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Effect of Tillage Practices, Irrigation Schedules and Nitrogen Fertilization on Productivity and Profitability of Wheat (*Triticum aestivum* L.) Grown in South Eastern Rajasthan, India

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Authors' contributions

This work was carried out in collaboration among all authors. Author RSN conceptualized the study, designed the manuscript, and wrote the first draft. Author RKY carried out sampling, laboratory analysis, and data analysis. Authors SS, VG, and SKY contributed to manuscript review and editing. All authors read and approved the final manuscript.

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Abstract

Background: Wheat productivity in south-eastern Rajasthan is influenced by tillage, irrigation scheduling and nitrogen management. Evaluating their combined management context is important for wheat cultivation on Vertisols.
Aims: To evaluate the effects of tillage practices, irrigation schedules and nitrogen fertilisation on wheat productivity, profitability, water-use efficiency and nitrogen uptake in the Vertisols of south-eastern Rajasthan.

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Study Design: A field experiment involving 18 treatment combinations of tillage practices, irrigation schedules and nitrogen fertilisation was conducted.
Place and Duration of Study: Agricultural Research Station, Kota, Rajasthan, India, during the winter (rabi) seasons of 2020–21, 2021–22 and 2022–23.
Methodology: The experiment comprised two tillage practices (zero tillage and conventional tillage), three irrigation schedules (0.8, 1.0 and 1.2 ETc) and three nitrogen fertilisation levels (75%, 100% and 125% of the recommended dose of nitrogen (RDN)). Data pooled over three years were analysed for crop growth, yield attributes, grain, straw and biological yields, harvest index (HI), water-use efficiency (WUE), water productivity, economic returns, benefit–cost (B:C) ratio, economic efficiency and nitrogen uptake.
Results: Zero tillage significantly increased effective tillers, net returns, B:C ratio, economic efficiency, nitrogen uptake by grain and total nitrogen uptake by the crop compared with conventional tillage. Irrigation at 1.2 ETc improved growth parameters, yield attributes, grain, straw and biological yields, economic returns, nitrogen uptake by grain and total nitrogen uptake by the crop compared with irrigation at 0.8 and 1.0 ETc. However, HI, WUE and water productivity did not differ significantly among irrigation schedules. Application of 100% RDN significantly improved growth parameters, yield attributes, grain and biological yields, water productivity, economic returns and nitrogen uptake by the crop compared with 75% RDN.
Conclusion: Zero tillage, irrigation at 1.2 ETc and application of 100% RDN (120 kg N ha^{-1}) may be recommended for achieving higher wheat productivity and profitability in the Vertisols of south-eastern Rajasthan.

Keywords: Wheat (Triticum aestivum L.); Vertisols; zero tillage; irrigation scheduling; crop evapotranspiration; nitrogen fertilisation; nitrogen uptake; grain yield; water productivity; economic returns.

1. Introduction

Wheat (*Triticum aestivum* L.) is one of the most important cereal crops worldwide and plays a pivotal role in ensuring food and nutritional security. It is cultivated extensively in diverse agro-ecological environments and contributes substantially to the food supply of millions of people. In India, wheat occupies a prominent position among the major foodgrain crops and is an important component of the prevailing cropping systems. The productivity of wheat, however, is strongly influenced by soil, climatic and management factors, particularly tillage practices, water availability and nitrogen nutrition.

A three-year field investigation in north-western India examined the combined effects of tillage, irrigation and nutrient supply on wheat yield and water-use efficiency, highlighting differences in crop responses among the management combinations (Rajanna *et al.*, 2024). A separate study of subsoiled wheat fields found that irrigation methods and scheduling regimes affected grain yield, water productivity, nitrogen-use indicators and economic outcomes (Liu *et al.*, 2024).

The rice–wheat cropping system is a dominant cropping system on the fertile, irrigated Vertisols of the humid south-eastern plain zone of Rajasthan. In this region, conventional rice establishment involves the manual transplanting of rice into puddled soil, whereas wheat is sown in a well-prepared, fine seedbed. These practices involve excessive tillage and, consequently, result in high energy consumption and the deterioration of soil structure (Jha *et al.*, 2011). Rice stubble makes it difficult to complete tillage operations within a short period. Under these circumstances, zero tillage offers benefits in terms of savings in fuel, time and labour, surface-residue retention, improved organic carbon and nutrient status, reduced soil-water loss, protection of the soil from the sun, rain and wind, preservation of soil microorganisms and fauna, reduced breakdown of soil structure, protection against machinery-induced soil compaction and reduced changes in soil chemistry through acidification or salinisation (Jha *et al.*, 2011; Shekhar *et al.*, 2014). Zero tillage with appropriate irrigation management may help mitigate the adverse effects of conventional farming practices by increasing soil organic carbon and soil-moisture availability and improving the long-term sustainability of the production system. Growing two cereal crops annually involves substantial removal of plant nutrients, thereby reducing soil fertility. It is therefore necessary to manage organic nutrient inputs optimally through residue management under zero-tillage conditions and their integration with fertilisers. Integrated nutrient supply can improve the productivity and economic performance of rice–wheat cropping systems (Singh, 2006). Grain development depends on the rate and duration of grain growth, which are determined by the supply of photosynthates and affected by several environmental factors, including water and nitrogen. Soil moisture is an important factor affecting plant growth, particularly under restricted water supply. Soil-surface evaporation contributes substantially to total evapotranspiration in cropped fields (Gupta *et al.*, 2021). Evaporation dominates moisture depletion from the root zone until the crop attains full vegetative cover. Water lost through evaporation does not contribute to crop production. Therefore, an appropriate irrigation regime is needed for growing wheat under different tillage, irrigation and nitrogen-management systems to conserve both water and nitrogen.

