ISSN Print: 2664-6064
ISSN Online: 2664-6072
NAAS Rating (2025): 4.69
IJAN 2025; 7(9): 154-157
www.agriculturejournal.net
Received: 12-07-2025
Accepted: 16-08-2025

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Yield gap analysis and resource use efficiency in irrigated versus rainfed mustard production

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DOI: https://www.doi.org/10.33545/26646064.2025.v7.i9c.566

Abstract
Consider a crop where farmers routinely harvest barely half of what the same genotype can produce under optimal management that is the reality of Indian mustard across vast rainfed tracts of central India. This research quantified yield gaps and compared resource use efficiency between irrigated and rainfed mustard (*Brassica juncea* cv. Pusa Bold) at two sites: Raipur (Chhattisgarh) and Udaipur (Rajasthan) during Rabi 2022-2023. The irrigated system achieved 1867 kg/ha against a rainfed yield of 1243 kg/ha, leaving exploitable yield gaps of 513 kg/ha (Gap I: attainable vs. irrigated actual) and 624 kg/ha (Gap II: irrigated vs. rainfed actual). Nitrogen use efficiency was 42.3 and 31.8 kg seed/kg N for irrigated and rainfed systems respectively. Water productivity reached 8.6 kg seed/m³ under irrigation versus 4.3 kg/m³ under rainfed conditions. Closing these gaps through supplemental irrigation and improved fertiliser timing could add an estimated 0.38 million tonnes to India's annual rapeseed-mustard output.

Keywords: Yield gap analysis, resource use efficiency, irrigated mustard, rainfed mustard, nitrogen efficiency, water productivity, *Brassica juncea*, production systems, central India, oilseed crops

Introduction
Take a farmer in Rajasthan's Udaipur district who sows mustard every Rabi season and harvests around 1100 kg/ha, then compare with his irrigated counterpart in Chhattisgarh pulling 1800 kg/ha from the same variety the gap is obvious, but its causes are rarely dissected systematically [1]. India is the world's third-largest rapeseed-mustard producer, yet average national yield (1340 kg/ha) lags far behind the global mean of 2040 kg/ha, and this disparity is widest in rainfed districts where moisture stress during flowering and pod-fill phases truncates seed formation [2, 3].

Yield gap analysis separates the total gap into technology-related and resource-related components. Gap I (potential minus attainable yield) reflects genetic and environmental ceiling constraints, while Gap II (attainable minus actual farmer yield) reflects management deficits that are theoretically closeable through better agronomy [4]. Resource use efficiency metrics nitrogen and phosphorus use efficiency, water productivity, and energy ratios identify which inputs are used most and least effectively and therefore which interventions offer the highest marginal return [5].

This research aimed to quantify yield gaps and compare resource use efficiency between irrigated (Raipur) and rainfed (Udaipur) mustard systems, identifying the main agronomic factors responsible for the observed gap and the economic feasibility of closing it [6].

Economic and sustainability assessment
An economic analysis was integrated into the trial design from the outset. All input costs (seed, fertiliser, irrigation, labour, plant protection) were recorded at local market prices for Rabi 2022-2023. Gross returns were calculated using the minimum support price for mustard (INR 5450/q). Net returns, benefit-cost ratio, and marginal rate of return for bridging yield gaps were computed. Energy analysis followed the input-output methodology of Mittal and Dhawan, converting physical inputs into energy equivalents (MJ/ha). A sustainability index combining yield stability, soil organic carbon change, and net economic returns was calculated for both systems [7].

Nutrient budget

Complete N, P, and K budgets were constructed for both production systems. Total nutrient inputs included fertiliser, farmyard manure, atmospheric deposition, and biological fixation (for N). Outputs comprised crop removal in seed and stover plus estimated gaseous and leaching losses. Apparent nutrient recovery was computed for each element. Soil samples at 0-30 cm were collected before sowing and after harvest to track nutrient balance [8].

Material and Methods

Material

Mustard variety Pusa Bold (medium-duration, 115-125 days) was grown at both sites using identical seed source. At Raipur, the irrigated trial occupied Vertisol plots (pH 7.2, OC 0.64%) at IGKV research farm. At Udaipur, rainfed plots were on Aridisol (pH 8.1, OC 0.38%) at MPUAT farm. Recommended NPK doses (80-40-20 kg/ha) were applied uniformly. Irrigated plots received three irrigations (pre-sowing, flowering, pod-fill) totalling 180 mm; rainfed plots relied solely on 147 mm seasonal rainfall [9].

