [[16], [42]]. In this study, we used multiple-bound format to gain efficiency and avoid potential response bias in follow-up bids. Moreover, we used multiple bound of DB approach but adapted the aspects of one and one half bound (OOHB), which is found to be higher consistent with follow-up bids and is more efficient [16].

First, we assessed the average market price of LLL services, based on the median service charge used by service providers in proximate districts to use it as an initial price for the bidding. Enumerators first asked respondents "yes" or "no" on this initial price bid. Enumerators only provided lower bids to the farmers who responded negatively to the initial LLL service charge. Farmers who responded positively to the initial bid were not asked a follow-up question to establish an upper price point because it may not provide additional research insights but is likely to have upward biases [42]. Although some literature criticizes the follow up bids due to lack of incentive compatibility [73], the follow-up question formats like in DB and OOHB increase statistical efficiency over SB; these methods have been used in earlier studies assessing farmers' WTP for agricultural technologies and related studies [[5], [17], [41], [48], [58], [62], [71]]. Cooper et al. [16] discusses that the OOHB method prevents from possible false value expectations and bargaining mindset of respondent. The bids are expected to be more consistent because the respondent could conveniently express their agreement on the higher to lower bids between first and follow-up bids.

The median price of the existing LLL services was NPR 1,500/hour (USD 15/hour). The bid structures to elicit the WTP for LLL technology

Table 3
Factors influencing WTP for LLL services from the interval regressions in the rice-wheat systems of Nepal.

Variables	Model-I Coefficient	Std. error	$P>Z$	Model-II Coefficient	Std. error	$P>Z$
Model intercept	664.32	165.53	***	780.87	182.52	***
Farm size of the household (ha)	880.15	131.64	***	881.39	134.23	***
Farm size squared	-127.25	23.58	***	-145.85	27.85	***
Number of parcels in the farm	2.66	26.67		3.39	26.53	
Household size (number)	14.74	11.93		14.64	11.85	
Groundwater irrigation (1=low access)	233.12	75.85	***	196.65	77.44	***
Forgone profit (NPR/ha)	–	–		0.02	0.01	*
Cost of irrigation, leveling, bunds construction and tillage (NPR/ha)	–	–		-0.003	0.002	
Number of years of farming (years)	1.49	2.05		1.71	2.04	
Sex of household head (1=male)	-32.95	94.38		-33.72	93.54	
Caste of household (1=upper caste)	-68.23	66.14		-61.61	65.82	
Education of household head (years)	9.87	7.30		10.75	7.27	
Number of household members migrated	-13.82	30.90		-17.31	30.51	
Number of bullocks raised for agriculture purposes	26.52	27.11		25.77	26.88	
Land tenure (1=leased)	-192.42	137.27		-191.17	136.55	
Sharecropping (1=shared-in)	-132.66	89.56		-159.08	89.72	*
Percentage of land parcels irrigated	0.04	0.61		-0.09	0.62	
Use four-wheel tractors for land preparation (1=yes)	-18.44	71.76		-37.26	71.82	
Off-farm income (NPR/year)	-2E-04	1E-04		-2E-04	2E-04	
Percentage share from on-farm income (%)	0.45	0.92		0.11	0.95	
Location (1= if farmers located in far-west region)	220.99	75.43	***	207.76	75.10	***
LR χ^2 [df]	173.46 [19]		***	178.46 [21]		***
Log likelihood	-330.12			-327.62		
Number of observations	406			406		

Notes: ***, **, and * indicate significant at 1%, 5%, and 10% level, respectively. Exchange rate: USD 1= NPR 100.

Table 4
Estimated WTP (*NPR*) for LLL services across districts, overall farms, and farm size quantiles.

