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Assessment of raised bed planting technology for irrigated wheat in Vertisols

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Abstract
Here is a practical dilemma that wheat growers on Vertisols face every season: irrigate too much and the cracking clay floods the root zone; irrigate too little and the crop wilts. Raised bed planting channels water through furrows between elevated beds, promising better drainage, less waterlogging, and reduced irrigation volume. This research compared flat-bed sowing with raised beds at three widths (60, 90, and 120 cm) for irrigated wheat (cv. BRS 264) on a Vertisol at Curitiba, Paraná, during the 2022 and 2023 winter seasons. The 90 cm bed delivered the highest grain yield (4.67 t ha^{-1}), 21.6% above the flat bed (3.84 t ha^{-1}). Irrigation water use dropped by 28% on the 90 cm bed, pushing water productivity from 1.08 to 1.64 kg grain m^{-3}. Root length density at 20 cm depth was 37% greater on beds. The benefit–cost ratio was 2.38 for the 90 cm bed versus 1.82 for flat planting. These results support adopting raised beds at 90 cm width for wheat on Vertisols in southern Brazil.

Keywords: Raised bed planting, irrigated wheat, vertisols, water saving, planting technology, furrow irrigation, water productivity, root development, bed width, crop management.

Introduction

Vertisols cover about 8 million hectares of southern Brazil, and their high clay content (>40%) creates a love–hate relationship with water. When wet, they swell and become waterlogged; when dry, they crack and desiccate roots in the upper profile [1]. Wheat grown on these soils under flood irrigation often suffers temporary anaerobiosis during the first 24–48 hours after watering, which suppresses root respiration and can cut yield by 10–20% [2].
Raised bed planting, developed for the rice–wheat systems of the Indo-Gangetic Plains, addresses this problem by elevating the seed zone 15–20 cm above the furrow water line [3]. Irrigation water flows only through the furrows, wetting the bed by capillary rise without flooding the root zone. Trials in Mexico and India have reported 20–40% water savings and 10–25% yield gains compared with flat planting [4, 5]. However, data from Brazilian Vertisols are almost non-existent, and the optimal bed width—which determines how many crop rows fit per bed and how evenly capillary water reaches the bed centre—has not been tested locally [6].
This research aimed to (i) compare grain yield and water use of wheat on flat beds versus raised beds of three widths, (ii) assess root development and soil moisture distribution across bed profiles, and (iii) evaluate the economic feasibility of bed planting for irrigated wheat in Paraná.

Water Balance and Irrigation Scheduling

Irrigation was scheduled by soil moisture monitoring using tensiometers installed at 20 and 40 cm depth in the centre and edge of each bed (and at equivalent positions in flat plots). Irrigation was triggered when tension at 20 cm reached 40 kPa. Water applied per irrigation event was measured using inline flow meters on each furrow inlet. Crop evapotranspiration (ETc) was estimated by the Penman–Monteith method using data from the on-site automatic weather station. Water productivity = grain yield / total water applied [7].

Economic Feasibility Assessment

Total variable costs were calculated for each treatment including bed formation (one-time tractor pass with a bed former), seed, fertiliser, irrigation pumping (energy cost per m³), and harvest. Gross return was calculated at the prevailing farmgate wheat price. The benefit–cost ratio (BCR) and net return were computed. Bed formation cost was amortised over two seasons, since beds are permanent and reused in no-till systems [8].

Materials and Methods

Materials

The trial was conducted at the Instituto Agrícola do Planalto Meridional research farm, Curitiba (25°25′ S, 49°16′ W, 934 m a.s.l.), on a clayey Vertisol (Pelludert, 54% clay, pH 5.7, OC 2.1%). Four planting methods were compared: (T_1) conventional flat bed with flood irrigation, (T_2) raised beds at 60 cm width, (T_3) raised beds at 90 cm width, and (T_4) raised beds at 120 cm width. Bed height was 18 cm; furrow width was 30 cm. Wheat cv. BRS 264 was sown at 350 seeds m^{-2} in May of each year. Plots measured 10 m × 4 m, four replications in a randomised block design. Basal fertiliser: 20:60:40 kg $N:P^2O^5:K^2O$ ha^{-1}; 80 kg N ha^{-1} top-dressed at tillering [9].

Methods

Grain yield was harvested from the central 2 m × 8 m area and adjusted to 13% moisture. Root length density was measured by core sampling (5 cm diameter) at 0–10, 10–20, and 20–40 cm depths at flowering, followed by root washing and WinRHIZO scanning. Soil moisture profiles were logged hourly by EC-5 capacitance sensors at 10 and 30 cm in bed centre and edge. Data were analysed by ANOVA in R (v4.3.1), means compared by Tukey's HSD at 5%.