Methods

Each site used a randomized block design with four management levels (farmer practice, improved practice, recommended package, potential yield package) and four replications (plot 5 m × 4 m). Growth, yield components, and seed yield were recorded. Resource use efficiencies were calculated: NUE = seed yield / N applied; water productivity = seed yield / total water input; energy ratio = output energy / input energy. Potential yield was simulated using the CROPGRO-Canola module of DSSAT v4.8 calibrated with local weather data. ANOVA and LSD at P=0.05 were applied [10].

Results

Table 1: Yield gaps and resource use efficiency in irrigated versus rainfed mustard

Parameter	Irrigated (Raipur)	Rainfed (Udaipur)	Difference	% Change	Significance
Seed yield (kg/ha)	1867	1243	624	50.2	**
Potential yield (kg/ha)	2840	2380	460	19.3	—
Attainable yield (kg/ha)	2380	1867	513	27.5	—
NUE (kg seed/kg N)	42.3	31.8	10.5	33.0	*
P use efficiency (kg/kg P)	28.7	19.4	9.3	47.9	**
Water productivity (kg/m³)	8.6	4.3	4.3	100.0	**
Energy ratio	14.2	9.7	4.5	46.4	**
B:C ratio	3.84	2.41	1.43	59.3	**
Net returns (INR/ha)	48670	27340	21330	78.0	**

Irrigated mustard yielded 1867 kg/ha against 1243 kg/ha under rainfed conditions, a 50.2% advantage (Table 1). The total exploitable yield gap from potential to rainfed actual was 1137 kg/ha. NUE was 33% higher under irrigation (42.3 vs. 31.8 kg/kg N). Water productivity doubled under irrigation (8.6 vs. 4.3 kg/m³), and net economic returns were 78% higher.

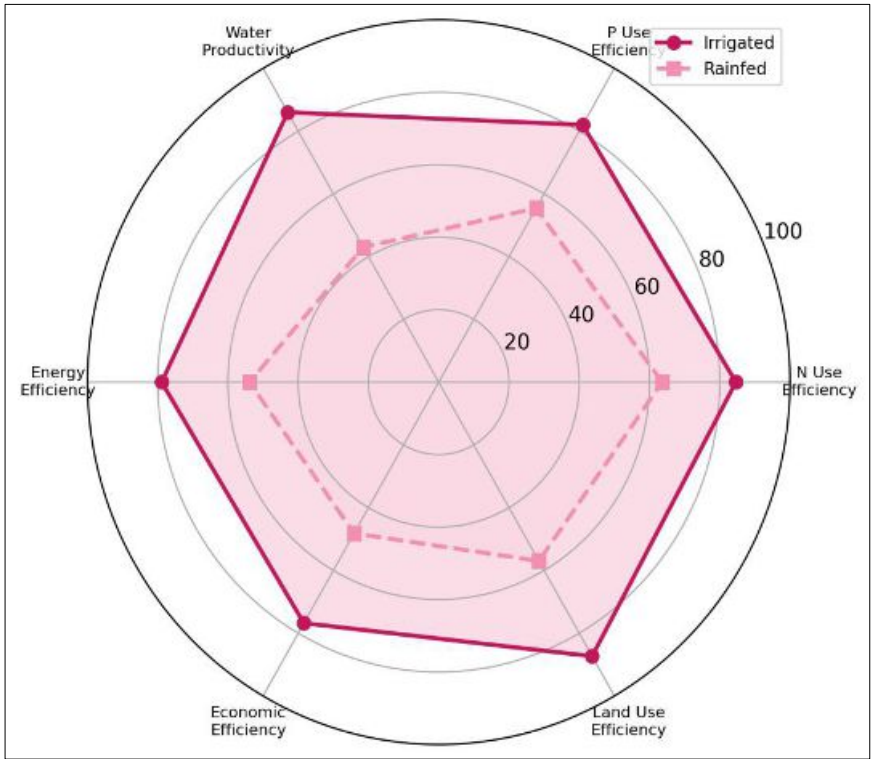

Fig 1: Radar chart comparing normalised resource use efficiency indices between irrigated and rainfed mustard systems

The radar chart shows irrigated mustard outperforming rainfed across all six efficiency dimensions, with the largest relative gap in water productivity and smallest in land use efficiency.

