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Effect of Residue Management and Irrigation Scheduling on Grain Yield and Water Productivity of Wheat in North-West India

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ABSTRACT

Background: The continuous farming of cereal-cereal (rice-wheat) cropping sequence and crop residue burning has resulted in soil health degradation, environmental pollution, stagnation of yield and shrinking groundwater resources. The management of rice crop residues (RCRs) could be helpful in the enhancement of soil properties and agriculture output. The two-year experiments were conducted to assess the effects of keeping residue and irrigation scheduling strategies on soil properties, crop yield and water productivity.

Methods: The study used three wheat establishment techniques: Conventional tillage (CTW), Happy seeder (HSW) and super seeder (SSW) in main plot fields. In sub-plot fields, four irrigation scheduling strategies were set up, *i.e.* irrigation at crop growth stages (IS_1), climatological approach, IW/(CPE-rain) ratio of 0.9 with first irrigation at the CRI stage (IS_2), IW/(CPE-rain) ratio 0.9 for the entire crop season (IS_3) and 50% available soil moisture depletion (DASM) in the crop root zone (IS_4).

Result: The pooled results indicated that HSW sowing method coupled with IS_3 irrigation scheduling have a significant impact on attributes of yield and crop yield. It has also been observed the highest irrigation water productivity (WPI) was 54.36 kg ha^{-1} mm^{-1} in the HSW sowing method and IS_3 irrigation scheduling practice. The higher returns over variable cultivation cost and benefit-cost ratio (BCR), *i.e.* 99261.40 Rs ha^{-1} and 1.43, respectively, were observed in HSW sowing methods of wheat. The study suggests keeping the RCRs using appropriate machinery and following optimum irrigation scheduling practices to curb residue burning and conserve natural resources for sustainable and profitable farming.

Key words: Crop yield, Irrigation scheduling, Residue management, Water productivity, Wheat.

INTRODUCTION

Rice-wheat (R-W) is the major cereal farming sequence widely cultivated on more than 13.5 million hectares (Mha) for food security in South Asian countries (Gora *et al.*, 2024). Primarily cultivated in sequence, the R-W cropping system has spanned over nearly 9.2 Mha in the Indo-Gangetic Plains of India (Jat *et al.*, 2020). The North-Western (N-W) states, particularly Haryana, Punjab and Uttar-Pradesh, predominantly host this cropping system in IGPs of India. In this region, the sustainability of the R-W cropping sequence is at risk due to stagnation of crop yield and decreasing factor productivity. The situation may worsen due to significantly diminishing soil fertility, damage to natural resources, escalating salt and alkalinity issues, groundwater depletion and a growing prevalence of weeds, insect pests and diseases (Banjara *et al.*, 2021) resulting in reduced benefits due to enhancement in cost incurred on input materials. Traditionally, the rice crop has been cultivated by transplanting the nursery seedlings onto a ponded water field. Moreover, the sowing of subsequent crop wheat in the winter season has been delayed owing to harvesting and cumbersome residue management issues of rice crop. In the N-W states of India, mostly farmers harvest major cereal crops mechanically using combine harvesters (Abdurrahman *et al.*, 2020). This mechanized harvesting leaves high amounts of standing and loose crop residues in swaths over the surface of the field. Given the significant role in animal feed, most wheat residues are removed using a straw reaper following mechanical harvesting. Meanwhile, rice crop residues (RCRs) are considered poor animal feed by farmers in Haryana and Punjab due to their substantial silica content. Thus, farmers generally burn the RCRs over existing farmer fields to clear them for timely wheat planting because residues obstruct field preparation and planting

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implements. The open field burning of RCRs releases greenhouse gases (GHG), toxic pollutants, including particulate matter (PM2.5 and PM10) and volatile organic compounds (VOCs) into the atmosphere (Saini and Bhatt, 2020; Li *et al.*, 2017).

