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Research Article

Gradient-based LASER Land Leveling Increases the Water Use Efficiency, Growth, and Yield of Cotton Crop under Changing Climate

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Abstract: Increasing water shortage has compelled farmers to develop plans for efficient use of water resources. The improvement in water use efficiency at the field level is very important and can redress water scarcity. LASER land leveling is increasing quickly in the world to increase water use efficiency. However, in developing countries, the practice of LASER leveling is to level land or field with zero (0 %) gradient due to unawareness of gradient-based land leveling while a small gradient (e.g., 0.1 %) is usually kept during land leveling in developed countries of the world. But farmers of developing countries are not well, therefore, an experiment was conducted in farmers' fields covering an area of 3 acres in south Punjab of Pakistan to assess the LASER leveling with a 0 % and 0.05 % grade and general farmer's practice of leveling. Land leveling with LASER using a 0.05 % gradient considerably decreased the amount of irrigation water and/or enhanced water use efficiency by increasing crop yield followed by LASER leveling with a 0 % gradient. Similarly, with a 0.05 % gradient, bolls per plant and final cotton yield increased considerably followed by a 0 % gradient while minimum bolls per plant and cotton yield were obtained from the farmer's practice of leveling. LASER land leveling with a 0.05 % gradient resulted in higher net benefit due to increased yield and a considerable decrease in irrigation amount that significantly improved use efficiency. The outcomes suggest that benefits from land leveling with LASER keeping a 0.05 % gradient are significantly higher when compared with 0 % gradient and/or farmers' practice of leveling.

Keywords: Land LASER Leveling, Gradient, Cotton, Yield, Water Use Efficiency

1. INTRODUCTION

On the eve of climate change, a rapid decrease in irrigation water is causing significant threats to agriculture in different parts of the world. The growing water scarcity as a result of climate change has brought us together on this point that the available water resources must be used judiciously. It is a dire need of time to encourage growers and farmers to use and adopt different water-saving technologies [1,2]. Increasing the water use efficiency at the field level is one of the most suitable solutions to address the water shortage [3]. LASER leveling is a mechanical process of leveling soil. With LASER leveling, the slope of the soil can be leveled up to zero grade. The practice of LASER leveling is increasing rapidly in South Asia, and by 2015, 1.5 million hectares were LASER leveled [4]. LASER leveling improves the uniformity of water application in the field and thus results in

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better crop yield with less amount of irrigation [4-6]. It also increases cultivable cropping soils through the reduction of unnecessary field channels and bunds in the field, decreases weed density, and improvement in input-use efficiencies such as fertilizers and pesticides [7-9].

LASER land leveling is also increasing in the Indo-Gangetic Plains of India and Pakistan. However, the current practice of leveling in these areas is to level the land to a zero (0 %) grade while in developed countries, a slight slope or grade (e.g., 0.1 %) is given during leveling of the agricultural land, but it is not so common in developing countries and nor our farmers have much knowledge about gradient-based LASER leveling [10]. Although, benefits of common LASER land leveling have been well-established in South Asian farmers [4] whereas land LASER leveling using a slight gradient such as 1 % or 0.05 % would further confer remunerations in terms of irrigation water use efficiency and/or yield improvement [10]. For example, in some parts of Australia, a small gradient of 0.08–0.2 % in 100–700-meter-long fields is common to irrigate crops in both beds and flat [10-12] Field layout with a small gradient i.e. 0.4–0.5% are generally kept to ease the drainage. A small gradient from the head (front) of field to the tail (end) increases surface water movement from the waterfront to the field, thus decreasing the time required for irrigation, and preventing excessive water accumulation (waterlogging) in the root zone of crops [10]. Previous studies showed that suitable field gradients decreased the amount of irrigation water in different crops by up to 20 % [10, 13-15]. Thus, gradient-based LASER leveling has the potential to save irrigation water amount and improve crop yields. However, there is no study exists in Pakistan. Therefore, the present study was conducted at farmer's field to evaluate the impact of gradient-based LASER land leveling on water use efficiency, growth, yield, and quality of cotton crops.

