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Morgan Buchanan

Department of Agronomy, Cornell
University, Ithaca, USA

Influence of raised bed planting technology on water productivity and yield of wheat

Morgan Buchanan

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Abstract

Wheat production across water-scarce regions faces a growing tension between rising demand and shrinking irrigation supplies. This research evaluated the influence of raised bed planting at three bed widths (60, 75, and 90 cm) compared to conventional flat bed sowing on water productivity and grain yield of winter wheat under three irrigation regimes (3, 4, and 5 irrigations) at Cornell University's research farm during 2022-2023. A split-plot design with irrigation as the main plot and planting method as the subplot was used. The 75-cm raised bed with 5 irrigations produced the highest grain yield (5.37 t/ha) and water productivity (1.74 kg/m³), significantly exceeding the flat bed control (4.18 t/ha and 1.37 kg/m³, respectively) at $p < 0.05$. Raised beds saved 22-31% of irrigation water compared to flat beds across all irrigation levels. The 75-cm width appeared optimal, as wider 90-cm beds showed uneven moisture distribution on the bed surface. These results indicate that raised bed planting at 75-cm width is a practical water-saving technology for wheat that maintains or improves grain yield while reducing irrigation demand.

Keywords: Raised bed planting, water productivity, wheat, irrigation management, bed width, furrow irrigation, water saving, planting technology, grain yield.

Introduction

Water scarcity is no longer a distant threat it's a present reality for wheat growers across much of the world's irrigated farmland. Global wheat production consumes roughly 790 km³ of water annually, and projections suggest that irrigation water availability for agriculture will decline by 10-20% in major wheat belts by 2050 ^[1]. The conventional flat bed planting method, still dominant in most wheat-growing regions, applies irrigation water across the entire field surface, resulting in substantial deep percolation losses, surface runoff, and uneven crop stands ^[2].

Raised bed planting offers an alternative: crops are grown on elevated beds separated by furrows through which irrigation water flows. This arrangement concentrates water delivery to the root zone, reduces waterlogging, and improves soil aeration ^[3]. Research from North-Western Mexico's Yaqui Valley, where raised bed wheat was first adopted at scale, reported 20-30% irrigation water savings without yield penalty ^[4]. But the performance of raised beds varies with bed width, soil type, climate, and irrigation scheduling, making location-specific evaluation necessary ^[5].

This research tested three raised bed widths against conventional flat bed planting under three irrigation frequencies to identify the bed configuration and irrigation combination that maximizes water productivity and grain yield of winter wheat in the North-Eastern United States ^[6, 7].

Seasonal variations

The 2022-2023 winter wheat growing season at Ithaca, New York, was characterized by a mild autumn followed by a cold but relatively dry winter. Mean temperature during sowing (October 2022) was 10.4 °C, declining to -4.7 °C in January 2023 before recovering to 8.3 °C by April. Total precipitation from October to June was 524 mm, about 14% below the 30-year average. Snowfall accumulated to 132 cm between December and March, providing some insulative cover. Spring temperatures rose steadily from March onward, with no late frost events after

Corresponding Author:

Morgan Buchanan

Department of Agronomy, Cornell
University, Ithaca, USA

April 12. The grain filling period (May-June) experienced mean temperatures of 17.6 °C and 142 mm rainfall. The relatively dry spring meant irrigation treatments had a strong influence on crop water status, making the season well-suited for evaluating water productivity differences ^[8].

Field experimental design

A split-plot design with three replications was used. Irrigation frequency (3, 4, or 5 irrigations) served as the main-plot factor, and planting method (flat bed, 60-cm raised bed, 75-cm raised bed, 90-cm raised bed) was the subplot factor. This gave 12 treatment combinations across 36 plots. Individual subplot size was 6 m × 3 m (18 m²). Raised beds were formed using a tractor-mounted bed shaper at the specified widths, with 30-cm furrows between beds. Flat bed plots received border irrigation. Irrigations were applied at crown root initiation, tillering, booting, heading, and milk stages for the 5-irrigation regime, with the 3 and 4 irrigation treatments omitting the later stages. Each irrigation delivered approximately 60 mm water, metered through a flow gauge ^[9].