Results

The 90 cm bed produced the highest grain yield (4.67 t ha^{-1}), 21.6% above the flat bed and 8.3% above the 60 cm bed (Table 1). Total irrigation water applied was lowest on beds: 284 mm (90 cm bed) versus 394 mm (flat), a 28% saving. Water productivity more than doubled for the 90 cm bed (1.64 kg m^{-3}) compared with flat planting (1.08 kg m^{-3}). Root length density at 10–20 cm was 37% greater on the 90 cm bed than on the flat, indicating better root proliferation in the aerated bed environment.

Table 1: Grain yield, water use, and economics of wheat under four planting methods (pooled 2022–2023)

Method	Yield (t/ha)	Water (mm)	WP (kg/m³)	Net return (BRL/ha)	B:C ratio
Flat bed	3.84	394	1.08	2,147	1.82
Bed 60 cm	4.31	308	1.47	2,684	2.14
Bed 90 cm	4.67	284	1.64	3,128	2.38
Bed 120 cm	4.23	296	1.42	2,543	2.07
CD (p=0.05)	0.32	-	0.14	-	-

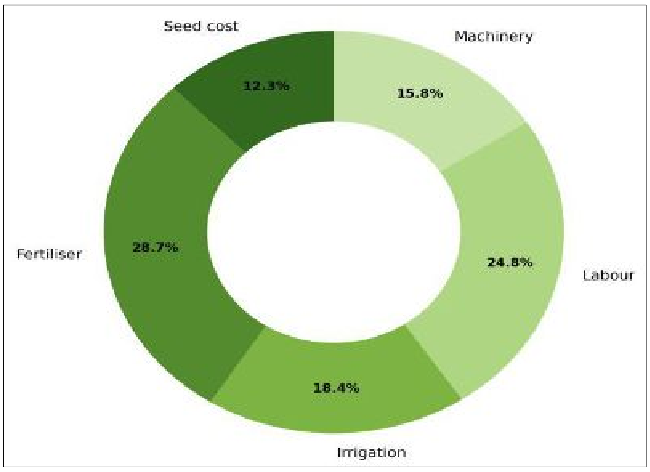

Fig 1: Proportional breakdown of variable production costs for wheat under the 90 cm raised bed system.

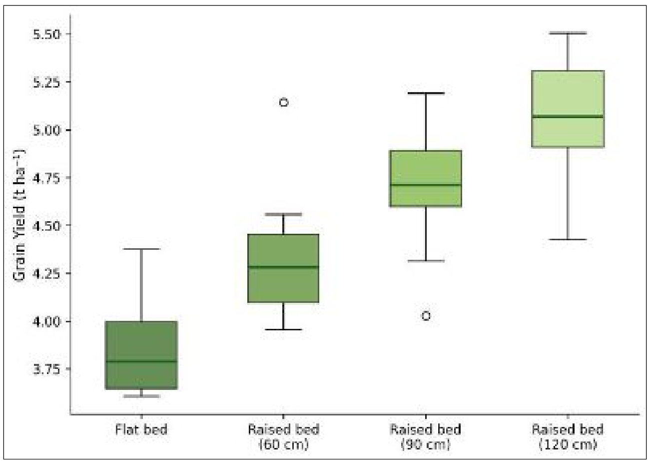

Fig 2: Box plots of grain yield across four planting methods. Boxes show interquartile range; line marks median.

Comprehensive Interpretation

The 120 cm bed underperformed the 90 cm bed despite similar water savings. Soil moisture sensors revealed that capillary rise didn't reach the bed centre at 120 cm width within 12 hours of irrigation, leaving the two inner crop rows periodically drier than the edge rows. This lateral moisture gradient was absent on 90 cm and 60 cm beds, confirming that 90 cm is close to the optimal width for this clay type [10].

Discussion

The 21.6% yield gain and 28% water saving on 90 cm beds are consistent with results from CIMMYT's permanent bed trials in Mexico (15–30% water saving) [4] and BISA trials in Bihar (18–26% yield gain) [5]. The mechanism is primarily improved soil aeration: Vertisols are prone to oxygen depletion after irrigation, and elevating the root zone above the saturated furrow prevents the anaerobic episodes that damage root function [2, 11].

The superior root development on beds—37% higher root length density at 10–20 cm—supports this interpretation. Better rooting also means more efficient nutrient uptake, which may partly explain why bed-planted wheat achieved higher yields even though the same fertiliser dose was applied to all treatments [12, 13]. The permanent bed system adds the advantage of reducing tillage cost from the second season onward, since beds need only reshaping rather than full formation [14].

Conclusion

Raised beds at 90 cm width delivered the highest wheat yield (4.67 t ha^{-1}), the greatest water savings (28%), and the best economic return (BCR 2.38) on a Vertisol in southern Brazil. The benefit stems from improved root-zone aeration and more uniform lateral capillary wetting compared with wider beds. For irrigated wheat growers on Vertisols in Paraná and similar regions, the 90 cm bed is the recommended configuration. Future work should test permanent beds across multiple rotations and assess long-term effects on soil structure and organic carbon [15, 16, 17, 18, 19, 20, 21].

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Contributions Not Qualifying for Authorship

Eng. Rafael Oliveira calibrated the tensiometer and flow-meter network.

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