A field study of conservation tillage and irrigation regimes in wheat reported significant differences in total nutrient uptake among irrigation treatments, whereas nitrogen and phosphorus concentrations in grain and straw showed no significant variation across the evaluated tillage practices (Priya *et al.*, 2025). In an irrigated wheat experiment, integrated nutrient management involving mineral fertilisers and other nutrient inputs was associated with improvements in crop growth, grain yield and residual soil organic matter (Hyder *et al.*, 2021). Research on zero-tilled wheat has also evaluated precision irrigation and nitrogen management in relation to productivity, resource-use efficiency and nitrous oxide emissions (Pratap *et al.*, 2025).

The rapid and widespread expansion of the rice–wheat cropping system in irrigated areas has raised concerns about the sustainability of soil productivity. Unsustainable high yields have been observed despite substantial NPK application in this region. This declining trend has been attributed to multiple nutrient deficiencies and nutrient imbalances, which pose a serious threat to the long-term sustainability of crop production (Paul *et al.*, 2014). The combined responses of wheat to tillage practices, crop evapotranspiration-based irrigation schedules and nitrogen fertilisation under the Vertisol conditions of south-eastern Rajasthan therefore require assessment in relation to crop productivity, water use, profitability and nitrogen uptake.

In view of these considerations, the present investigation was undertaken to examine the effects of irrigation scheduling and nutrient management on the yield, nutrient uptake and economics of wheat grown under zero-tillage conditions in the humid south-eastern plain zone of Rajasthan.

2. Materials and Methods

A field experiment was carried out during the winter (rabi) seasons of 2020–21 to 2022–23 at Agricultural Research Station, Kota (26º N, 76º-6' E and 260 m above mean sea-level), Rajasthan. The soil was a Vertisol with bulk density 1.53 Mg/m3, pH 7.79 and cation-exchange capacity 35 C mol/kg. The soil had a very low infiltration rate (0.25 cm/hr) at the surface, but at deeper depths (1.2 to 1.5 m) was impermeable. The potential moisture-retention capacity of the soil was 120 mm of water at 1 m soil depth. The soil had medium organic carbon 5.2 g/kg, available nitrogen (318 kg/ha) and available phosphorus (23.7 kg/ ha) and high in available potash (301 kg K_2O/ha). The experiment was laid out in a split-split-plot design with three replications. The treatments comprised 18 factorial combinations of two tillage practices, i.e., zero tillage and conventional tillage, in the main plots, three irrigation schedules, i.e., irrigation at 0.8, 1.0 and 1.2 ETc, in the subplots, and three nitrogen fertilisation levels, i.e., 75%, 100% and 125% of the recommended dose of nitrogen. Wheat variety 'Raj 4037', at a seed rate of 100 kg/ha, was sown on 06, 10 and 16 November of 2020, 2021 and 2022 and harvested on 26 March 2021, 31 March 2022 and 4 April 2023, respectively. The crop was planted by direct seeding using a zero-till ferti-seed drill at a row spacing of 23 cm. The crop was raised using the recommended package of

