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# Residue and Irrigation Management for Optimizing Productivity and Profitability of Wheat in Ambala (Haryana)

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## ABSTRACT

**Background:** The rice-wheat cropping system in Haryana, Western Uttar Pradesh and Punjab faces sustainability risks due to soil fertility depletion, rising cultivation costs and environmental pollution hazards because of the large-scale burning of rice crop residues. Two-year field experiments investigated wheat sowing techniques by keeping rice crop residues under various irrigation schedules to optimize production and economic outcomes in Ambala, Haryana. Three sowing methods, *i.e.*, conventional sowing (CS), Happy Seeder (HS) and Super Seeder (SS) and four irrigations scheduling, *i.e.*, scheduling at critical growth stages ($IS_1$), IW/CPE ratio 0.9 with first irrigation at CRI ($IS_2$), IW/CPE ratio for whole crop season ($IS_3$) and depletion of 50% available soil moisture ($IS_4$).

**Methods:** Happy Seeder sown wheat exhibited a significantly higher average yield of 58.38 q $ha^{-1}$ than conventional (57.69 q $ha^{-1}$) and Super seeder (56.85 q $ha^{-1}$) sown wheat. Overall, Happy Seeder and irrigation schedule ($IS_3$) produces the highest grain yield of 65.23, 63.56 and 64.40 q $ha^{-1}$ in the first, second year and pooled year results. In conventional sowing of wheat, the average total cultivation cost was 107134.02 and 110907.71 Rs $ha^{-1}$, which was less in Happy Seeder sown wheat, *i.e.*, 99077.07 and 102932.27 Rs. $ha^{-1}$ respectively, in the year 2021-22 and 2022-23.

**Result:** The average benefit-cost ratio (BCR) for the happy seeder technique, 1.42 and 1.44, outperforms the conventional sowing wheat approach during both years of experiments. The recent wheat sowing using happy seeder under residue mulching conditions, must adopt modified irrigation scheduling practices to enhance yield and profitability, contributing to sustainable agricultural practices. The study highlights the potential of recent agricultural practices to boost farmer income, promote sustainable agricultural growth and environment conservation.

**Key words:** Economics, Irrigation scheduling, Productivity, Residue management, Wheat.

## INTRODUCTION

India, an emerging economy on the global platform, is the most populous country, sheltering 17.5 per cent of the population and occupying only 2.40 per cent of the world's area (Mandal, 2021). The residential land has increased in tandem with population growth, which has increased pressure on available cultivated land to generate adequate sustenance in the form of food grains to feed the burgeoning population. Intensive agriculture is necessary to feed an enormous population on limited land and natural resources. In Haryana, Punjab and western Uttar Pradesh (UP), the cropping pattern seems to have significantly changed during the Green Revolution period from conventional crops, including maize, pearl millet, pulses and oilseeds to rice-wheat (Anuradha *et al*., 2022). The paddy-wheat cropping system in India's Indo-Gangetic Plains, particularly in the northwest states of Haryana, Punjab, Uttarakhand and western Uttar Pradesh, covers approximately 4.1 million hectares (m ha) (NAAS, 2017). Currently, Haryana and Punjab comprise the most productive rice-wheat regions in the IGP, accounting for over 69% of the nation's total food output, consisting of nearly 84% wheat and 54% rice (Singh *et al*., 2022).

Cereal-cereal sequences are widely recognized as more demanding on soil resources, laborious and unsustainable compared to cereal-oilseed and cereal-legume sequences (Banjara *et al*., 2021). Long-term use of the same practice raises alarming issues regarding adverse effects on soil conditions (Bhatt *et al*., 2016), extensive tillage activities are carried out to plant the subsequent crop requires considerable resources in the form of labor and fuel after harvesting rice (Banjara *et al*., 2019), serious concerns about the environment degradation, loss of biodiversity and food security (Sheng *et al*., 2018). Conventional farming techniques and the incineration of crop leftovers on farms have led to a deterioration in the soil ecosystem and quality of the air, a falling groundwater level and elevated cultivation expenses (Jat *et al*., 2020). Continuous adoption of these practices enhances soil

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strength, decreases groundwater recharge, lowers infiltration rates and hydraulic conductivity, leading to stagnation of water at the soil surface, inadequate root growth and artificial stress of moisture, leading to decreased productivity of wheat crop (Radheshyam *et al*., 2024). Traditionally, rice has been transplanted by wet tillage after ponding water in Kharif (summer) and succeeded by planting wheat in Rabi (winter) after burning the rice crop residues (RCRs). As a consequence, the continuing implementation of the R-W system has generated a hardened soil layer near the root zone, which inhibits penetration and development of crop roots, consequently affecting the growth of the succeeding crop wheat (Dhanda *et al*., 2022).