2. MATERIALS AND METHODS

The experiment was conducted in a farmer field at Chak-109/1L in 2021, district Rahim Yar Khan, Pakistan (Fig. 1). District Rahim Yar is located at 28◦ 41′ N latitude and 70◦ 30′ E longitude and falls within an extensive alluvial plain located adjacent to the Indus River. The experimental soil texture is clay loam (Table 2) and the climate of district Rahim Yar Khan is sub-tropical according to weather indicators (Table 1). During crop season 2021, the maximum average temperature prevailed from 38.7 ℃ to 43.1 ℃ during the last week of April to June (Table 1). While a minimum temperature of 23 ℃ to 30.5 ℃ was observed in the crop season from April to November. Rainfall occurred in July (18 mm) August (43 mm) and September (11 mm) during crop season 2021. It can be figured out that overall crop season was dry and hot. Rainy season started from July to the end of September during which more than 85 % of rainfall was received during August.

2.1 Design and Treatments

Experimental treatments were land LASER leveled with 0.0 % and 0.05 % gradient and farmers' practice of leveling. Total area of the experiment was 3 acres from which 1 acre was leveled with LASER with 0 % gradient, 1 acre with 0.05 % gradient, and 1 acre with farmers' practice of leveling.

2.2 Land Preparation and Crop Husbandry

The fields to be LASER leveled were ploughed 3 times with tractor mounted cultivator. After cultivation, the field was leveled with tractor mounted LASER land leveler. The LASER

Table 1. Weather data of experimental trial during 2021

	April	May	June	July	August	September	October	November
Avg. min. Temp. ˚C	23.0	27.8	30.5	30.5	29.1	27.3	23	16.4
Avg. Max. Temp. ˚C	38.7	42.1	43.1	40.8	38.6	38	34	30.1
Rainfall (mm)	-	-	-	18	43	11	-	-
Humidity (%)	28	23	34	48	57	50	43	46

Fig. 1. Map of Pakistan indicating study area in District Rahim Yar Khan, Punjab province.

transmitter sends a LASER beam that is caught by the signal receiver attached to a leveling blade mounted to the tractor. The control panel attached to the tractor reads the signal from the receiver and closes or opens the hydraulic control valve that downs or raises leveling blade. The gradient of 0.05 % was created and then it was confirmed using a LASER land leveler receiver and transmitter.

Plot size of each treatment was 88 meters long, and 46 meters wide, so in the case of gradient-based LASER leveling, 0.05 % gradient resulted in 4.0±0.02 cm alteration in elevation between irrigation inlet side (head) and tail ends of the plot. When the soil was leveled, samples from different sites of each plot were drawn to a depth of 30 cm (0-15 cm and 15-30 cm) with the help of an auger to analyze the physicochemical properties of the soil. The collected samples of soil were numbered for identification and then sent to the soil and water testing laboratory of the district Rahim Yar Khan, and the report is given in Table 2. After sampling in

Table 2. Physiochemical properties of the experimental soil

Soil Properties	**Soil depth**	
	0-15 cm	**15-30 cm**
Texture	clay loam	clay loam
pH	8.1–8.3	8.4–8.6
EC (mS-cm)	1.4–2.3	1.2–1.7
Organic matter (%)	0.62–0.73	0.51–0.59
Bulk density (g cm^{-3})	1.10	1.10
Saturation (%	52–60	49–54
Available N (%)	0.048	0.026
Available P (mg kg^{-1})	4–6.5	3.5–5.8
Available K (mg kg^{-1})	115–125	100–118

each plot, beds were developed through bed shaper and the distance between the centers of adjacent beds was 75 cm while furrow width and depth were 30 and 15 cm, respectively.

Seed of cotton variety CKC-3 @ 20 kg ha^{-1} was used. Seeds were sown with manual labor keeping plant to plant distance 30 cm. Recommended doses of fertilizers such as nitrogen (200 kg ha^{-1}), phosphorus (120 kg ha^{-1}) and potash (100 kg ha^{-1}) were used. All the amount of potash and phosphorus while 1/3rd of N were used during seed bed making. The remaining nitrogen was applied at squaring formation and at the flowering stage. The phosphorus was applied as DAP, and nitrogen was applied as urea and potassium as potassium chloride. Weeds such as purple nutsedge (*Cyperus rotundus*), Bermuda grass (*Cynodon dactylon)*, horse purslane (*Trianthema portulacastrum*), common purslane (*Portulaca oleracea*), wild rice (*Echinochloa colonum*), green amaranth (*Amaranthus viridis*), puncture vine (*Tribulus terrestris*) and false amaranth (*Digera muricata*) were control through manually by hand weeding whereas pesticides were used to control the pests of cotton such as whitefly (*Aleurodicus dispersus*), jassid (*Amrasca biguttula*), thrips (*Frankliniella schultzei*), pink bollworm (*Pectinophora gossypiella*), American bollworm (*Helicoverpa armigera*) and spotted bollworm (*Earias vittella*).