Districts	All farms (NPR/hr) Mean	Std. error	Bottom quantile farms (NPR/hr) Mean	Std. error	Top quantile farms (NPR/hr) Mean	Std. error
Banke	1332	38	1101	34	1886***	58
Bardiya	1639	39	1159	20	2198***	54
Kailali	1585	43	1164	24	2254***	57
Kanchanpur	1580	46	1148	23	2200***	76
Overall farms	1550	22	1143	14	2174***	33

Notes: *** Significantly different from bottom quantile farms at 1% level. Exchange rate: USD 1= NPR 100.

are shown in appendix Table A1. Since the follow-up bids were asked for the farmers who responded negatively to the initial bid, it is likely that farmers could say "no" to the second bids if they were close to the initial price [57]. Therefore, the method maintains a difference of 7% (NPR 100) between the largest second bids and the initial price bid. However, a range of 3.3% (NPR 50) was maintained for the rest of the follow-up bids to see how farmers responded to additional discounts. Eleven possible follow-up bids were formulated. The lowest bid was NPR 900, which was the same price as tractor services used for soil tillage. This bid can represent as an LLL technology price premium of zero. All farmers were asked to respond to the first bid. The second bids were randomly selected by the enumerators and asked to the farmers who responded negatively to the initial bid price.

Based on the framework described above and the bids structure, the range of WTP for the LLL services values can be estimated for "yes" responses in the range of $(P, +\infty)$, for "no" – "yes" responses in the range of (P_d, P), and for "no" – "no" responses in the range of $(0, P_d)$, where P is the initial bid price and P_d is the follow-up bids. In our case, for the farmers who responded against the first and the second bids, the study assumed their minimum WTP as "zero." Hence, the three probabilities for bid responses can be represented as:

$$P\ (Yes) = \text{Prob}\ (WTP \geq P) \tag{1}$$

$$P\ (No - Yes) = \text{Prob}\ (WTP \leq P) - (\text{WTP}\ \leq P_d) \tag{2}$$

$$P\ (No - No) = \text{Prob}\ (WTP \leq P_d) \tag{3}$$

The likelihood functions from the range of above-described values of the WTP for LLL services model can be estimated in the following way:

$$\ln L = \sum_{i=1}^{N} d^Y \ln\left[1 - \Phi\left(\frac{P - \beta' x}{\varepsilon}\right)\right] + d^{NY} \ln\left[1 - \Phi\left(\frac{P - \beta' x}{\varepsilon}\right) - \Phi\left(\frac{P_d - \beta' x}{\varepsilon}\right)\right] + d^{NN} \ln\left[\Phi\left(\frac{P_d - \beta' x}{\varepsilon}\right)\right] \tag{4}$$

Here, d^Y, d^{NY} and d^{NN} are binary indicator variables for three response groups and x is the vector of farm and household-level attributes that are likely to influence the WTP for LLL services. The parameter ε is the standard error of the regression, which captures the randomness in the bid function of the LLL services. The estimation coefficient β can be directly interpreted as the marginal effect of the variables x on WTP for LLL services. The mean WTP for LLL services is obtained by evaluating the estimated coefficient at variables mean values.

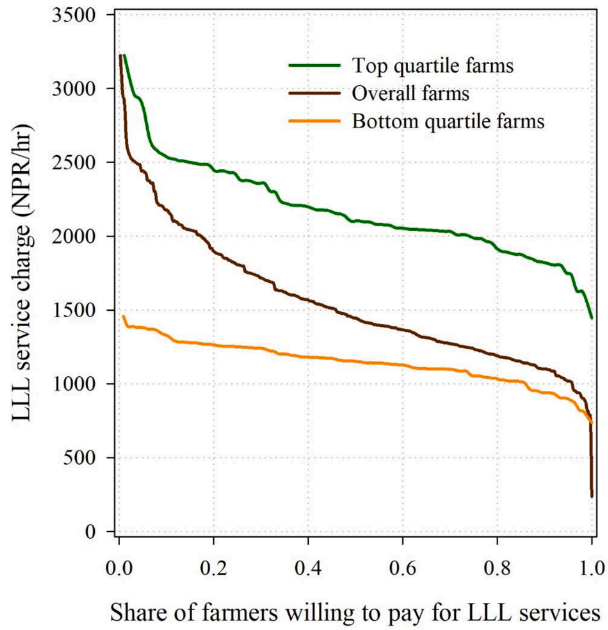

Fig 4. Demand curves for LLL services across farm size quantiles and overall farms.

