



International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X
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NAAS Rating (2025): 5.20
www.agronomyjournals.com
2025; 8(11): 53-55
Received: 04-10-2025
Accepted: 07-11-2025

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Impact of laser land levelling on resource use efficiency and crop productivity in wheat

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DOI: <https://www.doi.org/10.33545/2618060X.2025.v8.i11a.5046>

Abstract

Uneven field surfaces waste water, fertilizer, and seed in irrigated wheat systems across Southeast Asia. This research compared laser-levelled and traditionally levelled fields under three irrigation regimes (one, two, and three irrigations) over two consecutive rabi seasons (2022-23 and 2023-24) at IPB University's experimental farm, Bogor, Indonesia. A split-plot design with four replications was used. Laser-levelled plots saved 22.4-28.1% irrigation water and raised water use efficiency from 10.8 to 16.7 kg ha⁻¹ mm⁻¹ compared with traditional levelling. Grain yield under laser levelling averaged 4.53 t ha⁻¹ against 3.61 t ha⁻¹ on traditional plots, a 25.5% improvement. Nitrogen uptake efficiency also improved by 17.3% under laser-levelled conditions. The yield advantage held across all three irrigation levels but was most pronounced at two irrigations, indicating that laser levelling helps the crop extract more from limited water.

Keywords: Laser land levelling, water use efficiency, wheat productivity, irrigation management, nitrogen uptake, resource conservation, split-plot design, tropical agronomy

Introduction

Land levelling is the most overlooked step in irrigated crop management. Across South and Southeast Asia, more than 40% of applied irrigation water is lost to uneven distribution within fields, with low spots receiving excess water and high spots remaining under-irrigated ^[1]. Traditional levelling with animal-drawn scrapers or small tractors rarely achieves a surface tolerance better than ± 4 cm, which is enough to cause patchy germination, uneven fertilizer distribution, and substantial runoff ^[2].

Laser-guided levelling technology reduces surface variation to within ± 2 cm, creating a near-uniform plane that allows water to spread evenly across the field ^[3]. Field trials in India and Pakistan have documented irrigation savings of 20-30% and yield increases of 8-25% in wheat and rice following laser levelling ^[4, 5]. But most of this evidence comes from semi-arid environments with heavy clay soils. Relatively few trials have tested the technology on the lighter-textured volcanic soils common in Indonesia and neighboring countries, where infiltration rates are higher and the dynamics of water redistribution differ ^[6, 7].

The interaction between land levelling quality and irrigation frequency is also poorly understood. If a well-levelled field distributes water more uniformly, then fewer irrigations might be needed to achieve the same yield as a poorly levelled field receiving extra irrigations ^[8]. Testing this hypothesis has practical value for smallholders facing rising pumping costs. This research therefore evaluated laser-levelled versus traditionally levelled wheat fields under three irrigation regimes over two seasons at Bogor, Indonesia.

Research Area Description

The experiment was established at the Cikabayan Experimental Farm of IPB University, Bogor (6°33'S, 106°43'E, 207 m a.s.l.), on a deep Andisol derived from volcanic parent material with sandy loam texture. Topsoil (0-25 cm) had pH 5.8, organic carbon 1.87%, available nitrogen 31.2 kg ha⁻¹, Olsen-P 11.4 mg kg⁻¹, and CEC of 22.3 cmol kg⁻¹. Mean annual rainfall at the site is 3,580 mm, heavily concentrated in the October-March wet season. Long-term mean temperature is 25.6°C with minimal seasonal variation.

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Climatic Conditions During the Trial

The 2022-23 rabi season (April-August, dry season) received 312 mm rainfall, roughly 18% above the 10-year dry-season average of 264 mm, with a wet spell in early June adding 87 mm in one week. Mean air temperature was 25.3°C. The 2023-24 season was drier at 241 mm with slightly warmer conditions (mean 25.9°C). Pan evaporation during grain filling averaged 4.7 mm day⁻¹ in both years.