2.3 Irrigation Water and its Measurement

The crop was irrigated by canal water. The inflow rate of irrigation water was monitored through a cutthroat flume (Fig. 2) (122 cm length × 72 mm width), fixed at several meters upstream from inlet of the field trial. The inflow rate readings of the flume and time were recorded periodically until the flow cut-off (stopped). Each field plot was irrigated independently to estimate the correct amount of irrigation water. Soil moisture was noted daily from each plot through a digital soil moisture meter (Misol WH0291, China). The crop was irrigated when average soil moisture reached 25 % on the basis of a soil moisture meter. In gradient-based land leveled plot, irrigation water was stopped ("cut-off") as soon the water flowing over the soil surface reached the mid-point of the bottom edge of the plot.

The quantity of irrigation water was measured using the float method through a cutthroat flume [16]. The cutthroat flume was fixed in water-channel and cemented so that water can only pass through the flume. When water depth in the cutthroat flume was constant then the downstream flow depth ($h\ b$) and upstream flow depth ($h\ a$) were recorded in meters using scale. The flow condition was determined through the following equation:

Flow condition = $h\ b\ /h\ a$

If the value of $h\ b\ /h\ a$ is less than 0.65 then it will be free flow. In our experiment, flow condition was free flow ($h\ b\ /h\ a = <0.65$). After determining the condition for upstream flow, the discharge was measured with the value of h a and $h\ b$ for a flume size of 122 × 92 cm. Stop-watch was used to record time taken to fill each plot.

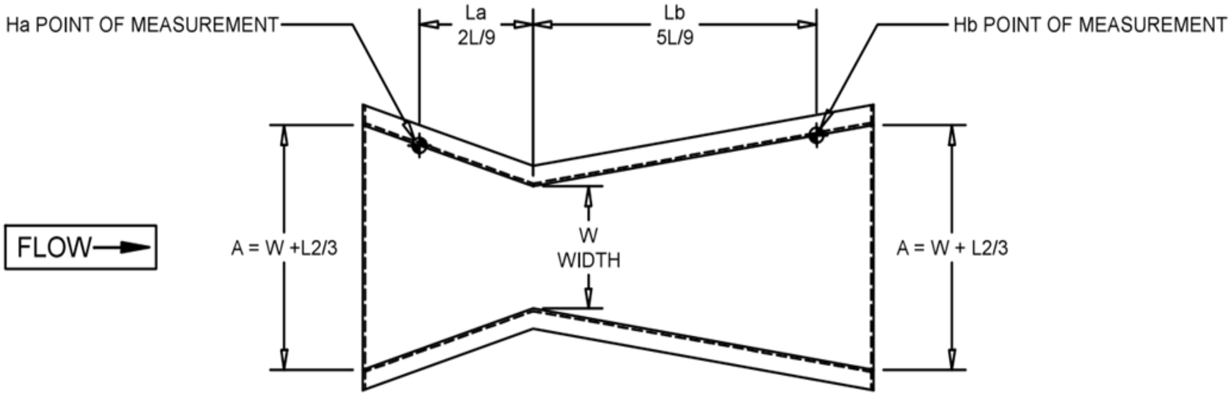

Fig. 2. Plain view of a cutthroat flume

Then discharge (Q) and amount of irrigation water were measured using the following formula:

Discharge (Q) = 2.85 × Hu × 1.82 .... (1)

Where;

Q is discharge (m^3 Sec^{-1}) and Hu shows the upstream head reading of the cutthroat flume.

Volume of irrigation water applied (V) = Q × T...(2)

Where;

V is the volume (m^3), Q is discharge (m^3 Sec^{-1}) and T is the time taken in seconds to fill the field.

2.4 Observations

Three sites, front, middle and tail, from each plot, were selected for data collection. From each site, 10 plants were tagged for measurements of leaf area index, plant height, bolls per plant and average boll weight. At the end, total seed-cotton yield was measured and samples were taken for ginning out turn (%), staple length (mm), fiber uniformity index (%), micronaire or fiber fineness (µg/inch), and fiber strength (tppsi). Plant height and intermodal distance were recorded using a meter rod and scale, respectively, and then the average was calculated. Similarly, the number of bolls from each plant was counted and then averaged, and these bolls were picked from plants and their weight was noted in grams with the help of digital balance and then averaged. For the leaf area index, three plants were cut from the front, middle and tail sites of each plot. The leaves from harvested plants were removed from the stem and then the leaves and stems were weighed separately. A sub-sample of leaves (5 g) was brought to the laboratory and their leaf area was noted through a digital leaf area meter and then the leaf area index was derived through a formula [17].