The left-over cereal crop residues retain substantial quantities of nitrogen (N) and phosphorus (P), potassium (K) and sulphur (S) by 25%, 25%, 75% and 50%, respectively, absorbed during their growth period (Mehta *et al.*, 2023). Hence, burning of crop residues in the N-W states resulted in the loss of physical and chemical properties, including soil organic matter, available phosphorus, pore space, water retention capacity, soil moisture, pH and electrical conductivity from soil (Tripathi *et al.*, 2015), which leads to deterioration in soil health, declining groundwater table resulting in continuously decreasing or stagnated crop and water productivity (Bhatt *et al.*, 2021). In this major cereal-cereal cropping sequence, improving irrigation might reduce the release of harmful gases and mitigate the risk of environmental degradation (Sapkota *et al.*, 2020). All developmental phases require optimum moisture in the root zone for optimum development and growth, which may be accomplished by using precision scheduling of irrigation to minimize water losses (Meena *et al.*, 2018). To mitigate the ill effects of RCR burning, researchers developed the Happy Seeder, which can sow wheat using zero-tillage and simultaneously keep the RCR on the field surface (Sidhu *et al.*, 2015). More recently developed, Super Seeder for incorporation and seeding of wheat (Anonymous, 2023). We must evaluate wheat sowing techniques using different residue management techniques and suitable irrigation schedules to address these issues. Developing practical and innovative techniques for sowing methods and scheduling irrigation will help farmers in irrigated areas produce wheat with the optimum water use while managing RCRs to conserve natural resources and the environment.

MATERIALS AND METHODS

Experimental site

The experiments were carried out at the farm of Krishi Vigyan Kendra-Ambala, Haryana (30°18′15.0"N 76°55′48.5"E), in the Rabi season of year 2021 and 2022. Annual rainfall averaging 1000-1100 mm from July to September accounting for 75-80% of this total. The rice and wheat crops were cultivated traditionally for 15 years at experimental location. According to the hydrometer method, the soil (0-15 cm) of the site has clay loam texture with 44.54% sand, 23.95% silt and 31.52% clay (Bouyoucos, 1962). The initial soil samples have pH 8.12, electrical conductivity 0.22 dS m^{-1} (Jackson, 1967), organic carbon 0.32% (Walkley and Black, 1934), available nitrogen 187.63 kg ha^{-1} (Subbiah and Asija, 1956), available phosphorus 13.30 kg ha^{-1} (Olsen *et al.,* 1954) and 1 N ammonium acetate extractable K of 172.13 kg ha^{-1} (Jackson, 1967) before the start of the study. The climatological data on temperature and relative humidity of both growing seasons have been presented in (Fig 1).

Experimental set-up

Three different methods of sowing wheat were used as the main plot treatments in the current study: conventional tillage sowing following residue burning (CTW), zero tillage sowing using Happy Seeder (HSW) with full residue mulching and Super Seeder (SSW) with full residue incorporated in a split-block design. In a subplot measuring 7 m × 20 m (140 m^2), four irrigation scheduling treatments were set up: (IS_1) irrigation at crop growth stages; (IS_2) climatological approach of scheduling irrigation with first irrigation at the CRI stage, followed by scheduling when the ratio of irrigation water (IW) to the cumulative pan evaporation minus rain reached 0.9, *i.e.*, IW/(CPE-rain) ratio of 0.9; (IS_3) scheduling at IW/(CPE-rain) ratio of 0.9 for the entire crop season; and (IS_4) scheduling at 50% available soil moisture depletion (DASM) in the crop root zone.

Crop management

The seed rate of 112.5 kg ha^{-1}, wheat cultivar DBW-187 was planted in rows spaced 22.5 cm apart on November 6th and 10th in the first and second years. Chlorpyrifos 20 EC (4 ml kg^{-1}) was applied to the seeds to protect them from termites and other insect pests that damage roots. Nitrogen was applied (Urea, 275 kg ha^{-1}) in two equal splits, broadcasted before sowing and 25-30 days after sowing. Full doses of zinc (zinc sulphate, 25 kg ha^{-1}), potassium (MOP, 50 kg ha^{-1}) and phosphorus (DAP, 137.5 kg ha^{-1}) were