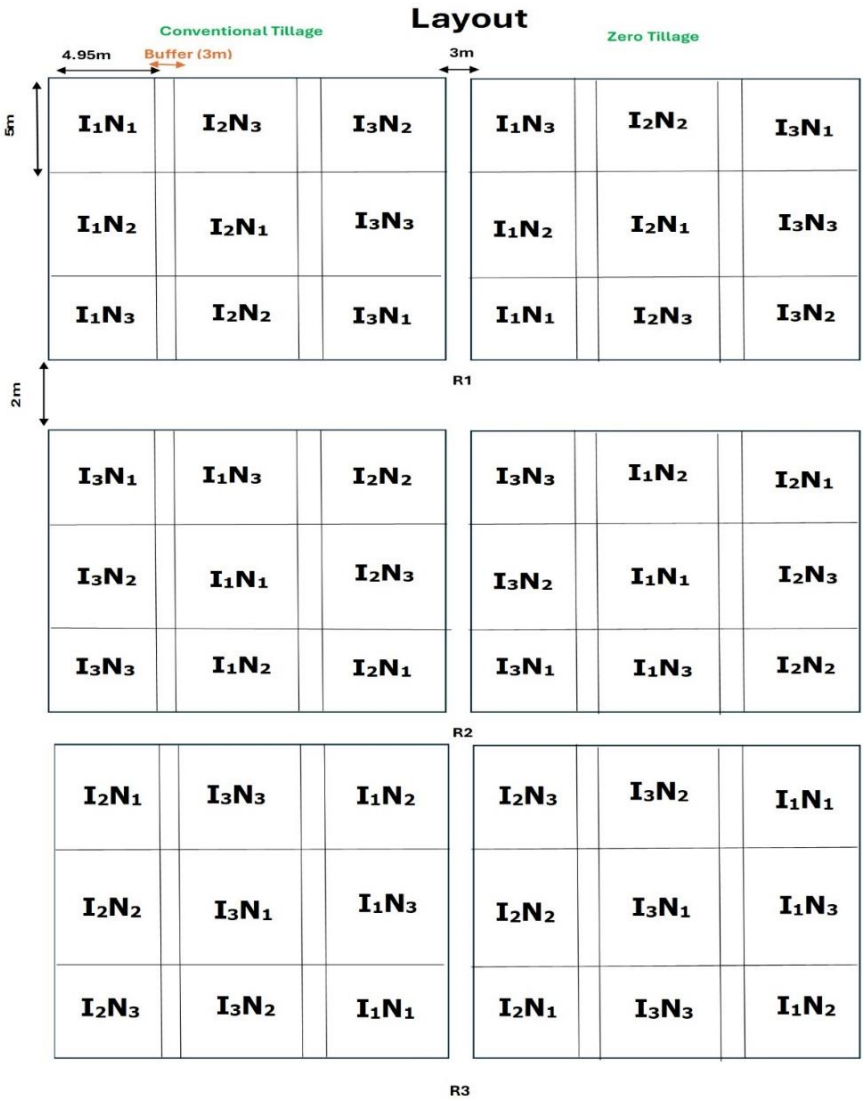


Fig. 1. Layout of the Field Experiment showing the arrangement of treatments across three replications (R1, R2, And R3) on wheat (*Triticum Aestivum* L.) in South-Eastern Rajasthan, India

NOTE: Main Plots Consist of Two Tillage Practices (Conventional Tillage and Zero Tillage Separated By a 3 m Buffer); Sub-Plots Comprise Three Irrigation Schedules (I_1 = 0.8 Etc, I_2 = 1.0 Etc, And I_3 = 1.2 Etc); And Sub-Sub-Plots Include Three Nitrogen Fertilization Levels (N_1 = 75% RDN, N_2 = 100% RDN, AND N_3 = 125% RDN)

practices, viz. seed treatment and weed management. The field plots, measuring 5.06 m × 5.5 m were separated by 1 m buffer rows. The recommended weed-control practice, namely the application of 2,4-D at 0.8 kg/ha at 30 days after sowing, was followed. Irrigation was applied according to the treatment. The recommended fertiliser dose for the wheat crop was N:P:K 120:40:30 kg/ha. For basal fertiliser application according to the treatments, half the nitrogen dose and the full P and K doses were applied through diammonium phosphate and muriate of potash, respectively. The remaining N was top-dressed as urea in two equal splits at crown-root initiation (CRI) and tillering stage. A uniform basal dose of zinc sulphate (21% Zn) @ 25 kg/ ha was applied uniformly to all plots only in the first year of the experiment. The rainfall and pan evaporation recorded during growing seasons was 80, 272.2 mm in 2020-21, 86, 431.8 mm in 2021-22 and 39.2, 379.6 mm in 2022-23, respectively. Growth and yield-attributing characteristics were recorded at 90 days after sowing and at harvest under the different treatments. Plant height was recorded for 10 selected plants from each plot. Dry-matter accumulation in the sampled plants from each plot was recorded at 90 days after sowing (DAS) and expressed per square metre. The plant material was first air-dried, then chopped and oven-dried at 70oC for 72 hr to a constant weight. Leaf-area index (LAI) was recorded using the Sun Scan Canopy Analyser. Ear-bearing tillers in a 1 m row length of each net plot were counted at maturity and recorded as the number of effective tillers per metre of row length at harvest. Five ears were randomly selected from each plot to determine ear length and the number of grains per ear. To determine test weight, 1,000 grains from each treatment were counted and weighed. The crop was harvested manually with the help of sickle when the grain was almost mature and the straw had turned yellow and grain and straw yields were recorded. The sun-dried bundles were threshed and winnowed, and the grain obtained was weighed. Straw yield was calculated by subtracting grain yield from the biological yield. The daily meteorological data, including temperature (maximum and minimum), relative humidity, wind velocity and sunshine hours were obtained from the meteorological observatory located within the research farm and appropriate adjustments were made according to the FAO Penman–Monteith recommendations. FAO Penman–Monteith (FAO 56 pm) equation (Allen *et al.*, 1998) was used to calculate reference crop evapotranspiration (ETo) from daily average meteorological data, and the crop coefficient (kc) was calculated from the relationship ETc= Kc X ETo, where the Kc value was selected according to the crop growth stages, Kc 0.40 for growth, Kc 1.15 for reproductive stage and Kc 0.41 for maturity stage. Irrigation requirements for each treatment were met using groundwater, irrespective of rainfall. Nitrogen uptake by the crop in each plot was estimated by multiplying the grain and straw yields at harvesting with their respective percentage nitrogen contents in grain and straw. The colorimetric method was used to determine nitrogen (Jackson, 1973). All observations were statistically analysed for significance in individual years, followed by a pooled analysis across years. Water-use efficiency (WUE) and water productivity (WP) were calculated using standard procedures (Devasenapathy *et al.*, 2008; Singh & Kumar, 2011).