Leaf area index (LAI) = Leaf area/Ground area

For the number of days taken to squaring, flowering and boll splitting, an area of 3 m^2 was selected and when 50 % of plants had squared, flowered and boll opened then the date was noted. Seed cotton yield was noted during each picking from each plot. After the last picking, the total seed-cotton yield was calculated from each plot. With the help of the following formula, ginning out turn was measured.

Ginning out turn (GOT) % =

$$\frac{\text{Lint weight}}{\text{Weight of seed cotton}} \times 100$$

For fiber uniformity index, staple length, micronaire or fiber fineness, and fiber strength, 40 grams of lint from each plot (front, middle, and tail end) was taken and sealed in envelopes that were brought to Central Cotton Research Institute, Multan for analysis.

2.4.1. Water Use Efficiency (WUE)

Crop WUE was calculated according to the procedure followed by Neal *et al.* [18].

Crop water use efficiency (kg m^{-3}) = Economic yield / total amount of water supplied.

2.4.2. Economic Analysis

Economic analysis shows the cost and income of the system. It was calculated by following the method of Byerlee [19]:

Cost of production (USD/ha) = Permanent cost (USD/ha) + variable cost (USD/ha)

2.5 Statistical Analysis

All the obtained data of parameters were analyzed statistically using Statistix 8.1 [17] and the difference between treatments was assessed through the least significant difference test (LSD) at a 5 % probability level [20].

3. RESULTS

Results showed that there was a consistent trend for higher plant height (131 cm) and intermodal distance (4.75 cm) in the farmer's practice of leveling followed by LASER leveling with 0 % gradient (Table 3). Minimum plant height (110 cm) and intermodal distance (4.10 cm) were measured in LASER leveling with a 0.05 % gradient. Similar trend was recorded for leaf area index, cotton grown on the field with the farmer's practice of leveling had a leaf area index of 3.75 followed by LASER leveling with a 0 % gradient (3.47) whereas less leaf area index (3.19) was recorded for LASER leveling with 0.05% gradient (Table 3). However, the maximum number of bolls per plant (32 bolls per plant) was recorded in 0.05 % gradient LASER leveling than in the 0 % gradient LASER leveling 7 bolls per plant) while the minimum number of bolls (21 bolls per plant) was recorded for farmers' practice of leveling (Table 3).

Cotton took more days to reach squaring, flowering, and boll splits when planted on a field leveled with farmers' practice followed by soil leveled with a 0 % gradient (Table 4) might be due to higher soil moisture content. Cotton planted on soil level with a 0.05 % gradient through LASER leveling took a minimum number of days for squaring, flowering, and boll splitting.

Boll weight increased in cotton (2.89 g) planted on 0.05% gradient LASER leveling soil (Table 5) but the difference was non-significant with 0 % gradient (2.82 g) whereas cotton planted on farmers' practice of leveling had minimum boll weight (2.63 g). Due to more bolls per plant, yield of cotton (seed-cotton) was higher (2267 kg ha^{-1}) when cotton was planted on 0.05 % gradient soil as compared to those planted on 0.0 % gradient soil (2019 kg ha^{-1}) whereas minimum cotton yield (1715 kg ha^{-1}) was recorded for cotton planted on farmers' practice of land leveling. Similarly, ginning out turn (GOT) was maximum (39.73 %) in cotton grown on soil LASER leveled with 0.05 % gradient as compared to those grown on soil LASER leveled with 0 % gradient (38.26 %) while minimum GOT (35.14 %) was recorded for cotton planted on soil with farmers' practice of leveling (Table 5).

