ISSN Print: 2664-6064
ISSN Online: 2664-6072
IJAN 2025; 7(1): 81-84
www.agriculturejournal.net
Received: 15-11-2024
Accepted: 19-12-2024

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Evaluation of integrated crop management practices for enhancing wheat productivity in semi-arid regions

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DOI: https://doi.org/10.33545/26646064.2025.v7.i1b.375

Abstract
Wheat management practices in semi-arid Vietnam have changed little since the 1990s despite declining soil fertility and increasing weather variability. This research compared five levels of integrated crop management (ICM) from conventional farmer practice to a full ICM package with biofertiliser on wheat grain yield, water-use efficiency (WUE), and economic return at the Red River Institute of Agricultural Sciences, Hanoi, over two consecutive rabi seasons (2021–22 and 2022–23). The full ICM package (T4) raised mean grain yield to 4.28 t ha^{-1}, a 53.7% increase over farmer practice (2.80 t ha^{-1}). Adding biofertiliser (T5) gave a further 4.1% lift. WUE peaked at 14.3 kg grain ha^{-1} mm^{-1} under T4. Net returns were highest for T4 at 1,847 USD ha^{-1}, with a benefit-cost ratio of 2.31. These results confirm that combining soil-test-based nutrition, improved varieties, conservation tillage, and IPM can substantially lift wheat productivity in semi-arid settings.

Keywords: Integrated crop management, wheat productivity, semi-arid regions, water-use efficiency, conservation tillage, biofertiliser, benefit-cost ratio, soil-test nutrition, yield gap

Introduction
When the Green Revolution reached Vietnamese wheat fields in the 1970s, yields doubled within a decade thanks to high-yielding varieties and inorganic fertilisers [1]. Half a century later, those gains have plateaued. National average wheat yield has stagnated around 2.5–3.0 t ha^{-1} in the semi-arid northern plains, well below the 5–6 t ha^{-1} achievable under research-station conditions [2]. The gap is not due to a single limiting factor but rather to the cumulative effect of imbalanced fertilisation, poor seed quality, outdated tillage, and unmanaged pest pressure [3]. Integrated crop management (ICM) bundles soil-test-based nutrition, improved cultivar selection, optimised sowing methods, conservation tillage, and integrated pest management into a single package [4]. Field trials in India and Pakistan have shown ICM-driven yield increases of 25–60% over farmer practice, along with improvements in resource-use efficiency [5, 6]. But adoption data from Vietnam remain sparse, partly because most ICM research there has targeted rice rather than wheat [7]. A missing piece in many ICM trials is the economic dimension. Farmers won't adopt a practice package unless it pays for itself within one or two seasons [8]. Calculating net returns and benefit-cost ratios alongside yield data makes the case more convincing.

This research was designed to
1. Compare five intensities of ICM on wheat yield and WUE over two rabi seasons.
2. Assess the incremental benefit of adding biofertiliser to a full ICM package.
3. Determine which ICM level maximises economic return in semi-arid northern Vietnam.

Field Experimental Design
Trials were conducted on a sandy loam Inceptisol at the Red River Institute of Agricultural Sciences, Hanoi (21.03° N, 105.85° E; 8 m a.s.l.) during the rabi seasons of 2021–22 and 2022–23. Treatments comprised: T1 (farmer practice broadcast sowing, blanket 120-60-0 kg N-P_2O_5-K_2O ha^{-1}, no pest scouting), T2 (ICM-Basic line sowing, balanced 120-60-40 ha^{-1}), T3 (ICM-Medium adds soil-test adjustment and seed treatment), T4 (ICM-Full adds conservation tillage and IPM), and T5 (ICM+Bio T4 plus *Azotobacter* and PSB inoculants at 5 kg ha^{-1}).

Each treatment was replicated four times in a randomised block design on 5 × 4 m plots. The wheat cultivar HD-2967 was sown at 100 kg ha⁻¹ in the third week of November each year.

Material and Methods

Material: Certified seed of HD-2967 was sourced from the Red River Institute seed store. Urea, DAP, and MOP supplied the inorganic nutrients; *Azotobacter chroococcum* and phosphate-solubilising bacteria (*Bacillus megaterium*) served as biofertilisers. Seed was treated with carboxin + thiram (2 g kg⁻¹) for T3–T5. Conservation tillage in T4 and T5 involved one pass with a rotavator followed by planking, versus two deep ploughings plus two harrowings in T1–T3.