3. Results and discussion

3.1. Descriptive analysis

Farmers' reasons for splitting their largest farm fields into several small plots by constructing bunds are presented in appendix Table A2. Over two-thirds of the surveyed farmers reported that the main reason they constructed bunds was to improve within-field irrigation conveyance and water management, while other farmers reported precision fertilizer applications, easy weeding and convenience for growing various crops. Farmers across all farm size quantiles reported reasons related to water management efficiency, such as saving water, addressing water holdings in the plots and better water distribution (appendix Fig. F1). These responses indicate that water management is a significant issue in the region (appendix Table A2).

Economic considerations as they pertain to rice-wheat production in the study area are presented in Table 1. Sampled farmers grew rice and wheat on around 1.2 ha in the study area on average.[2] The results are analyzed by dividing responses into farm size quantiles using survey data. The top quantile farms allocated a significantly higher land area to rice-wheat cultivation (2.27 ha) compared to the bottom quantile farms (0.72 ha). Only 4% of the sampled farmers leased the land for cultivation, while the rest cultivated their own farms. Additionally, almost 14% of the farms practiced share cropping, mostly bottom quantile farms. The average land preparation cost is around NPR 14,600 (USD 146) per ha; however, bottom quantile farms are paying significantly higher land preparation costs than the top quantile farms, possibly due to smaller and more fragmented plots. They also add to the cost of production through traditional leveling (NPR 3,850 or USD 38.5 per ha) and bunds construction (NPR 3,190 or USD 32 per ha). It should be noted that farmers already knew the benefits of leveling plots. However, they also use a substantial amount of money and labor for traditional leveling, which is accomplished using bullocks and wooden planks that are dragged repetitively across the soil surface. This technique does not necessarily smooth the soil surface as evenly as LLL technology does. Traditional leveling also add to the cost of production (Table 1). Moreover, even after traditional leveling, farmers split their plots into several sub-plots through bunds. The costs of bunds construction and costs for traditional leveling are significantly higher for bottom quantile farms than for top quantile farms. If farmers use LLL, at the existing service charge of NPR 1,500 (USD 15) per hour of services, farmers can level the plots within two to three hours. It shows that almost NPR 3,000 (USD 30) to 4,500 (USD 45) per ha is sufficient to level the plot. This indicate that famers are investing more money in traditional leveling methods. Additionally, the average seasonal bunds occupy around 702 square meters per hectare area that amounts to an opportunity cost (lost land that could have been cultivated with a crop) of around NPR 1,460 (USD 15) per ha. However, the forgone profits were higher for top quantile farms than bottom quantile farms, indicating that the bunds area increases with the increase in farm size, as expected (Table 1).

The average total labor cost for rice-wheat production in the study area is around NPR 50,110 (USD 501) per ha. The bottom quantile farmers are paying significantly higher labor costs (NPR 58,000 or USD 580 per ha) than the top quantile farmers (NPR 49,510 or USD 495 per ha). This indicates that the bottom quantile farmers rely more heavily on labors than machines, perhaps reflecting the low adoption level of mechanization. The increase in the labor cost for rice-wheat systems contributes to a higher total variable cost and a higher cost of production for bottom quantile farms. The average rice-wheat system productivity in the study area is around 6.42 tons/ha per year. The system's productivity for the bottom quantile farms is significantly lower (6.08 tons/ha) than the top quantile farms (6.72 tons/ha). The gross revenue and the gross margin from rice-wheat cropping systems in the study area are around NPR 141,240 (USD 1,412) and NPR 25,080 (USD 251), respectively. However, due to the lower yield among the bottom quantile farms, naturally, the gross revenue and gross margin are significantly lower for the bottom quantile farms (Table 2).

The bidding structure for the complete LLL WTP elicitation is presented in the appendix Table A1, which shows that nearly 50% of farmers responded positively at the initial market price of LLL services. However, 75% of farmers responded positively at the discounted bids. These results indicate that the LLL services are sensitive to price and that farmers' WTP increases when the LLL service charge decreases,

[2] In order to represent the rice-wheat cropping systems level productivity and profitability, farmers cultivated area under rice-wheat, rice-fallow, and fallow-wheat cropping systems are considered is in this study.

following the general law of demand. The socioeconomic attributes of the sample farmers and the comparison among the top and bottom quantile farms are presented in Table 2. Farm size in the study area for the overall farms is around 0.81 ha, which is similar to the national average in Nepal. However, the bottom quantile farms (0.24 ha) are significantly smaller than the top quantile farms (1.82 ha). The average farm household in the study area has more than two parcels of lands. The average household size consists of 7.03 members, though the bottom quantile farms have significantly smaller households than top quantile farms. Additionally, Table 2 shows that over 90% of sampled households are headed by males. Household heads have an average of around five years of formal education and 26 years of farming experience. Around 35% of these households belong to the upper castes.[3] Note that a higher percentage of households belonging to upper castes are from the bottom quantile farms, whose household heads also have significantly less farming experience.