Lint quality parameters such as staple length, fiber uniformity index and were affected by gradient-based land leveling while no effect on fiber strength. Minimum value of staple length (27.16 mm), fiber uniformity index (85 %), and high micronaire (4.93

Table 3. Effect of land gradient on plant height, intermodal distance, leaf area index, and number of bolls per plant in cotton

Treatments	Plant height (cm)	Intermodal distance (cm)	Leaf area index	Bolls per plant
Farmers' practice of leveling	131 a	4.75 a	3.75 a	21 c
LASER leveling with 0.0% gradient	125 b	4.31 b	3.47 b	27 b
LASER leveling with 0.05% gradient	110 c	4.10 c	3.19 c	32 a
LSD value	4.89	0.12	0.17	1.68

Table 4. Effect of land gradient on days to squaring, flowering, and boll splits in cotton

Treatments	Days to squaring	Days to flowering	Days to boll splits
Farmers' practice of leveling	38 a	58 a	132
LASER leveling with 0.0 % gradient	33 b	52 b	124
LASER leveling with 0.05 % gradient	30 c	50 c	120
LSD value	1.03	0.85	2.12

Table 5. Effect of land gradient on boll weight, seed-cotton yield, ginning out turn and staple length in cotton

Treatments	Boll weight (g)	Seed-cotton yield (kg ha^{-1})	Ginning out turn (%)	Staple length (mm)
Farmers' practice of leveling	2.63 b	1715 c	35.14 c	27.16 c
LASER leveling with 0.0% gradient	2.82 a	2019 b	38.16 b	27.90 b
LASER leveling with 0.05% gradient	2.89 a	2267 a	39.73 a	28.14 a
LSD value	0.12	149	0.45	0.11

Table 6. Effect of land gradient on fiber uniformity index, micronaire, irrigation amount and crop water use efficiency in cotton

Treatments	Fiber uniformity index (%)	Micronaire (µg/inch)	Fiber strength (tppsi)	Irrigation amount (mm)	Crop water use efficiency (kg m^{-3})
Farmers' practice of leveling	85 c	4.93 a	94 a	546 a	0.41
LASER leveling with 0.0 % gradient	86 b	4.43 b	94 a	364 b	0.91
LASER leveling with 0.05 % gradient	87 a	4.17 c	94 a	254 c	1.12
LSD value	0.44	0.12	0.25	0.34	0.10

µg/inch) were noted for cotton grown on farmers' practice of leveling followed by LASER leveling with 0.0%. Cotton grown on soil with a 0.05 % gradient through LASER leveling showed better lint quality (Tables 5 and 6). Land gradient significantly affected the amount of irrigation in cotton crops (Table 6). Land LASER leveling 0.050 % gradient reduced the irrigation amount in cotton by about 26 % (254 mm) compared with a 0 % gradient (384 mm) and 53 % compared with farmers' practice of leveling (546 mm). Similarly, land gradient greatly affected the water use efficiency (Table 6). Water use efficiency was significantly lower in farmers' practice of leveling (0.41 kg m^{-3}) than in gradient-based leveling. Within the land gradient, there was a trend for higher water use efficiency with a 0.05 % gradient (1.12 kg m^{-3}) than a 0 % gradient (0.91 kg m^{-3}).

Economic analysis showed that with farmers' practice of leveling, the total expenses of cotton production was USD 508 ha^{-1} followed by LASER leveling with 0 % gradient (477) while the minimum was in LASER leveling with 0.050 % gradient (430) (Table 7). The high cost of cotton was probably due to the high irrigation cost in farmers' practice of leveling. LASER leveling significantly reduced the cost of production of cotton over farmers'= practice of leveling due to the reduced cost of irrigation water. LASER leveling with a 0.05 % gradient enhanced cotton production by USD 1570 ha^{-1} and reduced the cost of production (USD 430 ha^{-1}). LASER leveling with 0 % and 0.05 % gradients significantly enhanced the net returns from cotton in comparison with the farmer's practice of leveling. Beds with a 0.05 % gradient further increased returns of cotton crops relative to farmers' practice of leveling (Table 7).

4. DISCUSSION

Results indicated that plant height, intermodal distance and leaf area index were maximum in the farmer's practice of leveling followed by a 0 %