Since the mid-1980s, the introduction of combine harvesters has supplanted the human harvesting method, leaving a significant amount of RCRs distributed and anchored remnants on the surface of the field (Singh *et al*., 2024). Furthermore, because of higher silica content, poor digestibility, low palatability and insufficient protein, RCR is not an acceptable feed for animals (Thakur *et al*., 2018). The rice crop residues impede the cultivation and planting of succeeding crop wheat by which nearly 2 million growers in the northwestern region (Haryana and Punjab) and an estimated 23 million tons (mt) of RCRs burn annually in various parts of eastern India (NAAS, 2017). Managing rice residue is particularly difficult mainly due to the shorter time-frame between harvesting of rice and sowing of the following crop wheat, the costlier residue handling machinery, the laborious process of residue disposal and the absence of infrastructure for generating energy and storage (Kumar *et al*., 2021). Thus, farmers in NW India resort to the expensive and unsustainable practice of burning residue to plant wheat in combined harvested rice fields. Continuous burning of such huge amounts of agricultural residues results in a significant loss of biodiversity and nutrients, ultimately raising the fertilizer input costs and reducing crop productivity and fertility in soil (Venkatramanan *et al*., 2021).

With continuous efforts, the researchers have developed and demonstrated several potential technological options to stop infield residue burning, including mulching and incorporating residue while wheat sowing after rice harvest. Happy Seeder can plant wheat with zero-tillage technique while mulching the whole amount of RCRs on the field's surface. For complete mixing of the rice crop residues, simultaneous drilling of wheat can be successfully achieved by the Super Seeder. Another sowing option, the Smart Seeder, was developed more recently. It uses strip-till technology for wheat sowing, which enables it to partly incorporate and mulch the RCRs into and at the surface of the soil, respectively. The developmental phases of wheat need adequate moisture in soil for proper development and growth require scheduling of irrigation (Meena *et al*., 2018). A particular irrigation scheduling technique can be suitable for a specific crop under conventional sowing conditions, but that may not apply under recent sowing conditions with residue management combinations. Limited information on irrigation scheduling in wheat for residue management is available compared to scheduling irrigation in conventional wheat sowing. Therefore, the research investigates the impact of various wheat sowing technologies and irrigation scheduling on productivity and production cost economics under different residue management techniques.

## MATERIALS AND METHODS

### Experimental site

Field experiments were carried out in 2021-22 and 2022-23 *Rabi* (two years, winter) at the farm of Krishi Vigyan Kendra, Ambala (30°18′15.0″N 76°55′48.5″E) Haryana, India, to investigate the impact of wheat establishment techniques and irrigation scheduling on grain production and production cost economics. The experimental location has a semiarid sub-tropical with a hot and wet summer environment with an average annual rainfall of 1000-1100 mm, with 75-80% of this rainfall occurring in the months of July and September. The site had been under a rice-wheat cropping system for the previous 15 years using conventional wet puddling and burning rice crop residues for wheat sowing. The soil texture of the experimental field was clay loam, slight alkaline pH, normal electrical conductivity, low organic carbon, available potassium, available nitrogen and medium in available phosphorus.

### Experimental set-up

The field investigation consisted of three wheat establishment techniques: $T_1$- Conventional Tillage and sowing, $T_2$- Happy Seeder and $T_3$-Super Seeder as main plot treatments. The subplot treatments of irrigation scheduling were ($I_1$) crop growth stages, ($I_2$) climatological approach in which the ratio of applied irrigation water (IW) to the cumulative pan evaporation minus rain reached 0.9, *i.e.* IW/(CPE-rain) ratio of 0.9 with first irrigation at the CRI stage, ($I_3$) IW/(CPE-rain) ratio of 0.9 for whole crop season and ($I_4$) depletion of 50% available soil moisture (DASM). A total of 60 mm of water was given with each irrigation in both years of the trial. Whole RCRs were burned, mulched and incorporated using conventional, Happy Seeder and Super Seeder techniques of wheat sowing, respectively. Wheat stubbles were left out using a straw reaper after combined harvesting in all the treatments. The field investigation was arranged using a split-plot design involving three replications, each plot measuring 140 $m^2$ (7 m×20 m). Table 1 presents the treatment specifics of different wheat establishment and scheduling of irrigation strategies.