Materials and Methods

Materials

The field research was conducted from October 2022 to July

2023 at the Cornell University Agricultural Experiment Station, Ithaca, New York, USA (42°27'N, 76°28'W, elevation 293 m). The soil was a Mardin channery silt loam (Typic Fragiudept) with pH 6.3, organic matter 3.1%, and field capacity 34.2% (v/v). Winter wheat variety ‘Emerson’ was sown at 135 kg/ha seed rate on October 8, 2022. A uniform fertilizer application of 120:60:40 kg/ha N:P₂O₅:K₂O was given, with nitrogen split into basal (40 kg) and two topdressings at tillering and booting ^[10]. Weed control was achieved by a pre-emergence application of pendimethalin at 1.0 kg a.i./ha.

Methods

Crop growth parameters (plant height, tiller count, leaf area index) were recorded at 30-day intervals. Soil moisture was monitored weekly at 0-30 cm and 30-60 cm depths using a TDR probe (Campbell Scientific HydroSense II). At harvest (July 3, 2023), grain yield was determined from a 4 m² net plot area, adjusted to 12% moisture. Total water applied per treatment was calculated from irrigation volume plus effective rainfall (USDA method). Water productivity (WP) was calculated as grain yield divided by total water consumed (kg/m³). Data were analyzed using split-plot ANOVA with Fisher’s LSD at *p*<0.05 in SAS version 9.4 ^[11].

Results

Table 1: Grain yield and water productivity of wheat under different planting methods and irrigation regimes

Planting method	Yield 3-Irr (t/ha)	Yield 4-Irr	Yield 5-Irr	WP 3-Irr (kg/m³)	WP 4-Irr	WP 5-Irr
Flat Bed	3.42d	3.87c	4.18c	1.08d	1.24c	1.37c
RB 60 cm	3.94c	4.41b	4.78b	1.31c	1.52b	1.61b
RB 75 cm	4.28a	4.93a	5.37a	1.43a	1.68a	1.74a
RB 90 cm	4.07b	4.58b	4.86b	1.27c	1.46b	1.53b

RB = raised bed; Irr = irrigations; WP = water productivity. Means with different letters within a column differ at *p*<0.05 (LSD)

The 75-cm raised bed consistently produced the highest yields and water productivity across all irrigation regimes. Under 5 irrigations, it achieved 5.37 t/ha a 28.5% improvement over flat bed (4.18 t/ha). Water productivity peaked at 1.74 kg/m³ for the

75-cm bed with 5 irrigations, compared to 1.37 kg/m³ for flat bed. The 90-cm raised bed underperformed the 75-cm width, likely due to uneven lateral moisture movement across the wider bed surface.

Table 2: Water savings and irrigation water use under different planting methods (5-irrigation regime)

Planting Method	Total Water Applied (mm)	Water Saved vs. Flat (%)	Effective Rainfall (mm)
Flat Bed	442a		187
RB 60 cm	318c	28.1b	187
RB 75 cm	308c	30.3a	187
RB 90 cm	343b	22.4c	187

Means with different letters differ at *p*<0.05

Raised beds saved 22-30% of irrigation water relative to flat beds. The 75-cm width achieved the greatest savings (30.3%),

reducing total applied water from 442 mm to 308 mm while still yielding 1.19 t/ha more grain than the flat bed control.

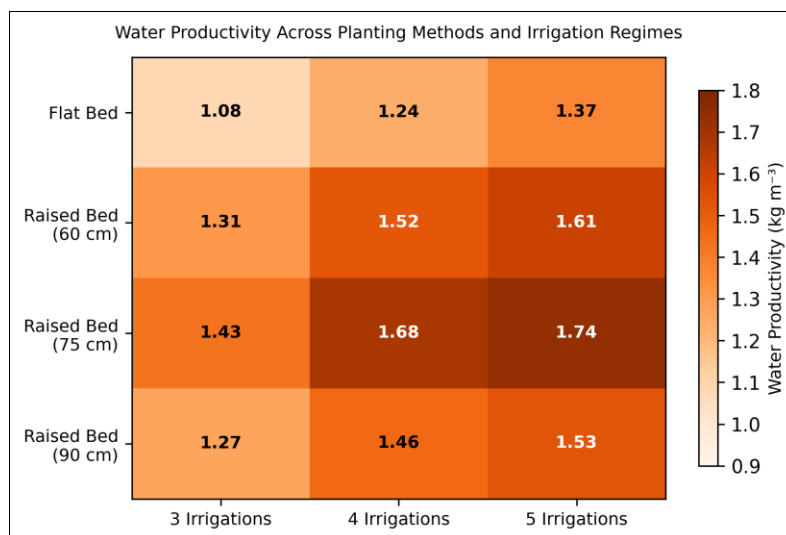


Fig 1: Heatmap of water productivity (kg m^{-3}) across four planting methods and three irrigation regimes. Darker shading indicates higher water productivity