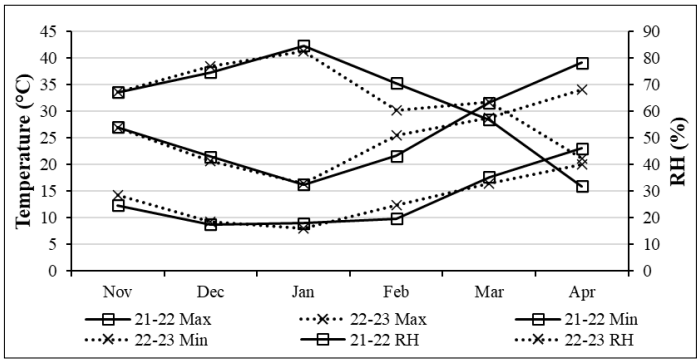


Fig 1: Monthly average maximum and minimum temperature and average relative humidity (2021-22 and 2022-23).

applied during sowing. Topik 15 WP, 400 g ha^{-1} (Clodinafop) and Algrip 20 WP, 25 g ha^{-1} (Metsulfuron) were sprayed 30-35 days after sowing using a tank mix solution of 375 liter water for management of grassy and broadleaf weeds. To prevent yellow rust and aphids, 500 ml ha^{-1} of propiconazole (Tilt 25 EC) and 375 ml ha^{-1} dimethoate (Rogor 30 EC) were sprayed once at the booting and earing stage, respectively.

Data curation and analysis

Periodic soil samples were collected at varying depths weekly and analysed gravimetrically for moisture-based irrigation scheduling. The moisture characteristics in the soil, distribution of soil particles and bulk density from 0-120 cm have also been shown in Fig 2 and Fig 3. Rainfall and evaporation were measured by the non-recording type rain gauge and evaporation pan installed near the experimental site. Daily pan evaporation readings were taken and cumulative totals were computed by deducting rainfall. The monthly data on evaporation and rainfall for the study period is presented in (Fig 4). The irrigations were applied as per plan with 60 mm depth of irrigation in each irrigation during both years of the study. In climatological approach-based scheduling of irrigation, the IW/(CPE-rain) ratio of 0.9 is equivalent to CPE of 67 mm. The moisture content at the permanent wilting point is subtracted from field capacity to determine the available soil moisture (ASM). The obtained critical moisture content was 21.63%, an indicator for moisture-based irrigation scheduling. During the study, the information and data pertaining to various parameters of crop growth and yield

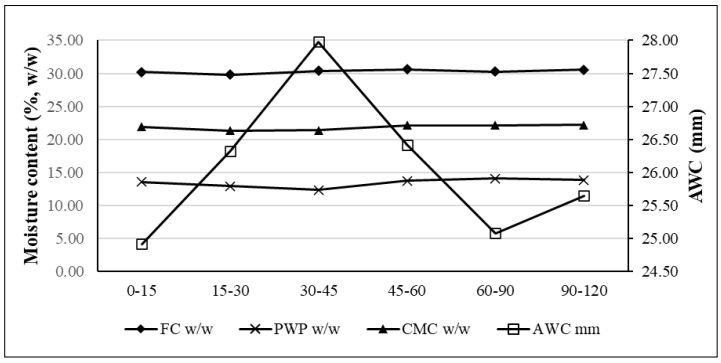


Fig 2: Soil moisture characteristics at different soil depth (cm).

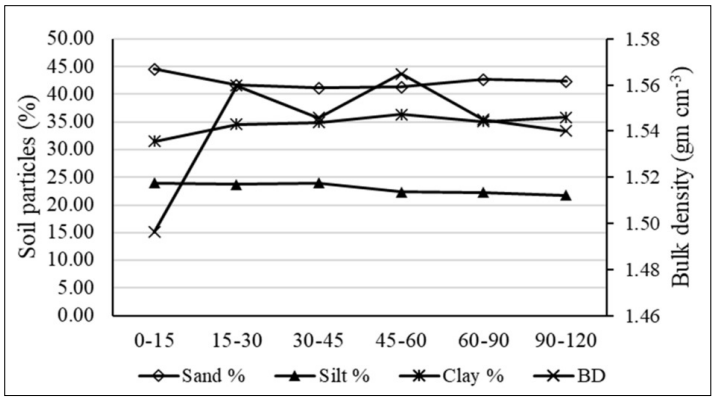


Fig 3: Depthwise distribution of soil particles (%).