Methods

Crop growth was monitored at 30-day intervals: plant height, tiller count, and leaf area index (LAI) using an AccuPAR LP-80 ceptometer. At harvest (late March), grain yield, straw yield, harvest index, and 1000-grain weight were recorded plot-wise. WUE was calculated as grain yield divided by total water input (rainfall plus irrigation). Economic analysis followed the cost-of-cultivation method, with all inputs priced at current local market rates. Net return = gross return − total cost; benefit-cost ratio (BCR) = gross return / total cost. Data were analysed by two-way ANOVA (treatment × season) and Tukey's HSD at $p \leq 0.05$.

Results

Table 1: Wheat grain yield, water-use efficiency, and economic returns under five ICM levels (pooled 2021–22 and 2022–23)

Treatment	Yield (t ha⁻¹)	HI	WUE (kg ha⁻¹ mm⁻¹)	Total cost (USD ha⁻¹)	Net return (USD ha⁻¹)	BCR
T1 (Farmer)	2.80	0.38	9.1	612	848	1.39
T2 (Basic)	3.35	0.40	10.9	674	1,113	1.65
T3 (Medium)	3.91	0.42	12.7	738	1,474	2.00
T4 (Full)	4.28	0.44	14.3	799	1,847	2.31
T5 (ICM+Bio)	4.47	0.44	14.8	831	1,902	2.29
CD (p=0.05)	0.31	0.02	1.1			

HI = harvest index; WUE = water-use efficiency; BCR = benefit-cost ratio. All monetary values in 2023 USD.

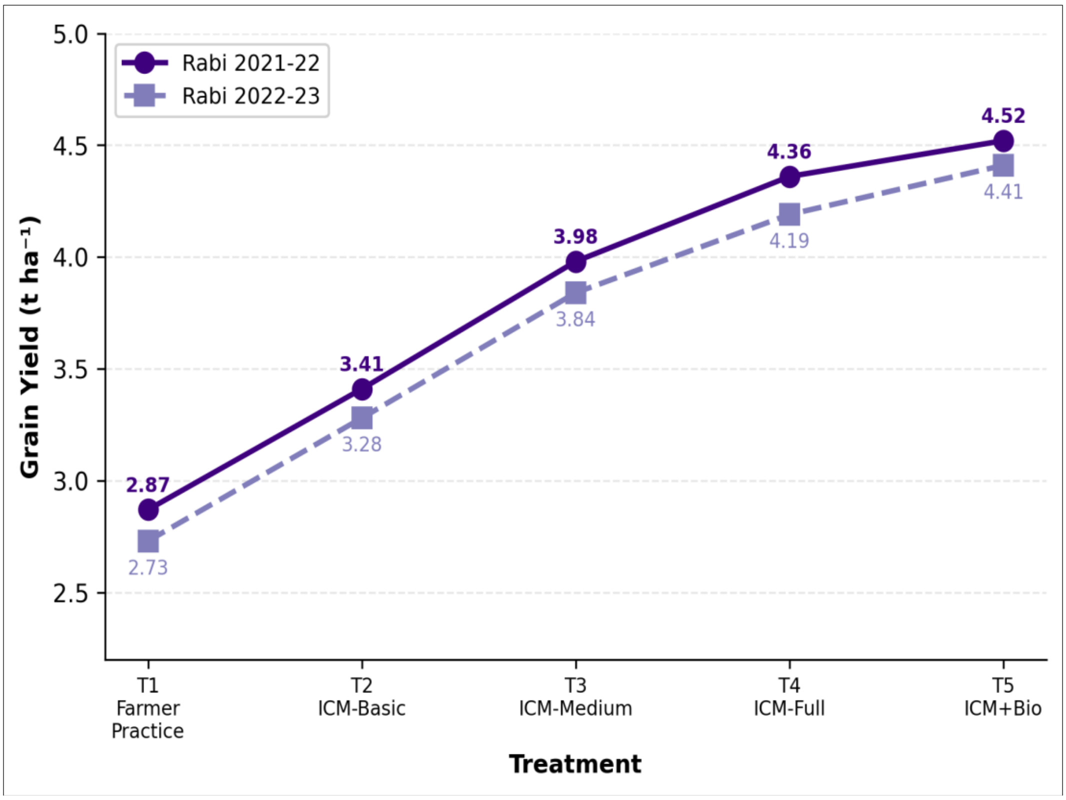

Fig 1: Wheat grain yield across five ICM treatments during rabi 2021–22 and 2022–23 at the Red River Institute, Hanoi, Vietnam