Table 7. Effect of land gradient on the economic return of cotton crop

Treatments	Land LASER leveling cost (US$)	Irrigation cost (US$)	Fertilizer cost + pesti-cides (US$)	Total cost (US$)	Total income (US$)	Net income (US$)	BCR
Farmers' practice of leveling	32	155	321	508	1511	1005	1.98
LASER leveling with 0.0 % gradient	51	105	321	477	1781	1304	2.73
LASER leveling with 0.05 % gradient	51	58	321	430	2000	1570	3.65

gradient. The increase in plant height, intermodal distance and leaf area index might be due to high moisture content that promoted the vegetative growth of plants. A planned moisture regime is very important because both the high moisture content in the soil and/or very low moisture are harmful to cotton crops. Under high moisture, more vegetative growth occurs which can interfere negatively with productivity [20]. During the vegetative phase, if the cotton crop is subjected to higher moisture content, the plant produces excessive vegetation and results in less number of bolls, reduced boll weight, and final seed-cotton yield. Opening of bolls was delayed and the time needed for maturity increased. On the other hand, cotton planted on LASER leveled soil with a 0.05 % gradient-based had ideal plant height, intermodal distance and leaf area index that resulted in higher seed-cotton yield. There was less number of bolls in cotton growing on the field with the farmer's practice of leveling and 0% gradient field might be due to higher vegetative growth and other common sub-optimal practices of farmers other than leveling [10] while cotton planted in fields with LASER leveled soil with 0.05 % gradient had a maximum number of bolls that resulted in higher seed-cotton yield. Ginning out turn was maximum in cotton that was planted in fields leveled with LASER with 0.05 % gradient probably due to higher seed-cotton yield. Lint quality such as staple length, fiber uniformity index, and micronaire was better in cotton planted on soil LASER leveled with 0.05 % while farmers' practice of land leveling reduced the lint quality might be b due to high soil moisture content, which delayed the maturity of cotton. Micronaire shows the thickness of the cell wall of cotton fibers and is usually used as an indicator of fiber maturity and fineness. Fiber fineness decreases when a cotton plant produces more quantity of carbohydrates than required to support the plant's development. Excess carbohydrates accumulate or are available to fiber cells wall and thicken the cell wall of fiber [22]. Fiber length generally depends on the growth environment, varietal interaction with the environment, and crop management. High temperature and moisture stress during boll development significantly affect the fiber length. Similarly, nutrient deficiencies and insect pressure can reduce the staple length. Previous research showed that frequent irrigation definitely delayed the maturity of crop. Higher water use efficiency of cotton planted on LASER land leveled with 0.05 % was higher due to higher yield and less amount of irrigation during the growing season. It seems that soil leveled by LASER with 0.05 % gradient provided suitable soil-moisture content to cotton crops and crop reached maturity by 6-8 days earlier (Table 2) and higher yields were obtained as compared to farmer's practice of irrigation or land leveled by LASER with 0% gradient. Cotton sown on soil with farmers of leveling delayed the maturing might be due to the high moisture content of the soil that promoted vegetative growth (Table 1).

The lower irrigation amounts and high water use efficiency of the LASER leveling with 0.05 % gradient in comparison with farmers' practice of leveling and also with 0 % gradient and are consistent with the findings of Devkota *et al.* [10] who documented high water productivity and lower irrigation amount in LASER leveling with 0.01 % gradient. Other studies by Aryal [6], Ferrari *et al.* [21], and Jat *et al.* [23] reported that LASER leveling increased water productivity in small farmers' fields in South Asia. Previous studies showed that a small gradient has the potential to decrease the irrigation amount as the length of the field or plot increases particularly for permeable soil [14]. For example, in the Philippines, a 0.1 % gradient decreased 22 % irrigation water amount for dry seeded rice on highly permeable clay loam soils rather than a 0 % gradient [24]. Alike, Gonzalez *et al.* [14] reported that a gradient of 0.04 % in 200 m × 50 meters plots resulted in a 20 % decrease in irrigation water for rice crops as compared to a 0 % gradient. In Brazil, Winkler *et al.* [25] compared land leveling using different gradients such as 0 %, 0.20 %, 0.25 %, 0.28 %, and 0.40 % in rice and reported that 0.1 % gradient enhanced the yield of rice by 10 % (0.5 t ha^{-1}) when compared with 0 % gradient. Maximum net income was obtained when the soil was leveled with LASER with a 0.05 % gradient while the farmer's practice of leveling resulted in minimum profit. The minimum profit in Farmers' practice is probably due to lower yield and maximum irrigation cost, but LASER leveling with 0.05 gave a high due to high yield and lower irrigation cost.

5. CONCLUSION

Under severe water scarcity due to climate change, there is a dire need to shift from traditional land leveling to an innovative gradient-based LASER land leveling technique that not only uses less irrigation water but also increases productivity and net profit in the context of future climate shifts.

6. CONFLICT OF INTEREST

The authors declared no conflict of interest.

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