### Crop management

The wheat variety DBW-187 was sown on November 6$^{th}$ and 10$^{th}$ in 2021-22 and 2022-23, respectively. The seed rate was 112.5 kg $ha^{-1}$, with 22.5 cm inter-row spacing and

treated to prevent termite damage and other root-damaging insect pests with Chlorpyriphos 20 EC (4 ml $kg^{-1}$ seed). At sowing, full doses of phosphorus (DAP, 137.5 kg $ha^{-1}$), potassium (MOP, 50 kg $ha^{-1}$) and zinc (zinc sulphate, 25 kg $ha^{-1}$) fertilizers were applied as basal by drilling and broadcasting. Half of the nitrogen was broadcasted during sowing and the remaining was used 25-30 days after sowing (Urea, 275 ka $ha^{-1}$) as standard practice for fertilizer application during the experiment. Irrigations (60 mm depth each) were applied as per the scheduling. For control of both broadleaf and grassy weeds, tank mix solutions of 375 liter water, metsulfuron (Algrip 20 WP) (25 g $ha^{-1}$) and clodinafop (Topik 15 WP) 400 g $ha^{-1}$ was sprayed at 30-35 days after sowing. The crop was sprayed at the booting stage with 500 ml $ha^{-1}$ of Tilt 25 EC (propiconazole) to prevent yellow rust and once, during the earing stage, with 375 ml $ha^{-1}$ of Rogor 30 EC (dimethoate) to control aphids. Both research years it involved manual harvesting of the crop in April.

### Production economics

The economics of wheat establishment techniques were assessed in budgetary analysis by figuring out the cultivation costs (Rs $ha^{-1}$) associated with different farm inputs, such as field preparation, seeds, fertilizers, custom hiring charges on sowing and harvesting, irrigation, labor costs, plant protection chemicals and interest on working capital (9%), which is also termed as the variable cost of cultivation (Esar *et al*., 2023). Adding outcomes from the multiplication of the grains and straw output with current market prices obtained the gross returns (GR, Rs $ha^{-1}$). Net returns (NR, Rs $ha^{-1}$) were determined by subtracting cultivation cost from gross return (Singh *et al*., 2023). The benefit-cost ratio (BCR) was determined using establishment techniques, gross returns and cultivation costs.

## RESULTS AND DISCUSSION

### Grain and straw yield

The impact of three sowing methods and four irrigation schedules on grain and straw yield was assessed during two consecutive growing seasons (2021-22 and 2022-23). The findings are reported with statistical significance evaluated at a significance level of 5% (Table 2). In the individual years, the conventional sowing method produced a significantly higher grain yield of 59.08 q $ha^{-1}$ in 2021-22. Happy Seeder sown wheat had a significantly higher yield of 58.43 q $ha^{-1}$ in 2022-23. The wheat planting with Super Seeder resulted in the lowest pooled grain yield of 56.85 q $ha^{-1}$ with 58.01 and 55.69 q $ha^{-1}$, respectively, in 2021-22 and 2022-23. Overall, Happy Seeder sown wheat exhibited a significantly higher average yield of 58.38 q $ha^{-1}$ than conventional (57.69 q $ha^{-1}$) and Super seeder (56.85 q $ha^{-1}$) sown wheat. Likewise, conventional and Happy Seeder sown wheat produced significantly equal pooled straw yields of 76.98 and 77.65 q $ha^{-1}$, while it was 75.59 q $ha^{-1}$ in Super seeder. Keeping crop residue as mulching in wheat sowing is substantially helpful in enhancing yield attributes and overall grain yield using Happy Seeder techniques (Puniya *et al*., 2023).

In the first year of study, the grain yield was at par in the $IS_2$ and $IS_3$, *i.e*., 60.28 and 60.17 q $ha^{-1}$, significantly higher than obtained in 54.8 and 58.65 q $ha^{-1}$ in $IS_1$ and $IS_4$, respectively. The irrigation scheduling at critical growth stages ($IS_1$) produced a higher grain yield of 57.66 in 2022-23. The remaining three irrigation scheduling practices gave almost equal grain yields in 2022-23. Whereas, in the pooled results, scheduling of first irrigation at CRI stage than at IW/CPE ratio ($IS_2$) for the rest of the crop season and IW/CPE (0.9) ratio for the whole crop season ($IS_3$) were produced significantly higher and equivalent grain yields, *i.e*., 58.37 q $ha^{-1}$ and 58.22 q $ha^{-1}$ respectively. Similarly, IS2, IS3 and IS4 produced equivalent pooled straw yields of 77.86, 77.11 and 76.94 q $ha^{-1}$, remarkably outperforming $IS_1$ 75.03 q $ha^{-1}$.