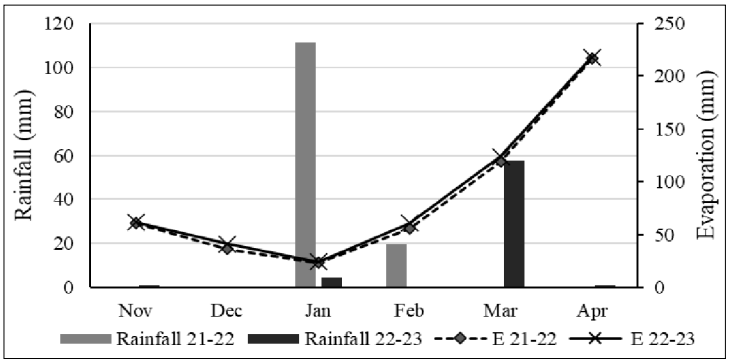


Fig 4: Distribution of rainfall and evaporation.

were collected using standard procedures. Water productivity (kg ha^{-1} mm^{-1}) was calculated as the ratio of grain yield to irrigation water and total input water productivity (WP_{I+R}) was calculated as the ratio of grain yield to total water input (rainfall+ irrigation). ANOVA for a split-plot design was used to evaluate the statistical significance of treatment effects on different parameters. OPSTAT software was utilized to examine the mean differences between the treatments using the Least Significant Difference approach at $p<0.05$.

RESULTS AND DISCUSSION

Soil properties

The experimental findings demonstrate the significant impacts of wheat sowing under residue management practices. The findings of the study (pooled) regarding soil health are presented in Table 1. The pH values across the residue-keeping methods show a declining trend over the two years. During the study, CTW, HSW and SSW sowing methods observed average pH of 8.119, 7.940 and 7.938, respectively, showing significantly lower pH under residue management sowing methods. In the absence of residue in CTW plots, the EC values had not changed, but in residue management plots, *i.e*. HSW and SSW plots observed significantly higher EC values of 0.237 and 0.236 dS m^{-1}. The pooled analysis showed that HSW and SSW sowing methods exhibit significantly higher organic carbon of 0.343 and 0.345 compared to 0.32 in CTW sowing methods. Korav *et al.* (2024) also observed similar results, stating that organic carbon has increased by 31% in zero-tillage sown wheat with surface retention of RCRs using Happy Seeder. Similar to the OC observations, the nitrogen levels were significantly higher in the HSW and SSW sowing methods, *i.e.*, 193.075 and 192.996 kg ha^{-1}, compared to 187.672 kg ha^{-1} in the CTW sowing method.

Regarding phosphorus, the values varied from 14.840, 14.862 and 13.254 kg ha^{-1} in HSW, SSW and CTW, which showed significantly higher phosphorus levels under residue management situations. Similarly, the soil under residue management treatments HSW and SSW contains significantly higher available potassium levels, *i.e.* 188.06 and 188.012 kg ha^{-1} than 172.262 kg ha^{-1} in CTW sown wheat. Similarly, Leharwan *et al.* (2023) also observed that wheat sown by keeping the RCRs increased the organic carbon, available nitrogen, phosphorus and potassium against no residue plots. Statistically insignificant results in soil testing parameters under the sub-plot treatments of irrigation scheduling, suggesting that the irrigation regimes did not have a notable impact on soil nutrient levels over the study period.