While 65% of the farms reported that they have access to groundwater, a significantly higher share of top quantile farms has access compared to bottom quantile farms. Additionally, Table 2 shows that a higher percentage of family members in bottom quantile farm households rely on out-migration. Our findings regarding on- and off- farm activities variables suggest that top quantile farms mostly rely on on-farm for income while the bottom quantile farms rely more on the off-farm income. Top quantile farms also own a significantly higher number of bullocks than bottom quantile farms. Although these bullocks are used for agricultural purposes, primarily for tillage operations, almost 76% of farmers reported that they used four-wheel tractors for agricultural land preparation. A higher percentage of top quantile farms used tractors for land preparation.

3.2. Factors affecting WTP for LLL services

We used two different models to assess the factors influencing farmers' WTP for LLL services. The model results are presented in Table 3. The first model includes only the farm-level socioeconomic attributes while the second model includes two additional independent variables: forgone profits (opportunity cost of gains from rice-wheat production on the bunds areas) and the cost of traditional leveling, irrigation, and bunds construction. Overall this study found similar coefficient that were consistent between two models. The results show that farm size is positively associated with the WTP for LLL services, indicating that owner of larger farms are willing to pay more for LLL services than the small farms. However, a negative coefficient of farm size-squared indicates that this increasing rate decreases after certain farm size.[4] It is plausible that farmers may purchase their own LLL technology and are less likely to demand LLL services once they reach a certain farm size or have higher land areas.

Our finding on positive association between farm size and WTP for LLL services is similar to earlier studies that have demonstrated farm size as one of the important determinants for agricultural technology adoption [[21], [22], [39], [60], [67]]. Our finding, though, is unique compared to earlier studies as it indicates that farm size plays an important role even in the service provision models. Since farm size is reflective of wealth in developing countries [37], the positive association with farm size and WTP for LLL services is not unexpected.

Moreover, farmers' forgone profit from the bunds area (i.e., the opportunity cost of using productive land for bunds) is positively associated with the WTP for LLL services. This result indicates that the area occupied by bunds, and the opportunity cost of bunds construction, tends to be an important determinant for farmers' WTP for LLL services. Our summary statistics suggests that these bunds occupy a substantial portion of the productive area among sampled farms (702 square meters per ha, almost 7% area). The positive association between forgone profit and LLL WTP is perhaps due to farmers' realization about potential losses on grain yields from the bund areas.

An additional relevant finding is that farmers having low access to irrigation water, such as groundwater, is positively associated with their WTP. From our direct observation and interaction with farmers in western Nepal, this research suggests that farmers having low access to water resources and irrigation often prepare more bunds. Bunds can be thought of as a risk-mitigation strategy for resource-constrained farmers due to the perception that water can be better managed and retained for a longer period with bunds. However, farmers likely incur higher labor costs in constructing and maintaining bunds, ironically leading to increased cultivation costs. The low access to groundwater, declining underground water table in areas, and higher overall costs associated with bunds construction are among several plausible reasons for this positive association.

Our results also show that sharecropping is negatively associated with WTP for LLL services, probably because tenant farmers have to share rice and wheat outputs with the landowner and perhaps care less on precise production and water utilization as compared to owner. Under sharecropping, the landlord provides land while inputs and other operational costs depend on the agreements with landlords and differ by region [66]. Finally, the study finds the spatial differences in WTP for LLL services. The results show that the farmers in the far-western Terai region have significantly higher WTP for LLL services than those in the mid-western Terai region. This result is plausible because water management issues are much more pronounced for farms located in the far-western region due to a rapidly-depleting groundwater table [[14], [46], [64]].