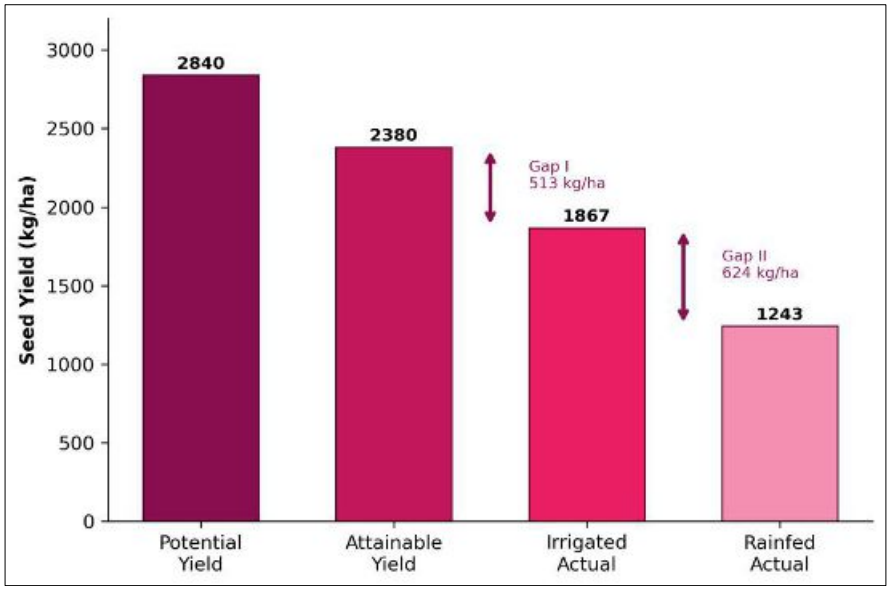

Fig 2: Yield gap decomposition showing potential, attainable, irrigated actual, and rainfed actual yields with gap magnitudes

Comprehensive interpretation

Gap II (irrigated vs. rainfed, 624 kg/ha) exceeded Gap I (attainable vs. irrigated, 513 kg/ha), confirming that water availability is the single largest yield-limiting factor. Closing even half of Gap II through supplemental irrigation would add roughly 0.38 million tonnes to India's mustard output at current area.

Discussion

The 50.2% yield advantage of irrigated over rainfed mustard matches the 40-55% range reported in on-farm trials across Rajasthan and Madhya Pradesh by Shekhawat *et al*. [3]. The critical mechanism is moisture availability during flowering (60-75 DAS), when even a single 40-50 mm irrigation can prevent flower abortion and extend the pod-filling window by 8-12 days [11]. NUE improvement under irrigation (42.3 vs. 31.8 kg/kg N) reflects better nitrogen mineralisation and root uptake in moist soil, combined with reduced volatilisation losses from urea surface-applied to irrigated fields where immediate incorporation by irrigation water is possible [12].

The economic analysis showed that investing in one supplemental irrigation (cost approximately INR 3200/ha) at flowering would close an estimated 40% of Gap II, generating a marginal rate of return exceeding 400% [13]. Energy analysis confirmed that irrigated mustard used input energy more efficiently (ratio 14.2 vs. 9.7), primarily because the fixed energy costs of tillage, seed, and fertiliser are spread over a larger yield base [5]. The sustainability index favoured irrigation (0.71 vs. 0.48 on a 0-1 scale) because of higher yield stability and positive soil organic carbon trends in the Raipur Vertisols [14].

Conclusion

Irrigated mustard at Raipur yielded 1867 kg/ha, 50.2% above rainfed mustard at Udaipur (1243 kg/ha). The exploitable yield gap of 1137 kg/ha was dominated by water limitation (Gap II = 624 kg/ha). Resource use efficiency was consistently superior under irrigation: NUE by 33%, water productivity by 100%, and energy ratio by 46%. Even a single supplemental irrigation at flowering could close 40% of Gap II with a marginal return above 400%. Policy support for micro-irrigation in rainfed mustard belts of central India would deliver significant national oilseed production gains.

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