Soil moisture was recorded at weekly intervals during first and second years of experimentations and presented in Fig 5(a) and 5(b). During the first year of the study, the curve is in decreasing flat order due to high and more rainfall spells. It is also important to note that depletion of available moisture to a critical level was observed a week later in HSW than in CTW and SSW sowing methods. Soil moisture content under HSW was also higher (20.13%) than 18.49 and 18.61% in CTW and SSW sowing methods at harvesting during the first year of the study. Due to less rainfall, the crop requires more irrigation in the second year of study (2022-23). The critical moisture condition was observed late; therefore, the first irrigation was delayed for two weeks in HSW sowing methods compared to CTW and SSW sowing methods. In the second season of the experiment, higher soil moisture of 20.14% was observed under the HSW sowing method, whereas CTW and SSW estimated 18.52 and 18.43% soil moisture at harvest. In a study (Kumar *et al.*, 2024) also observed improved bulk density, soil organic carbon and soil moisture storage in residue retention plots.

Crop yield

The data presented in (Table 2) suggests residue and irrigation management strategies lead to significant variations in yield attributes and yield of wheat. The plant height on 15, 30 and 60 DAS was significantly high in CTW, followed by SSW and HSW sowing methods. At 90 DAS, the CTW sowing method and (IS_4) irrigation scheduling has significantly higher plant height. Among different sowing

Table 1: Effect of residue management on soil properties (pooled).

Parameters	$pH_{(1:2)}$	EC (dS m^{-1})	OC (%)	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
Treatments			**Main plot - Sowing methods**			
CTW	8.119 a	0.213 b	0.320 b	187.672 b	13.254 b	172.262 b
HSW	7.940 b	0.237 a	0.343 a	193.075 a	14.840 a	188.060 a
SSW	7.938 b	0.236 a	0.345 a	192.996 a	14.862 a	188.012 a
SEm (±)	0.0061	0.0034	0.0036	0.5507	0.0471	0.4717
CD @ 5%	0.0199	0.0111	0.0117	1.7959	0.1536	1.5383
			Sub plot - Irrigation scheduling			
IS_1	7.997 a	0.230 a	0.335 a	191.462 a	14.281 a	182.539 a
IS_2	8.002 a	0.231 a	0.336 a	191.077 a	14.303 a	182.961 a
IS_3	7.995 a	0.227 a	0.337 a	191.079 a	14.343 a	182.861 a
IS_4	8.002 a	0.230 a	0.336 a	191.375 a	14.348 a	182.751 a
SEm (±)	0.0111	0.0027	0.0041	0.6335	0.0647	0.4915
CD @ 5%	NS	NS	NS	NS	NS	NS

methods, average plant height at harvest was highest for HSW (96.61 cm) and lowest for SSW (95.30 cm), with CTW falling in between (96.52 cm). At the same time, moisture-based irrigation scheduling (IS_4) gave a significantly higher plant height of 97.23 cm, followed by 96.06 and 95.95 in IS_3 and IS_2 irrigation scheduling practices. However, the pooled results indicated that HSW sowing method coupled with IS_3 irrigation scheduling significantly gave the highest plant height of 100.6 cm, followed by 98.56 cm in CTW sowing method and IS_4 irrigation scheduling (Fig 6). Kumar and Singh (2018) observed similar results that residue retention have significantly higher plant height and wheat yield of 89.49 cm and 34.22 q ha^{-1} than 84.78 cm and 32.26 q ha^{-1} in without residue plots.

The effective tillers were significantly higher in HSW sowing method, *i.e.* 413.27, compared to 401.22 and 392.58 in CTW and SSW sowing methods. Moreover, the HSW sowing method produced significantly the highest effective tillers 465