3.3. Heterogeneous demand for LLL services

Based on the WTP models, we predicted the service charges that the market could sustain for overall sampled farmers as well as by district. Results are presented by farm size quantiles in Table 4. We estimated that an average WTP for the overall sampled populations as NPR 1,550 (USD 15.5) per hour. Interestingly, the model predicted the average WTP for LLL services is very close to the prevailing service charge that the study accounted for the initial bidding. However, the result shows significant difference between the bottom and top quantiles: the predicted WTP for LLL services for top quantile farms is 47% higher (NPR 2,174 or USD 21.74 per hour) than the bottom quantile farms (NPR 1,143 or USD 11.43 per hour) and 40% higher than the average sampled farms. These difference among the top and bottom quantile farms are consistent across all four districts and indicate the high sensitivity of LLL service charge to farm size. Our results are consistent with earlier studies that have demonstrated the differential WTP for LLL services across farm size quantiles [[9], [45]]. Also note that the average WTP of the bottom quantile and top quantile farms are predicted around 31% lower and 45% higher than the prevailing average market price of LLL services, respectively. The results are consistent across all the districts considered in our study. These results indicate a greater likelihood of success of LLL service provision models in the top quantile farms, while targeted support programs are required to encourage LLL adoption in the bottom quantile farms.

Based on our model and predictions, the demand curves are derived for the LLL service provisions. Fig. 4 shows the downward sloping demand curves predicted for overall farms, top quantile and bottom quantile farms. Result shows that the demand curves for both top

[3] In Nepal different socially and hereditary determined caste systems exist which is broadly distinguished by the relative degrees of ritual purity or pollution and of the social status and class. There are four broad types of castes, Brahmin, Chettri, Vaish and Shudra. The Brahmin and Chettri and decedents are traditionally considered as relatively upper castes, while the Vaish and Sudra are traditionally considered as lower castes. For more detail, please see: Mosse [50].

[4] Based on Model 2 estimates (Table 4), this inflection point was computed to be around 6 ha (i.e., 881.39/145.85=6.04 hectares)

quantile and bottom quantile farms are elastic. However, the demand curve for the bottom quantile farms is relatively more elastic than overall farms and top quantile farms. This indicates that the bottom quantile farms are more sensitive to LLL service charges than the top quantile farms. This is consistent with our expectations as bottom quantile have less land and also likely to have lower other resources.

4. Conclusion and policy implications

We examined one of the precision agriculture technologies, Laser assisted Land Levelling (LLL) reviewing its adoption in plane areas of rice-wheat cropping systems. Specifically, in the areas where farmers use structures like bunds, dikes, and ditches on the flat plots and subplots even with relatively similar elevation, LLL could be a climate smart precision technology to save irrigation water, labor costs, reduce fuel costs and contribute to lower greenhouse gas emission. However, the adoption of LLL system has not gained wider adoption in Nepal. One of the important reasons is that the farmers with relatively low resources are not able to purchase the LLL system. Our study addresses this issue by specifically examining the pay-for-use service provision potential by estimating farmers' WTP for LLL services and predicting demand models.

Our results suggest that there is relatively high potential for enhancing LLL adoption and increasing its access to wider farming communities through service provision model. However, we also found a heterogeneous WTP for service provision that is different between top and bottom quantiles of farm size Correspondingly, the derived demand curves are with different elasticities. Our overall results, which suggests high potential for service provision, have important implications for efforts to balance food production with natural resources conservation and energy in the rice-wheat cropping systems of Nepal and the IGB. Additionally, the heterogeneous demand observed across different farm size quantiles suggests that small and large-sized farms need different policy instruments and rural development strategies. For example, a special subsidy or support program – perhaps including capital assistance for mechanization or equipment service procurement from public or government institutions – could enhance adoption of LLL technology among small sized farmers. It could also permit these farmers to become entrepreneurs and offer these services to other farmers. Conversely, farmers owning more land may need less assistance with capital. Programs could still target the development of viable business models for them to quickly recoup capital investments by making money providing services to other farmers. Additionally, targeted programs should integrate extension and outreach activities, while working to raise awareness among farmers of the cost implications and trade-offs between constructing structures like bunds, dikes, ditches in the flat land with that of using LLL services for precise efficient water use without loosing crop productivity. Such information could assist farmers in making improved and informed decisions about labor versus capital substitutions and trade-offs, while positioning them for enhanced uptake and sustained use of resource conserving technologies like LLL.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