Water-use efficiency = Economic crop yield (kg/ha)/ Evapotranspiration (ha-cm)

Water productivity = Net returns (Rs. /ha)/ Water applied (m^3)

The economics of the treatments were calculated using the prevailing market prices of inputs and outputs. Fig. 1 shows the arrangement of treatments across the three replications.

3. Results and Discussion

3.1 Growth and Yield Attributes

Tillage practices did not have a significant effect on the growth and yield attributes of wheat. However, growth and yield attributes were numerically higher under zero tillage than under conventional tillage.

Irrigation schedules had a significant effect on growth and yield attributes, viz. plant height, leaf-area index and dry-matter accumulation/m^2 at 90 days after sowing (DAS), effective tillers/m^2, grains/ear and 1,000-seed weight (Table 1). Irrigation applied at 1.2 ETc recorded significantly higher plant height, dry-matter accumulation/m^2 and leaf area index at 90 DAS, effective tillers, grains/spike and 1,000-seed weight compared with irrigation at 1.0 and 0.8 ETc. Thus, irrigation at 1.2 ETc increased plant height, dry-matter accumulation/m 2, leaf area index at 90 DAS, effective tillers, grains/spike and 1,000-seed weight by 4.65, 27.1, 10.57, 19.19, 26.97, and 5.48 per cent compared with 0.8 ETc, respectively. This may be attributable to adequate water availability and a more favourable rhizosphere environment for nutrient uptake, which may promote growth, leading to the development of higher yield attributes through an increased supply of photosynthates to sink tissues. Stress during the reproductive phase may have hampered the supply of photosynthates to sink tissues, resulting in poorer yield attributes under irrigation at 0.8 ETc. The results are in close conformity with the findings of Ziaeyan *et al.* (2020).

Among nitrogen levels, nitrogen fertilization had a significant impact on growth and yield attributes of wheat. Plant height, dry-matter accumulation/m, and leaf-area index recorded at 90 DAS increased significantly as the nitrogen dose increased to 100 per cent RDN. Application of 100 per cent RDN significantly increased in plant height, dry-matter production and LAI by 2.76, 11.7 and 5.38 per cent compared with 75 per cent RDN at 90 DAS, respectively. Nitrogen application may have promoted cell division and elongation, increased chlorophyll content and enhanced the net photosynthetic rate. Phosphorus supply may also have contributed to energy storage and carbohydrate metabolism, supporting subsequent growth and reproductive processes and potentially contributing to increased plant height. Greater meristematic activity associated with nitrogen fertilisation might have promoted greater canopy development in terms of leaf-area index. Thus, increased LAI resulting from nitrogen fertilisation seems to have resulted in greater interception, absorption and utilisation of solar energy with greater CO2 fixation and thereby increased the photosynthetic efficiency considerably. Significantly higher numbers of effective tillers, greater ear length, more grains per ear and higher 1,000-seed weight were recorded with the application of 100% RDN. However, the responses at 100 per cent and 125 per

cent RDN were comparable for some yield-attributing characteristics. The 100 per cent recommended dose of nitrogen resulted in 4.40, 5.83 and 2.26 per cent higher effective tillers/m^2, grains/ear and 1,000-grain weight, respectively. The higher number of effective tillers/m^2 may have resulted from greater nutrient utilisation and uptake, which contribute to photosynthesis and tillering in wheat. These results are in accordance with the findings of Ali *et al.* (2025).