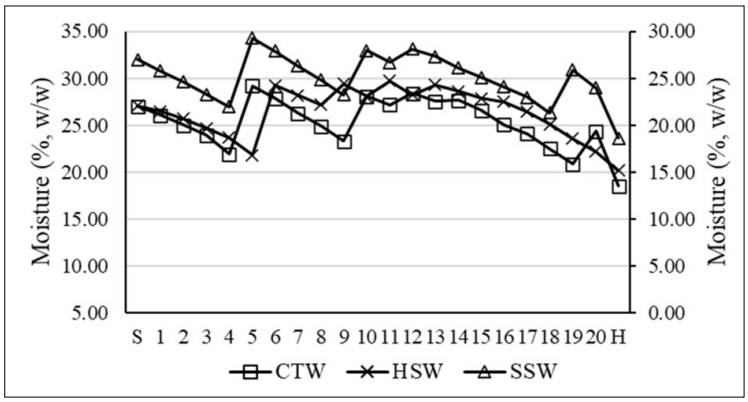


Fig 5 (a): Soil moisture at week interval under sowing methods (2021-22).

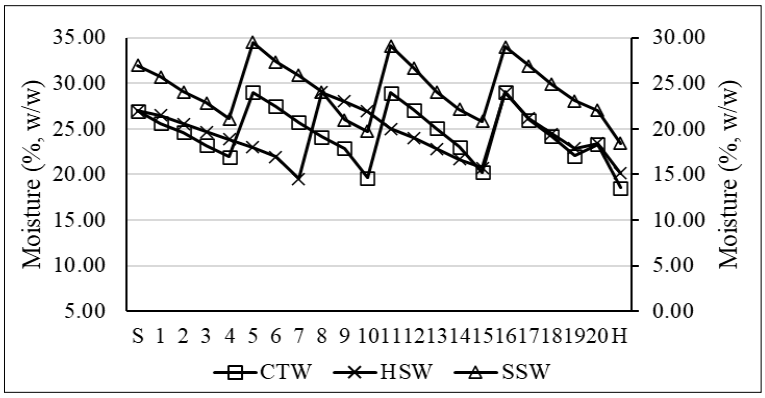


Fig 5 (b): Soil moisture at week interval under sowing methods (2022-23).

Table 2: Effect of sowing methods and irrigation scheduling on yield attributes and yield of wheat.

Treatments	Plant height (cm)	Effective tillers (m^{-2})	Spike length (cm)	Grains/ spike	1000 grains weight (gm)	Grain yield (q ha^{-1})	straw yield (q ha^{-1})	Harvest index
Main plot-Sowing methods								
CTW	96.52 b	401.22 b	10.31 b	48.16 b	47.66 b	57.69 b	76.98 a	42.83 a
HSW	96.61 a	413.27 a	10.55 a	49.88 a	49.09 a	58.37 a	77.64 a	42.92 a
SSW	95.30 c	392.58 c	10.12 c	47.34 c	46.31 c	56.85 c	75.59 b	42.92 a
SEm (±)	0.021	1.547	0.022	0.107	0.175	0.213	0.308	0.033
CD @ 5%	0.069	5.045	0.074	0.348	0.573	0.695	1.006	NS
Sub plot-Irrigation scheduling								
IS_1	95.34 d	385.94 b	9.80 b	45.90 b	45.53 b	56.23 c	75.03 b	42.86 b
IS_2	95.95 c	407.55 a	10.55 a	49.21 a	48.22 a	58.37 a	77.86 a	42.83 b
IS_3	96.06 b	409.75 a	10.48 a	49.10 a	48.17 a	58.22 ab	77.11 a	43.00 a
IS_4	97.23 a	406.19 a	10.49 a	49.62 a	48.83 a	57.74 b	76.94 a	42.87 b
SEm (±)	0.020	2.099	0.046	0.201	0.204	0.184	0.289	0.0345
CD @ 5%	0.066	6.846	0.151	0.656	0.667	0.601	0.945	0.1125

with IS_3 irrigation scheduling, followed by 413 and 405 in CTW and SSW under IS4 irrigation scheduling practices. Similarly, the spike length and grains per spike were significantly greater in HSW (10.55 cm and 49.88 grains, respectively) compared to CTW (10.31 cm and 48.16 grains) and SSW (10.12 cm and 47.34 grains). The 1000-grain weight also showed a similar trend, with HSW exhibiting the highest weight of 49.09 gm compared to 47.66 and 46.31 gm in CTW and SSW, respectively. The sub-treatment irrigation scheduling (IS_3) also significantly influenced the effective tillers, spike length, grains per spike and 1000-grain weight.