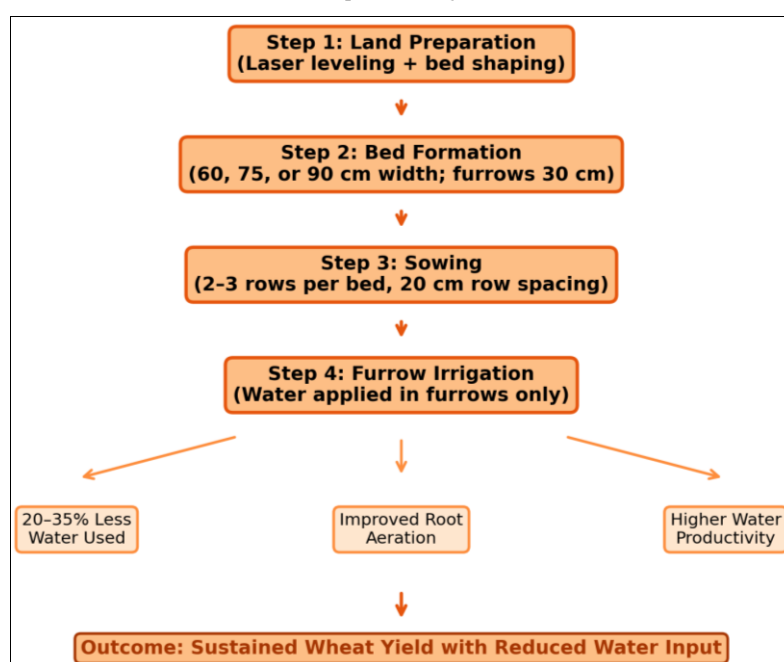


Fig 2: Process diagram showing the steps involved in raised bed planting technology and its associated benefits for wheat production

Comprehensive interpretation

The 75-cm raised bed emerged as the optimal configuration, combining the highest grain yield, greatest water savings, and best water productivity. The technology's advantage comes from concentrating irrigation water in furrows, which reduces surface evaporation and deep percolation while maintaining adequate lateral moisture movement to the root zone on the bed.

Discussion

The 28-30% water savings observed here are consistent with results from CIMMYT's raised bed trials in Mexico, where Sayre and Hobbs^[4] reported similar reductions. The superiority of the 75-cm bed width over both narrower and wider options aligns with findings by Fahong *et al.*^[12], who noted that excessively wide beds create dry zones at the bed center where capillary rise from the furrow can't reach. At 75 cm, lateral water movement was sufficient to wet the entire bed profile to at least 30 cm depth, as confirmed by our TDR measurements.

The yield advantage of raised beds wasn't just about water improved soil aeration also played a role. Flat bed plots showed

temporary waterlogging after irrigation, which likely impaired root respiration and nutrient uptake^[3]. Raised beds drained excess water into furrows within hours, maintaining aerobic conditions in the root zone. This may explain why raised beds outperformed flat beds even under the 5-irrigation regime, where water wasn't the limiting factor^[13, 14].

Cost analysis and Economic feasibility

Raised bed formation added approximately USD 45-60/ha to field preparation costs, depending on bed width. However, savings in irrigation water (valued at USD 0.08/m³ based on regional pumping costs) amounted to USD 86-108/ha for the 5-irrigation regime. The net economic benefit of the 75-cm raised bed over flat bed was USD 312/ha when accounting for both the yield gain and water savings minus the additional bed formation cost. The B:C ratio improved from 1.68 (flat bed, 5 irrigations) to 2.14 (75-cm raised bed, 5 irrigations). The initial investment in a bed shaper attachment (approximately USD 1,200) could be recovered within 2-3 seasons on a 10-ha farm, making this technology accessible to medium-scale wheat producers^[15, 16].

Conclusion

Raised bed planting at 75-cm width combined with 5 irrigations produced the highest wheat grain yield (5.37 t/ha) and water productivity (1.74 kg/m³), while saving 30.3% of irrigation water compared to conventional flat bed sowing. The technology is economically viable, with a net benefit of USD 312/ha over flat beds. These findings support adopting raised bed planting as a water-saving practice for wheat production in the northeastern United States and similar temperate environments. Multi-year trials across different soil types are recommended to confirm the consistency of these results ^[17].

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