Table 1. Effect of tillage practices, irrigation schedules and nitrogen fertilization on growth and yield attributes of wheat (Pooled data of three years)

Treatments	Plant height at 90 DAS (cm)	Dry matter accumulation at 90 DAS (g m^{-2})	LAI at 90 DAS	Effective tillers (no. m^{-1} row length)	Grains $spike^{-1}$	Test weight (g)
Tillage practices						
Zero tillage	87.7	852.3	3.58	117.0	47.78	37.14
Conventional tillage	83.3	802.0	3.41	113.8	47.48	36.69
SEm (±)	0.870	14.54	0.06	1.07	0.510	0.350
CD (P = 0.05)	NS	NS	NS	3.09	NS	NS
Irrigation schedules						
ETc 0.8	83.7	721.1	3.31	104.7	41.70	36.10
ETc 1.0	85.1	844.4	3.52	116.8	49.73	36.57
ETc 1.2	87.6	915.9	3.66	124.8	52.95	38.08
SEm (±)	0.768	12.84	0.046	1.58	0.53	0.302
CD (P = 0.05)	2.24	37.5	0.135	4.55	1.53	0.88
Nitrogen fertilization						
75% RDN (90 kg N ha^{-1})	83.3	750.0	3.34	111.2	45.90	36.27
100% RDN (120 kg N ha^{-1})	85.6	838.0	3.52	116.1	48.58	37.09
125% RDN (150 kg N ha^{-1})	87.4	893.4	3.63	119.0	49.83	37.39
SEm (±)	0.654	9.42	0.042	1.06	0.51	0.249
CD (P = 0.05)	1.84	26.5	0.12	2.98	1.44	0.70

DAS = days after sowing; LAI = leaf area index; ETc = crop evapotranspiration; RDN = recommended dose of nitrogen; SEm = standard error of the mean; CD = critical difference; NS = non-significant

3.2 Yield

The data indicated that tillage practices did not significantly affect grain, straw or biological yields of wheat. However, irrigation schedules significantly influenced these yields. Irrigation at 1.2 ETc produced significantly higher grain, straw and biological yields than irrigation at 0.8 ETc (Table 2). Compared with grain, straw and biological yields of 4,219, 4,622 and 8,647 kg/ha, respectively, under irrigation at 0.8 ETc, irrigation at 1.2 ETc increased these yields by 29.5%, 25.1% and 31.7%, respectively. Harvest index (HI) was not significantly affected by irrigation scheduling. The higher grain and straw yields may be attributable to greater soil-moisture availability in the root zone, which may have improved nutrient availability when the crop received five irrigations at 1.2 ETc. This may have enhanced the synthesis and translocation of photosynthates to developing ears, compared with the three irrigations applied at 0.8 ETc. The improved yields may also reflect better yield-contributing characteristics under irrigation at 1.2 ETc. These findings are consistent with those of Chhokar *et al.* (2023) and Ali *et al.* (2025).

The data further indicated that grain, straw and biological yields improved significantly as the nitrogen dose increased from 75% to 125% RDN. The additional improvement in grain yield at 125% RDN compared with 100% RDN was marginal and not statistically significant. Application of 100% RDN produced a significantly higher grain yield than 75% RDN. However, straw yield increased significantly up to 125% RDN, exceeding that at 75% and 100% RDN by 17.5% and 6.6%, respectively. Harvest index was not significantly affected by nitrogen fertilisation. Adequate nitrogen supply is important for rapid vegetative growth, including plant height, tiller number, leaf-area index and dry-matter production. Nitrogen application may stimulate seed setting and increase the number of effective tillers, grains per ear and 1,000-seed weight. Grain and straw yields reflect the cumulative effects of growth and yield-attributing characteristics associated with nitrogen fertilisation. These findings are consistent with those of Pratap *et al.* (2025).

3.3 Water Use

Water-use indices were not significantly affected by tillage practices (Table 2). Among the irrigation schedules, only water profitability differed significantly. Water profitability under irrigation at 1.0 ETc was 8.78% higher than that under 0.8 ETc. Nitrogen management significantly increased water productivity and water profitability, with values at 125% RDN comparable to those at 100% RDN (1.35 kg/m^3 and Rs. 22.28/m^3 of water applied, respectively). Additional nitrogen application beyond 100% RDN did not significantly increase either index. These findings are consistent with the importance of irrigation management for wheat productivity reported by Liu *et al.* (2024).