### Cost of cultivation

The sale price of the wheat grain was 2015 and 2125 Rs $quintal^{-1}$, respectively, in 2021-22 and 2022-23. An economic analysis has been conducted on the cost of cultivation associated with various sowing techniques, focusing on

**Table 1:** Description of the sowing methods and irrigation scheduling.

| Treatments | Wheat sowing methods (Main plot) |
|---|---|
| CS | Paddy harvesting without SMS fitted combine, RCRs were burned, followed by field preparation and line sowing of wheat. |
| HS | Paddy harvesting with SMS fitted combine, zero tillage wheat sowing by Happy Seeder and whole of the RCRs were mulched. |
| SS | Paddy harvesting with SMS fitted combine, tillage cum line sowing of wheat by Super Seeder and incorporation of RCRs. |
| | **Irrigation scheduling (Sub plot)** |
| $IS_1$ | Irrigation scheduling is based on 4 crop growth stages (CRI, late tillering, flowering and milking stage). |
| $IS_2$ | Irrigation scheduling at IW/(CPE-rain) ratio (0.9) with first irrigation at CRI stage. |
| $IS_3$ | Irrigation scheduling when ratio of IW/(CPE-rain) reached 0.9 for the whole crop season. |
| $IS_4$ | Irrigation scheduling on depletion of available soil moisture (DASM 50%). |

critical inputs during 2021-22 and 2022-23 in Ambala. The present study compares three different wheat sowing techniques: conventional sowing, happy seeder and super seeder (Table 3). The present study briefly assesses the costs associated with various sowing methods of wheat and highlights important patterns. The cost of preparatory tillage for the Conventional wheat sowing in 2021-22 was notably much higher at Rs 7425, in contrast to Rs 750 $ha^{-1}$ for both the Happy Seeder and Super Seeder methods of wheat sowing. In 2022-23, the difference persists, with Conventional tillage incurring a cost of Rs 7485, compared to Rs 875 $ha^{-1}$ for the other two approaches of wheat establishment. The cost incurred on preparatory tillage was extra charges paid to the SMS-fitted combine harvesting of paddy in haapy seeder and super seeder sowing of wheat. Conventional tillage is much more costly than the Happy Seeder and Super Seeder methods of wheat establishment.

Seed and seed treatment costs remain consistent across sowing techniques in both years, at Rs 3350 and Rs 3475 $ha^{-1}$ for 2021-22 and 2022-23, respectively. Similarly, the costs related to fertilizers and application remain consistent across all sowing techniques, amounting to Rs 9722.50 in 2021-22 and then declining slightly to Rs 9660.00 in 2022-23 due to lower prices of phosphatic

**Table 2:** Impact of sowing methods irrigation scheduling on grain and straw yields (q $ha^{-1}$).

| Treatments | Grains yield (q $ha^{-1}$) | | | Straw yield (q $ha^{-1}$) | | |
|---|---|---|---|---|---|---|
| | 2021-22 | 2022-23 | Pooled | 2021-22 | 2022-23 | Pooled |
| | | | **Sowing methods** | | | |
| CS | 59.08a | 56.30b | 57.69b | 76.80a | 77.16ab | 76.98a |
| HS | 58.34b | 58.43a | 58.38a | 75.75b | 79.54a | 77.64a |
| SS | 58.01b | 55.69b | 56.85c | 75.41c | 75.76b | 75.59b |
| SEm (±) | 0.0847 | 0.4181 | 0.2133 | 0.0709 | 0.6133 | 0.3087 |
| CD @ 5% | 0.3326 | 1.6417 | 0.6956 | 0.2784 | 2.4081 | 1.0067 |
| | | | **Irrigation scheduling** | | | |
| $IS_1$ | 54.80c | 57.66a | 56.23c | 71.25c | 78.81a | 75.03b |
| $IS_2$ | 60.28a | 56.46b | 58.37a | 78.35a | 77.37ab | 77.86a |
| $IS_3$ | 60.17a | 56.26b | 58.22ab | 78.11a | 76.12b | 77.11a |
| $IS_4$ | 58.65b | 56.83ab | 57.74b | 76.23b | 77.65a | 76.94a |
| SEm (±) | 0.1887 | 0.3166 | 0.1843 | 0.2745 | 0.5105 | 0.2898 |
| CD @ 5% | 0.5607 | 0.9407 | 0.601 | 0.8156 | 1.5168 | 0.9451 |