The significant increase in yield of wheat (58.37 q ha^{-1}) was noticed in HSW, followed by 57.69 and 56.85 q ha^{-1} in CTW and SSW sowing methods of wheat. In comparison, IS_2 and IS_3 irrigation scheduling produced significantly higher and at par grain yield of 58.37 and 58.22 q ha^{-1}, followed by 57.74 q ha^{-1} in IS_4. Overall, the significantly highest crop yield, 64.40 q ha^{-1}, was harvested under HSW sowing method coupled with I_3 irrigation scheduling. The CTW and SSW sowing methods gave the highest crop yield, 59.03 and 58.75 q ha^{-1}, under I_4 irrigation scheduling. Similarly, statically at par and higher straw yield of 77.64 and 76.98 q ha^{-1} were obtained in HSW and CTW than 75.59 q ha^{-1} in SSW sowing method. Singh *et al.* (2023) also reported similar results that wheat sowing with happy seeder and super seeder harvested significant increased grain and straw yield than conventional tillage treatments in coarse and fine-textured soils. In a two-year study, the data reveals that management of RCRs promotes the growth parameters of the crop by which 8.12% and 3.91% higher crop and straw yield of wheat were produced than in without residue plots (Puniya *et al.*, 2023). Elabbadi *et al.*, 2024 also observed higher water use efficiency and crop yield of wheat under zero tillage sowing than conventional sowing practices. The sowing method did not significantly influence the harvest index (HI). However, irrigation scheduling significantly affected the HI and IS_3 gave the highest HI of 43.00. The results suggest that HSW sowing method and IS_2 and IS_3 irrigation scheduling provided optimal conditions for plant growth. The differences in growth and yield attributes under different sowing methods and irrigation schedules were statistically significant, indicating their importance in improving crop performance.

Water productivity

In study years 2021 and 2022, the irrigation scheduling IS_1 received 3 irrigations in all the sowing methods. The rest of the three scheduling treatments have each two irrigations under all sowing methods. The total rainfall received in the first year was 131.02 mm. Therefore, a total of 311.02 mm water received in IS_1 and 251.02 mm in IS_2, IS_3 and IS_4 irrigation treatments in 2021-22. In the second year, IS_1 and IS_2 treatments received four irrigations under all the main plot treatments. Whereas IS_3 and IS_4 in CTW and SSW received three each irrigation and three and two, respectively, in HSW sowing method. The highest irrigation water productivity (WPI) of 54.36 kg ha^{-1} mm^{-1} in IS_3 and lowest

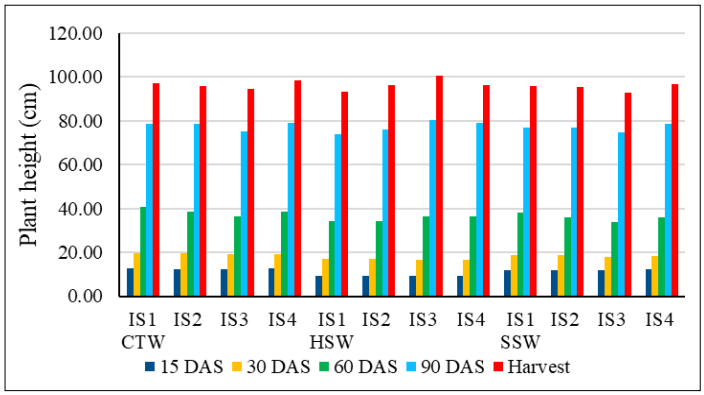


Fig 6: Average plant heights at different time intervals.