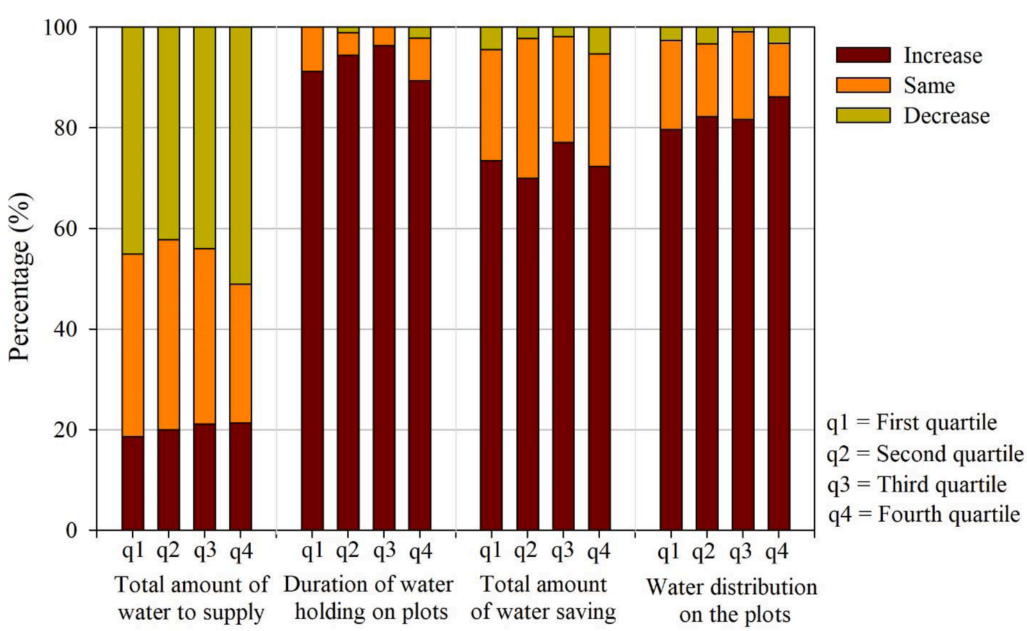

Fig. F1. Farmers' perception of water management after splitting a large plot into several.

Table A1
Bid structure for the laser land leveling services WTP elicitation.

	Discount (%)	Bid (NPR/hr)	Yes-response No. of farms	%	No-response No. of farms	%
Initial bid (overall)	0	1500	205	50.49	201	49.51
Initial bid (smallest 25% farms)	0	1500	16	14.16	97	85.84
Initial bid (largest 25% farms)	0	1500	84	89.36	10	10.64
Second bid†						
Bid 1	6.67	1400	3	51.23	8	48.77
Bid 2	10.00	1350	2	51.72	12	48.28
Bid 3	13.33	1300	5	52.96	12	47.04
Bid 4	16.67	1250	8	54.93	14	45.07
Bid 5	20.00	1200	14	58.37	5	41.63
Bid 6	23.33	1150	10	60.84	10	39.16
Bid 7	26.67	1100	8	62.81	8	37.19
Bid 8	30.00	1050	22	68.23	13	31.77
Bid 9	33.33	1000	5	69.46	3	30.54
Bid 10	36.67	950	13	72.66	11	27.34
Bid 11	40.00	900	8	74.63	7	25.37

Note: †The responses were elicited from farmers who answered negatively against the initial bid. Exchange rate: USD 1= NPR 100.

Table A2
Farmers' reasons for splitting large plots by constructing bunds.

	Overall farms (N=406)	Bottom quantile farms (N =113)	Top quantile farms (N =94)
Efficient water management (%)	75.62	78.76	75.53
Precision fertilizer application (%)	2.22	1.77	1.06
Easy weed management (%)	4.68	4.42	4.26
Easy harvesting (%)	0.74	0.00	0.00
Other reasons# (%)	16.74	15.05	19.15

Notes: #other reasons include undulated fields, easy to inspect crops, easy for crop cultural operations, and ability to grow legumes/fodders in bunds.

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