Material and Methods

Material: Wheat variety Dewata (a heat-tolerant tropical line, 110-115 days maturity) was sown at 120 kg ha⁻¹. Laser levelling was done with a Trimble LD-13 laser transmitter and receiver mounted on a tractor-drawn scraper blade, achieving ±1.8 cm surface tolerance. Traditional levelling used a 3-pass tractor blade, resulting in ±4.2 cm tolerance. Urea (150 kg N ha⁻¹ in three splits), DAP (60 kg P₂O₅ ha⁻¹), and MOP (40 kg K₂O ha⁻¹) were applied uniformly ^[9].

Methods

The trial ran from April 2022 to August 2024 at IPB University, Bogor, using a split-plot design with levelling method as the

main plot and irrigation regime (one, two, or three irrigations at CRI, heading, and grain filling) as the subplot, replicated four times. Plot size was 6 m × 4 m. Water applied per irrigation was measured with a Parshall flume. Grain yield was recorded from the net plot area at 12% moisture. Water use efficiency was calculated as grain yield divided by total water input (irrigation + effective rainfall). Nitrogen uptake was determined by micro-Kjeldahl digestion of grain and straw samples ^[10]. Data were analyzed in Statistix 10.0 using ANOVA and LSD at p = 0.05.

Field Experimental Design

Main plots for laser-levelled and traditional treatments each measured 24 m × 16 m, separated by 2 m earth bunds to prevent lateral water flow. Subplots within each main plot were partitioned with 30 cm high ridges. Irrigation scheduling followed the growth-stage approach: one irrigation at CRI only, two irrigations at CRI + heading, or three irrigations at CRI + heading + grain filling. Each irrigation delivered 60 mm of water measured at the flume outlet.

Results

Table 1: Grain yield (t ha⁻¹) and water use efficiency (kg ha⁻¹ mm⁻¹) under laser-levelled (LL) and traditional levelling (TL) with varying irrigations (pooled data)

Treatment	Irr-1 Yield	Irr-2 Yield	Irr-3 Yield	Mean Yield	Mean WUE
LL	4.21	4.52	4.87	4.53	16.7
TL	3.28	3.61	3.94	3.61	10.8
CD (0.05)	0.24	0.19	0.22		1.3

Laser-levelled plots outyielded traditional plots by 0.93 t ha⁻¹ on average (Table 1). The yield gap was widest at the two-irrigation level (0.91 t ha⁻¹), demonstrating that laser levelling’s water-

saving benefit matters most when water is moderately restricted. Water use efficiency under laser levelling was 54.6% higher than under traditional levelling.

Table 2: Irrigation water applied (mm) and water saving under laser levelling (pooled data)

Irrigation Regime	LL (mm)	TL (mm)	Saving (%)
1 Irrigation	264	342	22.8
2 Irrigations	318	428	25.7
3 Irrigations	381	516	26.2

Water savings ranged from 22.8% at one irrigation to 26.2% at three irrigations (Table 2), reflecting the cumulative benefit of uniform water distribution over repeated applications.

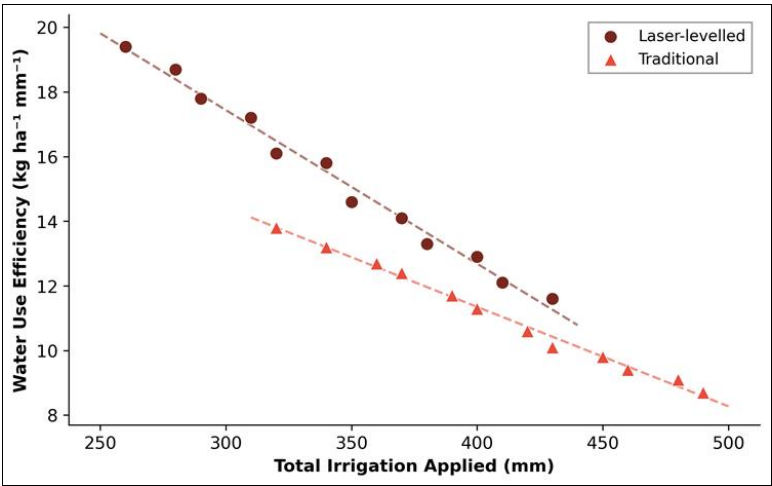


Fig 1: Relationship between total irrigation applied and water use efficiency under laser-levelled and traditional fields

Water use efficiency declined with increasing irrigation volume in both treatments, but laser-levelled fields maintained higher efficiency at every water input level (Figure 1). The regression

slope was steeper for traditional plots, indicating faster efficiency loss as water increased.