**Table 3:** Average wheat cultivation cost in Ambala (Pooled data, 2021-22 and 2022-23).

| Inputs | Conventional sowing | Happy seeder | Super seeder | Conventional sowing | Happy seeder | Super seeder |
|---|---|---|---|---|---|---|
| | | 2021-22 | | | 2022-23 | |
| Preparatory tillage | 7425.00 | 750.00 | 750.00 | 7485.00 | 875.00 | 875.00 |
| Sowing | 3250.00 | 3750.00 | 5750.00 | 3250.00 | 3750.00 | 5750.00 |
| Seed and seed treatment | 3350.00 | 3350.00 | 3350.00 | 3475.00 | 3475.00 | 3475.00 |
| Fertilizer and application | 9722.50 | 9722.50 | 9722.50 | 9660.00 | 9660.00 | 9660.00 |
| Irrigation | 2250.00 | 2000.00 | 2250.00 | 3250.00 | 3000.00 | 3250.00 |
| weedicide and application | 3212.50 | 3212.50 | 3212.50 | 3412.50 | 3412.50 | 3412.50 |
| P.P. Chemical and application | 3302.50 | 3302.50 | 3302.50 | 3332.50 | 3332.50 | 3332.50 |
| Harvesting and threshing | 15840.00 | 15840.00 | 15840.00 | 16500.00 | 16500.00 | 16500.00 |
| Interest on working capital @ 9% for six months | 2175.86 | 1886.73 | 1987.98 | 2266.43 | 1980.23 | 2081.47 |
| **(A) Variable Cost** | **50528.36** | **43814.23** | **46165.48** | **52631.43** | **45985.23** | **48336.47** |
| Transportation | 1500.00 | 1500.00 | 1500.00 | 1500.00 | 1500.00 | 1500.00 |
| Management charges @ 10% | 5052.83 | 4381.42 | 4616.54 | 5263.14 | 4598.52 | 4833.64 |
| Risk factor @ 10% | 5052.83 | 4381.42 | 4616.54 | 5263.14 | 4598.52 | 4833.64 |
| Rental value of Land | 45000.00 | 45000.00 | 45000.00 | 46250.00 | 46250.00 | 46250.00 |
| **(B) Fixed cost** | **56605.66** | **55262.84** | **55733.08** | **58276.28** | **56947.04** | **57417.28** |
| **(C) Total cost** | **107134.02** | **99077.07** | **101898.56** | **110907.71** | **102932.27** | **105753.75** |

fertilizers. Variability in irrigation expenses is seen across different sowing methods as the conventional method incurred higher irrigation costs of Rs 2250. In contrast, the Happy Seeder and Super Seeder methods generated irrigation costs of Rs 2000 and Rs 2250, respectively. Conventional irrigation expenses rose to Rs 3250, Happy Seeder expenses to Rs 3000 and Super Seeder expenses remained at Rs 3250. The expenses associated with weedicide and application continue to be similar across all available ways annually, totaling 3212.50 Rs $ha^{-1}$ in 2021-22 and 3412.50 in 2022-23, respectively. Annually, the weedicide and application costs varied from 3212.50 in 2021-22 and slightly higher to 3412.50 Rs $ha^{-1}$ in 2022-23.

Similarly, across sowing methods, the expenditures for harvesting and threshing amount to 15840 in 2021-22 and 16500 Rs $ha^{-1}$ in 2022-23. Including the costs incurred from field preparation to harvesting and threshing, the average costs were 48352.50, 41297.50 and 44177.50 Rs. $ha^{-1}$ in conventional sowing, Happy Seeder and Super Seeder, respectively. Up to this point, the computed expenses working capital interest @ 9% for six months (crop duration) were included and the resulting value was assigned as the variable cost of cultivation. Happy Seeder consistently demonstrates the lowest average variable costs in 2021-22 and 2022-23, amounting to 43814.23 and 45985.23 Rs $ha^{-1}$, respectively. On the other hand, Super Seeder produces average cultivation costs ranging from 46165.48 to 48336.47 Rs $ha^{-1}$ during the first and second years. However, the conventional wheat sowing method claims the highest cultivation costs, *i.e.*, 50528.36 and 52631.43 Rs $ha^{-1}$, during both the years of study.