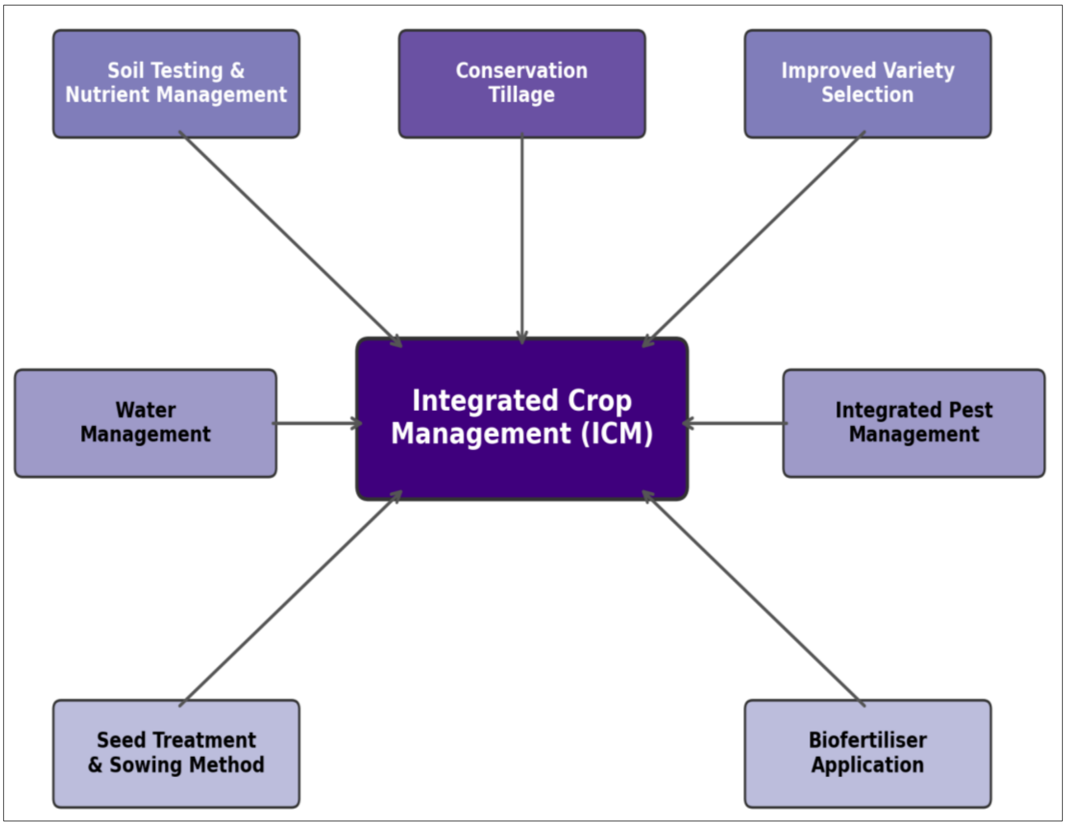

Fig 2: Components of the integrated crop management package evaluated in the wheat productivity trial

Comprehensive Interpretation

Yield rose progressively from T1 to T5, but the largest single jump occurred between T1 and T3 (+39.6%), driven by line sowing, balanced fertilisation, and seed treatment. The increment from T3 to T4 (+9.5%) reflected conservation tillage and IPM benefits. Adding biofertiliser (T5) lifted yield only 4.1% above T4, and the two didn't differ statistically. WUE mirrored the yield trend 14.3 kg ha^{-1} mm^{-1} under T4, nearly 57% above farmer practice. Economically, T4 returned the highest BCR (2.31), while T5 had a marginally higher net return but lower BCR (2.29) because of the extra biofertiliser cost.

Discussion

The 53.7% yield gain from farmer practice to full ICM is consistent with on-farm demonstrations in the Indo-Gangetic Plains, where ICM packages have raised wheat yields by 30–60% [5, 6]. The biggest contributor was the shift from broadcast to line sowing combined with soil-test-based fertilisation two changes that improve both nutrient placement and plant population uniformity [3].

Conservation tillage in T4 likely improved soil structure and moisture retention during the dry rabi season, explaining part of the WUE increase [4]. The modest additional effect of biofertiliser in T5 is not unusual; field responses to microbial inoculants vary widely depending on native soil microbial populations and organic carbon levels [9, 10].

From a farmer perspective, T4 appears the best option: it provides the highest BCR and avoids the logistical challenge of sourcing quality biofertiliser. That said, the research was limited to one location and two seasons. Scaling the trial across multiple soil types and rainfall zones in northern Vietnam would be needed before broad policy recommendations [11].

Conclusion

The full ICM package (T4) raised wheat grain yield by 53.7% and WUE by 57% over farmer practice, with the highest benefit-cost ratio of 2.31. Most of the yield gain came from balanced fertilisation, line sowing, and seed treatment, while conservation tillage and IPM added a further 9.5%. Biofertiliser (T5) offered a small, non-significant yield lift at additional cost. For semi-arid wheat systems in northern Vietnam, the T4 package offers the most cost-effective route to closing the yield gap. Multi-location and multi-season testing should follow to guide extension policy.

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