Table 2. Effect of tillage practices, irrigation schedules and nitrogen fertilization on productivity and profitability of wheat (Pooled data of three years)

Treatments	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Biological yield (kg ha^{-1})	HI (%)	WUE (kg ha^{-1} mm^{-1})	Water productivity (kg m^{-3})	Water profitability (Rs. m^{-3})
Tillage practices							
Zero tillage	5012	5408	10421	48.1	13.63	1.34	22.98
Conventional tillage	4868	5242	10110	48.2	13.26	1.33	21.06
SEm (±)	65.06	70.05	115.6	0.60	0.23	0.024	0.495
CD (P = 0.05)	NS	NS	NS	NS	NS	NS	NS
Irrigation schedules							
ETc 0.8	4219	4622	8647	48.8	13.43	1.30	20.94
ETc 1.0	5137	5571	10757	47.7	13.69	1.34	22.78
ETc 1.2	5465	5783	11392	48.0	13.21	1.37	22.34
SEm (±)	81.77	76.73	174.8	0.62	0.28	0.027	0.620
CD (P = 0.05)	235.5	221.0	510	NS	NS	NS	1.79
Nitrogen fertilization							
75% RDN (90 kg N ha^{-1})	4751	4946	9892	48.0	12.93	1.29	21.01
100% RDN (120 kg N ha^{-1})	4981	5412	10343	48.2	13.57	1.35	22.28
125% RDN (150 kg N ha^{-1})	5088	5618	10561	48.2	13.84	1.38	22.77
SEm (±)	50.41	64.78	99.6	0.13	0.18	0.015	0.384
CD (P = 0.05)	142.1	182.6	281	NS	NS	0.06	1.08

HI = harvest index; WUE = water-use efficiency; ETc = crop evapotranspiration; RDN = recommended dose of nitrogen; SEm = standard error of the mean; CD = critical difference; NS = non-significant

3.4 Economics

Net returns, the B:C ratio and economic efficiency were significantly affected by tillage practices. Zero tillage increased net returns, the B:C ratio and economic efficiency by 9.19%, 25.6% and 9.16%, respectively, compared with conventional tillage. This may be attributable to greater soil-organic-carbon content, improved soil-moisture availability and lower cultivation costs under zero tillage. Net returns, the B:C ratio, production efficiency and economic efficiency were highest under irrigation at 1.2 ETc, exceeding those at 0.8 ETc by 40.5%, 35.2%, 29.5% and 40.5%, respectively, and those at 1.0 ETc by 8.38%, 8.33%, 6.37% and 8.38%, respectively (Table 3). This may be attributable to higher wheat production under adequate soil-moisture availability. Under nitrogen management, 100% RDN also produced significantly higher net returns (Rs. 82,738/ha), B:C ratio (3.03), production efficiency (35.58 kg/ha/day) and economic efficiency (Rs. 591.1/ha/day) than 75% RDN (Table 3). These improvements may reflect higher yields under this treatment. The economic importance of irrigation management in wheat has also been reported by Liu *et al.* (2024).

3.5 Nitrogen Uptake

Nitrogen uptake by grain and total nitrogen uptake by the crop were significantly higher under zero tillage than under conventional tillage. This may reflect greater nutrient availability under zero-tillage conditions owing to residue decomposition. Irrigation at 1.2 ETc significantly enhanced nitrogen uptake by grain, straw and the whole crop compared with irrigation at 0.8 and 1.0 ETc. Compared with nitrogen uptake of 65.4 kg/ha by grain, 25.9 kg/ha by straw and 91.53 kg/ha by the whole crop under irrigation at 0.8 ETc, irrigation at 1.2 ETc increased uptake by 35.8%, 40.11% and 37.0%, respectively. Higher nitrogen uptake may be attributable to an effective root system and increased nutrient concentrations in the soil solution.

Table 3. Effect of tillage practices, irrigation schedules and nitrogen fertilization on economics and N uptake of wheat (pooled data of three years

Treatments	Net return (Rs ha^{-1})	B:C ratio	Production efficiency (kg ha^{-1} day^{-1})	Economic efficiency (Rs ha^{-1} day^{-1})	Grain N uptake (kg ha^{-1})	Straw N uptake (kg ha^{-1})	Total N uptake (kg ha^{-1})
Tillage practices							
Zero tillage	85435	3.34	35.80	610.2	80.0	33.0	113.5
Conventional tillage	78242	2.66	34.77	559.0	76.5	31.2	107.8
SEm±	1397	0.05	0.520	12.73	0.240	0.476	0.705
CD (P = 0.05)	4025	0.14	NS	44.1	0.83	NS	2.44
Irrigation schedules							
ETc 0.8	66341	2.50	30.13	474.0	65.4	25.9	91.53
ETc 1.0	85984	3.12	36.69	614.3	80.6	34.1	115.0
ETc 1.2	93190	3.38	39.03	665.8	88.8	36.3	125.4
SEm±	1756	0.07	0.734	15.94	1.57	0.514	2.05
CD (P = 0.05)	5060	0.19	2.14	46.5	4.58	1.50	5.99
Nitrogen fertilization							
75% RDN (90 kg N ha^{-1})	78074	2.91	33.93	557.8	74.0	29.4	103.7
100% RDN (120 kg N ha^{-1})	82738	3.03	35.58	591.1	79.2	33.0	112.6
125% RDN (150 kg N ha^{-1})	84702	3.06	36.34	605.1	81.5	33.9	115.7
SEm±	1086	0.04	0.452	9.97	0.99	0.452	1.41
CD (P = 0.05)	3063	0.11	1.28	28.1	2.78	1.27	3.97