The average fixed cultivation costs varied from 55262.84 to 56947.04 Rs $ha^{-1}$ in Happy seeder, lower than Conventional and Super Seeder fixed costs. Consequently, the cost ranges from 56605.66 to 58276.28 Rs $ha^{-1}$ and 55733.08 to 57417.28 Rs $ha^{-1}$ in conventional and Super Seeder sown wheat. These fixed costs included the management charges and risk factor @ 10% of variable costs, fixed actual transportation cost and rental value of the land for six months. Overall, the cost of wheat cultivation under conventional techniques, such as happy seeder and super seeder, is shown in Table 3. The findings showed that the average total cost of cultivation per hectare in traditional wheat sowing was 107134.02 and 110907.71 Rs $ha^{-1}$, which was estimated to be less in Happy Seeder sown wheat, *i.e.*, 99077.07 and 102932.27 Rs $ha^{-1}$ in 2021-22 and 2022-23. The comparable outcomes were also observed by Singh *et al*. (2021), on the cost of cultivating wheat crop using conventional and Happy Seeder techniques were 100561.70 and 91708.11 Rs $ha^{-1}$, respectively, in Haryana. The higher cost of cultivation in conventional wheat sowing is mainly due to multiple time cultivations of the land for field preparation after burning of rice crop residues in the field (Kaur *et al*., 2023).

**Economics and benefits**

Fig 1 and Fig 2 provide information on the impact of wheat planting techniques and irrigation scheduling on production costs and benefit-cost ratio (BCR) during 2021-22 and 2022-23. The data on three wheat sowing methods, including conventional, happy seeder and super seeder, included four irrigation schedule treatments ($IS_1$, $IS_2$, $IS_3$ and $IS_4$). The conventional wheat sowing method has inconsistent results depending on the irrigation scheduling in 2021-22. Irrigation scheduling $IS_2$ and $IS_4$ exhibit the highest performance for grain return, gross return, net return and return over variable cost (ROVC). In conventional wheat sowing, gross return, return over variable cost and net return was 147661.00, 97393.89 and 40840.47 in $IS_2$ and 146927.50, 96660.39 and 40106.97 Rs $ha^{-1}$ in $IS_4$ during the first year (2021-22) of the experiment. Both the irrigation schedules attained a benefit-cost ratio (BCR) of 1.38. $IS_1$ had the lowest response across all schedules, having a BCR of 1.24. Whereas, during the 2022-23 experiments, irrigation scheduling $IS_1$ emerges as the most efficient in terms of gross returns of

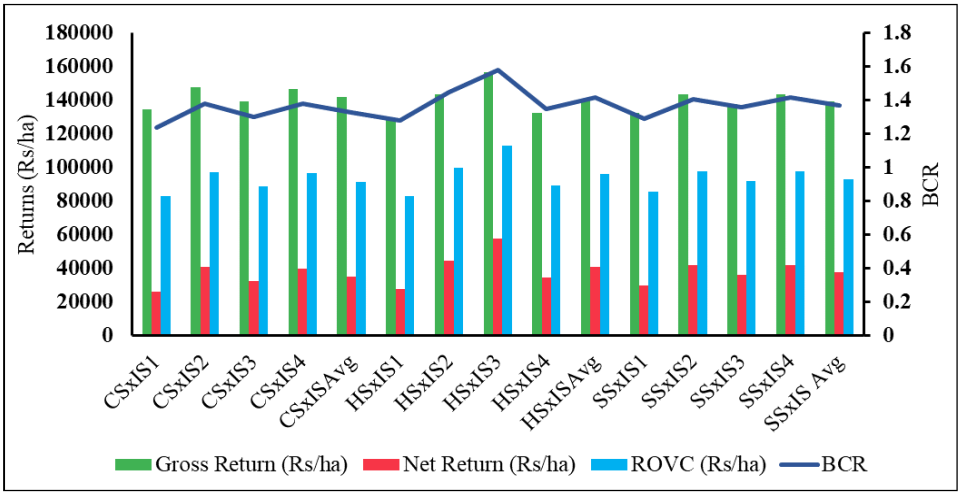


**Fig 1:** Treatment wise economics of the study (2021-22).

151449.75 Rs ha$^{-1}$, returns over variable costs 98034.58 Rs ha$^{-1}$ and net returns 39601.54 Rs ha$^{-1}$. Overall, the average BCR in the conventional wheat sowing method was 1.33 and 1.29 during the first and second years.