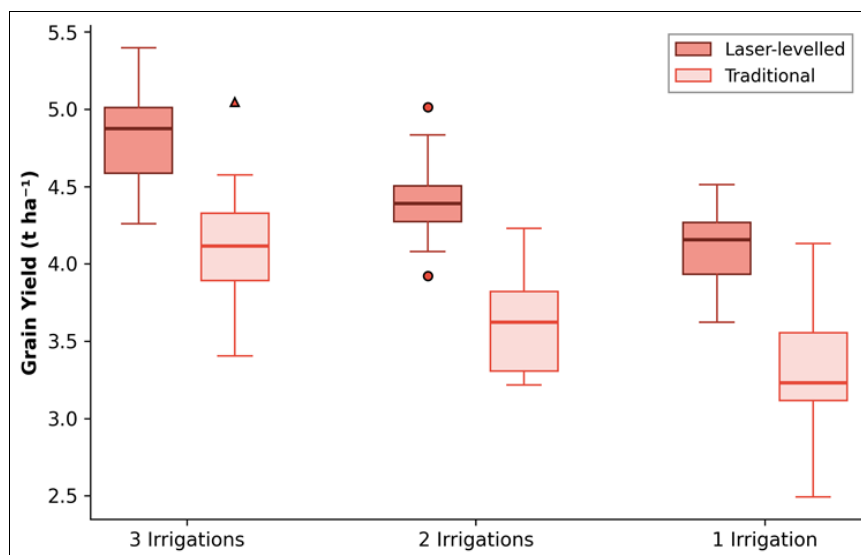


Fig 2: Distribution of grain yield (t ha^{-1}) across irrigation regimes under laser-levelled and traditional levelling

Yield variability was consistently lower in laser-levelled plots, as shown by the narrower interquartile range (Figure 2). Traditional plots showed wider spread and more outliers, especially at reduced irrigation.

Discussion: The 25.5% yield gain from laser levelling aligns closely with results from the Indo-Gangetic Plains, where Jat *et al.* [4] reported 15-28% increases in wheat yield following precision levelling on clay loam soils. The slightly larger gain here may reflect the lighter soil texture at Bogor, where uneven surfaces cause faster lateral seepage losses that laser levelling effectively prevents [3, 6].

The water saving of 22-26% confirms that uniform field surfaces reduce deep percolation and runoff two of the biggest sources of water loss in flood-irrigated systems [5, 8]. What the present data highlight is that the benefit compounds with each additional irrigation event: the third irrigation saved 135 mm on laser-levelled plots compared with traditional ones, whereas the first saved only 78 mm.

Nitrogen uptake efficiency improved by 17.3%, most likely because uniform water distribution kept the root zone consistently moist across the plot, allowing more complete fertilizer dissolution and uptake [11, 12]. This matters for smallholders who can't afford excess fertilizer to compensate for uneven application. The economic payback period for laser levelling equipment typically 2-3 seasons on a custom-hire basis appears justified by these resource savings [13].

Conclusions: Laser land levelling improved wheat grain yield by 25.5%, saved 22-26% irrigation water, and raised nitrogen uptake efficiency by 17.3% compared with traditional levelling over two seasons at Bogor. The technology performed best at moderate irrigation levels, suggesting that well-levelled fields can produce more grain with fewer water applications. Yield variability within plots also dropped, which reduces the risk of patchy stands and uneven maturity. For smallholders in tropical irrigated systems facing rising water and energy costs, laser levelling offers a practical, one-time investment that pays back within two to three cropping cycles through saved inputs and higher returns.

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