B:C ratio = benefit–cost ratio; ETc = crop evapotranspiration; RDN = recommended dose of nitrogen. SEm± = standard error of the mean; CD = critical difference at P = 0.05; NS = non-significant

Nitrogen fertilisation significantly affected nitrogen uptake by grain, straw and the whole crop. Application of nitrogen beyond 100% RDN did not produce a further statistically significant increase in nitrogen uptake. Increased grain and straw yields, combined with higher nitrogen contents in these plant parts, may account for the higher nitrogen uptake associated with nitrogen fertilisation. These findings are consistent with those of Ali *et al.* (2025).

4. Conclusion

The pooled results of this three-year field experiment indicate that tillage practices, irrigation scheduling and nitrogen fertilisation influenced wheat productivity, profitability and nitrogen uptake under the agroclimatic conditions of south-eastern Rajasthan. Zero tillage maintained grain, straw and biological yields comparable to those under conventional tillage while producing significantly higher net returns, B:C ratio, economic efficiency and nitrogen uptake, suggesting an economic advantage over conventional tillage.

Among the irrigation schedules, irrigation at 1.2 ETc improved growth and yield attributes and produced higher grain, straw and biological yields. It also resulted in the highest net returns, B:C ratio, production efficiency, economic efficiency and nitrogen uptake. However, water-use efficiency and water productivity did not differ significantly among the irrigation schedules. Irrigation at 1.0 ETc resulted in higher water profitability than irrigation at 0.8 ETc. Regarding nitrogen fertilisation, 100% RDN significantly improved growth and yield attributes, grain yield, profitability and nitrogen uptake compared with 75% RDN. Increasing the nitrogen dose to 125% RDN resulted in a marginal, statistically non-significant improvement in grain yield over 100% RDN.

Therefore, zero tillage, irrigation at 1.2 ETc and application of 100% RDN (120 kg N ha^{-1}) may be considered for improving wheat productivity and profitability in the Vertisols of south-eastern Rajasthan. Under limited irrigation-water availability, 1.0 ETc may be considered as an alternative irrigation schedule for maintaining satisfactory productivity with a comparatively lower irrigation requirement.

5. Limitations

The experiment was conducted at one research station over three winter seasons using one wheat variety, which may limit the transferability of the findings to other soils, cultivars and climatic conditions. The presented results emphasise pooled main effects; interaction effects among tillage, irrigation and nitrogen treatments are not reported, limiting direct assessment of particular combinations. Irrigation was supplied from groundwater, and profitability estimates depend on the input and output prices prevailing during the experiment. Multi-location studies incorporating interaction analyses would help establish the wider applicability of these findings.

Declaration of AI Use

This manuscript was prepared through the intellectual contributions of the author(s) to the study design, data analysis, interpretation of results, and scholarly content. Grammarly and ChatGPT were used solely to assist with grammatical refinement and reference formatting during manuscript revision. The author(s) accept full responsibility for the accuracy, integrity, and final content of the manuscript.

Competing Interests

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Ali, A., Singh, M., Bharat, R., Arya, V. M., Dadhich, S. M., Kumawat, S. N., Khajuria, S., Bochalya, R. S., & Kumar, V. (2025). Effect of tillage methods, irrigation and nitrogen management in wheat crop under sub-tropical condition of Jammu and Kashmir. *Agriculture Association of Textile Chemical and Critical Reviews, 13*(2), 66–72. https://doi.org/10.21276/AATCCReview.2025.13.02.66

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). *Crop evapotranspiration: Guidelines for computing crop water requirements* (FAO Irrigation and Drainage Paper No. 56). Food and Agriculture Organization of the United Nations. https://www.fao.org/4/x0490e/x0490e00.htm

Chhokar, R. S., Sharma, R. K., Kumar, N., Singh, R. K., & Singh, G. P. (2023). Advancing sowing time and conservation tillage: The climate-resilient approach to enhance the productivity and profitability of wheat. *International Journal of Plant Production, 17*(1), 121–131. https://doi.org/10.1007/s42106-022-00216-1

Devasenapathy, P., Ramesh, T., & Gangwar, B. (2008). *Efficiency indices for agriculture management research*. New India Publishing Agency. https://www.nipaers.com/book/9788189422882/efficiency-indices-for-agriculture-management-research

Gupta, N., Humphreys, E., Eberbach, P. L., Singh, B., Yadav, S., & Kukal, S. S. (2021). Effects of tillage and mulch on soil evaporation in a dry seeded rice–wheat cropping system. *Soil and Tillage Research, 209*, 104976. https://doi.org/10.1016/j.still.2021.104976