Happy Seeder's wheat sowing method demonstrates noticeable yield patterns across different irrigation schedules in the first year of the experiment. In this sowing method, irrigation scheduling $IS_3$ outperforms all other irrigation schedules, showing the highest grain return, gross return, net return and ROVC, *i.e.*, 131438.45 Rs ha$^{-1}$, 156779.45 Rs ha$^{-1}$, 57702.37 Rs ha$^{-1}$ and 112965.21 Rs ha$^{-1}$ respectively. Consequently, during the second year, $IS_3$ again achieved the highest grain and net return of 135086.25 and 57893.98 Rs ha$^{-1}$ with a BCR of 1.56. The average benefit-cost ratio (BCR) for the happy seeder technique, 1.42 and 1.44, outperforms the conventional sowing wheat approach during both years of experiments. Similar findings were also reported that lower production costs were the reason for higher profitability in wheat sown by the Happy Seeder techniques (Radheshyam *et al*., 2024), Leharwan *et al*., 2023). Iqbal *et al*. (2017) have also documented that the happy seeder using zero tillage approach gave the highest net income of 112938 Rs ha$^{-1}$, with a benefit-cost ratio of 1.51 as compared to the net income of 102602 Rs. ha$^{-1}$ and a BCR of 1.33 in the traditional method of wheat cultivation. A new research investigation conducted by Singh *et al*. (2023) also found that the Happy Seeder sowing technique of wheat with residue mulching was profitable due to a higher gross return of 95,788.00 Rs. ha$^{-1}$ and benefit-cost ratio of 1.72, respectively, among all seven different wheat sowing techniques in Punjab.

The super seeder method shows more consistent results across irrigation schedules than the other two sowing methods. In the first year, $IS_4$ performs slightly better than $IS_2$ in this category, with the highest grain return (120,497.00 Rs. ha$^{-1}$, gross return (143,807.00 Rs. ha$^{-1}$, net return (42,221.92 Rs. ha$^{-1}$ and ROVC (97,902.76 Rs. ha$^{-1}$. However, $IS_2$ and $IS_4$ have similar BCRs at 1.41 and 1.42, respectively. Meanwhile, in 2022-23, $IS_1$ produced the highest gross return of 148008.75 and net return of 41314.48 Rs. ha$^{-1}$, supported by a BCR of 1.39. However, $IS_3$ marks the lowest BCR of 1.25, indicating the need for optimization in irrigation scheduling. The average benefit-cost ratio (BCR) for the super seeder technique was 1.37 and 1.33 during the experiments. During the same study period, Bishnoi *et al*. (2023) compared the conventional and super seeder wheat sowing methods. Higher net return and BCR were observed in Super Seeder sown wheat, *i.e.* 18724.44 Rs ha$^{-1}$ and 2.91, compared to 7688.95 Rs. ha$^{-1}$ and 2.64 obtained using the conventional wheat sowing.

The Individual and pooled interaction on sowing methods and irrigation scheduling during the first and second year has been represented in the figure (Fig 3). It shows that the combination of wheat planted with the Happy Seeder and irrigation schedule ($IS_3$) produces the highest grain yield 65.23, 63.56 and 64.40 q ha$^{-1}$ respectively in the first, second year and pooled year results. Conversely, wheat sowing with the conventional method and Super Seeder combined with irrigation schedule ($IS_3$, IW/CPE ratio 0.9 for whole crop season) and Happy Seeder with traditional irrigation scheduling practices, *i.e.*, on critical growth stages, produces the lowest grain yield, *i.e.*, 55.56, 54.70 and 54.08 q ha$^{-1}$ in the pooled year data. Higher soil moisture storage at the harvest of wheat represents the retention of rice residue during the wheat sowing, which is helpful in the availability of higher soil moisture between the irrigations and enhances crop yields (Kumar *et al*., 2024). Meena *et al*. (2018) also highlighted that maintaining residue on the surface enhances aggregate stability, augments organic matter and consequent infiltration, conserves soil moisture and promotes better crop nutrient availability, among the key factors contributing to improved wheat yields.

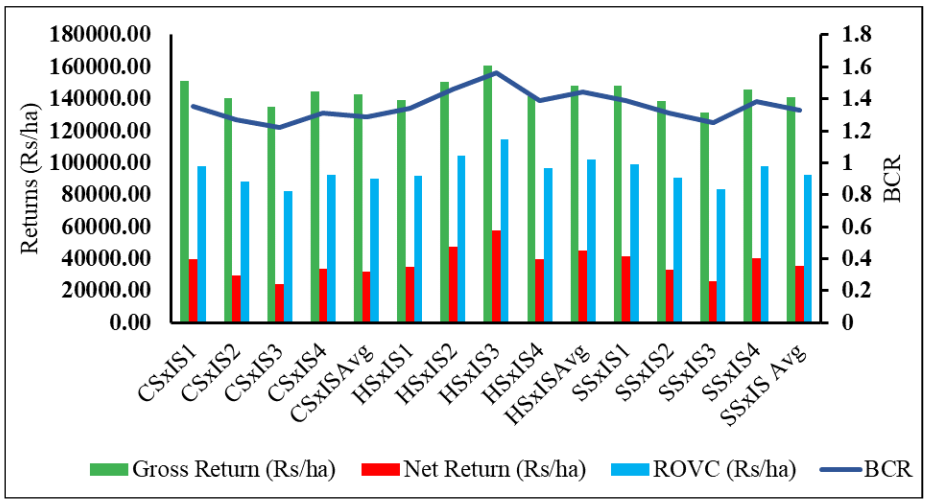


**Fig 2:** Treatment wise economics of the study (2022-23).

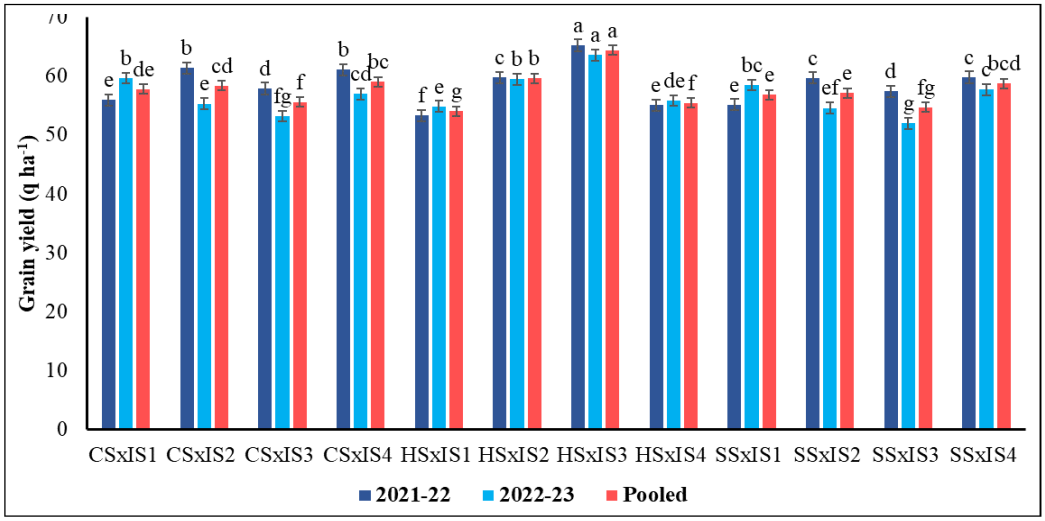


**Fig 3:** Grain yield interaction in sowing methods and irrigation scheduling.

The significant variation among various combinations emphasizes the necessity of choosing an appropriate planting technique and irrigation schedule to optimize the intended result. It has also been noticed that, across all sowing methods, irrigation scheduling at critical growth stages followed by most of the wheat growing farmers in north India consistently showed the lowest economic performance, suggesting that this irrigation schedule may not be optimal for wheat production in the given conditions. The research indicates that customized agricultural techniques, including planting and irrigation methods, are essential for enhancing crop yield. Hence, irrigation scheduling is crucial in improving grain yield and determining the economic outcomes of wheat production, regardless of the sowing method used. The Happy Seeder method, particularly when combined with irrigation scheduling based on IW/CPE ratio of 0.9 for the whole crop season, appears to be the most economically efficient approach for wheat cultivation under residue mulching conditions. Singh *et al*. (2011) also emphasized the importance of scheduling irrigation, especially in mulched conditions, similar to wheat sowing with Happy Seeder.

## CONCLUSION

The study assessed the impact of three sowing methods and four irrigation schedules on grain and straw yield during two consecutive growing seasons. Results showed that the Happy Seeder sown wheat produced significantly higher yields. The research revealed that the average fixed cultivation expenses for wheat using innovative methods, such as Happy Seeder and Super Seeder, were lower than those incurred using conventional wheat sowing techniques. The elevated costs associated with traditional wheat planting mainly arise from the repeated land cultivations required for field preparation after burning rice crop residues. In conclusion, this study highlights the importance of selecting the right combination of sowing methods and irrigation schedules in wheat cultivation. This study particularly highlights that conventional wheat sowing methods are profitable under conventional irrigational scheduling practices adopted mainly by farmers. However, innovative wheat sowing methods, especially under residue mulching conditions like the Happy Seeder, must adopt modified irrigation scheduling practices to enhance yield and profitability, contributing to sustainable agricultural practices. This analysis provides crucial insights for farmers and stakeholders in making informed decisions for future wheat cultivation strategies, emphasizing the advancement of wheat sowing techniques to address productivity and economic considerations in the rice-wheat cropping system.

### Conflict of interest

All author declare that they have no conflict of interest.

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