Hyder, S. I., Khan, A., Khan, R. U., Hameed, M. A., Aziz, H., & Abbas, M. (2021). Wheat (*Triticum aestivum* L.) productivity and soil organic matter (SOM) improvement by integrated nutrient management (INM) under irrigated conditions. *Asian Journal of Plant and Soil Sciences, 6*(1), 195–201. https://doi.org/10.56557/ajopss/2021/v6i131

Jackson, M. L. (1973). *Soil chemical analysis*. Prentice-Hall of India. https://spices.res.in/opac/cgi-bin/koha/opac-detail.pl?biblionumber=179

Jha, A. K., Kewat, M. L., Upadhyay, V. B., & Vishwakarma, S. K. (2011). Effect of tillage and sowing methods on productivity, economics and energetics of rice (*Oryza sativa*)–wheat (*Triticum aestivum*) cropping system. *Indian Journal of Agronomy, 56*(1), 35–40. https://doi.org/10.59797/ija.v56i1.4666

Liu, X., Liu, J., Huang, C., Liu, H., Meng, Y., Chen, H., Ma, S., & Liu, Z. (2024). The impacts of irrigation methods and regimes on the water and nitrogen utilization efficiency in subsoiling wheat fields. *Agricultural Water Management, 295*, 108765. https://doi.org/10.1016/j.agwat.2024.108765

Paul, T., Bisht, P. S., Pandey, P. C., Barman, A., Bhattacharjya, S., Saha, T., & Nath, C. P. (2014). Rice productivity and nutrient-use efficiency as influenced by nutrient management in long-term rice (*Oryza sativa*)–wheat (*Triticum aestivum*) system. *Annals of Agricultural Research, 35*(2), 171–175. https://epubs.icar.org.in/index.php/AAR/article/view/42189

Pratap, V., Dass, A., Krishnan, P., Sudhishri, S., Choudhary, A. K., Bhatia, A., Jinger, D., Verma, S. K., Singh, A., San, A. A., Nithinkumar, K., Sachin, K. S., Kumari, K., Sadhukhan, R., Kumar, S., Paramesha, V., Singh, T., Kaur, R., & Yadav, S. P. (2025). Precision nitrogen and water management in double zero-till wheat: Effects on photosynthetic parameters, productivity, nutrient-use efficiency and N_2O emission. *Frontiers in Plant Science, 16*, 1654933. https://doi.org/10.3389/fpls.2025.1654933

Priya, S., Singh, M. K., Kumar, B., Kumar, S., Pal, A. K., Kumar, R., Srivastava, J. N., & Kumari, S. (2025). Influence of conservation tillage practices and irrigation levels on nutrient dynamics and uptake in wheat. *International Journal of Environment and Climate Change, 15*(8), 343–350. https://doi.org/10.9734/ijecc/2025/v15i84978

Rajanna, G. A., Dass, A., Venkatesh, P., Choudhary, A. K., Upadhyay, P. K., Chandrashekar, A. B., Francaviglia, R., Sannagoudar, M. S., Rangappa, U. M., Singh, V. K., Harish, M. N., & Shyam, C. S. (2024). Soil moisture dynamics, rooting traits, crop and water productivity of wheat under different tillage, irrigation and nutrition conditions. *Farming System, 2*(2), 100087. https://doi.org/10.1016/j.farsys.2024.100087

Shekhar, C., Singh, D., Singh, A. K., Nepalia, V., & Choudhary, J. (2014). Weed dynamics, productivity and soil health under different tillage and weed-control practices in wheat (*Triticum aestivum*)–maize (*Zea mays*) cropping sequence. *Indian Journal of Agronomy, 59*(4), 561–567. https://doi.org/10.59797/ija.v59i4.4597

Singh, R., & Kumar, A. (Eds.). (2011). *Manual on enhancing water use efficiency in canal commands*. Directorate of Water Management, Indian Council of Agricultural Research. https://www.scribd.com/document/694157899/Enhancing-Water-Use-Efficiency-in-Canal

Singh, V. (2006). Productivity and economics of rice (*Oryza sativa*)–wheat (*Triticum aestivum*) cropping system under integrated nutrient-supply system in recently reclaimed sodic soil. *Indian Journal of Agronomy, 51*(2), 81–84. https://doi.org/10.59797/ija.v51i2.4976

Ziaeyan, A., Mousavi, S. M., Moradi, A., Karami, A., Zaraeian, G., & Ziaeian, M. (2020). Effects of different tillage systems, nitrogen and irrigation on growth indicators and water productivity of wheat (*Triticum aestivum*). *The Indian Journal of Agricultural Sciences, 90*(8), 1616–1621. https://doi.org/10.56093/ijas.v90i8.105978

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