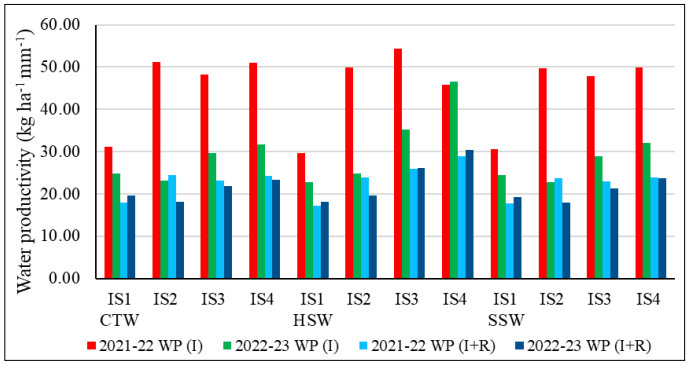


Fig 7: Water productivity of wheat under different sowing methods.

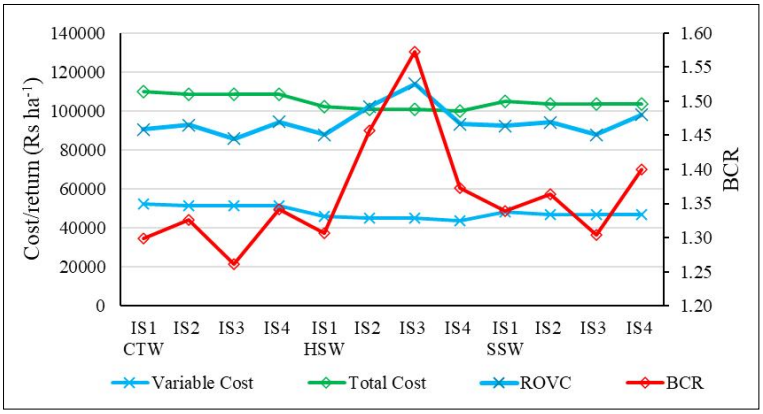


Fig 8: Economics of the experiments (pooled data).

29.61 kg ha^{-1} mm^{-1} was recorded in and IS_1 under HSW sowing method across all the planting and irrigation strategies in the first year. Gandhamanagenahalli *et al.*, 2024 also found improved irrigation water productivity in zero tillage than in traditional planting of wheat. Whereas in the second year of the experiment, IS_4 under HSW and IS_1 under SSW recorded 46.53 kg ha^{-1} mm^{-1} (highest) and 22.75 kg ha^{-1} mm^{-1} (lowest) WPI respectively (Fig 7). Prajapat *et al.* (2020) also reported higher water use efficiency in irrigation scheduling of 0.9 ETc in wheat. In a two-year research trial in Karnal (Haryana), Radheshyam *et al.*, 2024 also observed higher total water productivity under zero tillage residue management wheat sowing techniques.

Economic analysis

The economic analysis pertaining to the cultivation costs (Rs ha^{-1}) was conducted using the cost incurred on wheat sowing to grain threshing in the field. The two-year pooled data presented in (Fig 8). shows the average variable cultivation cost of 51579.89 Rs ha^{-1} was highest under CTW and the lowest was 44899.73 Rs ha^{-1} in HSW sowing method. The average total cultivation cost in CTW, HSW and SSW sowing methods was 109020.87, 101004.68 and 103826.18 Rs ha^{-1}, respectively. Due to low cultivation cost, the highest return over variable cost of cultivation, 99261.40, was observed in HSW followed by 93052.68 and 90859.60 Rs ha^{-1} in SSW and CTW sowing methods. Therefore, the benefit-cost ratio (BCR) was also high, 1.43 in HSW followed by 1.35 and 1.31 in SSW and CTW sowing methods. Similarly, Singh *et al.*, 2023 and Bishnoi *et al.*, 2023 observed higher benefit-cost ratio in wheat sowing by Happy Seeder and Super Seeder in Haryana and Punjab.

CONCLUSION

The present study's findings indicated that adopting recent sowing methods of wheat and irrigation scheduling strategies significantly affected soil properties growth parameters, resulting in improved crop yield and water productivity. The major important soil parameters, *i.e.*, organic carbon, available nitrogen, phosphorus and potassium, were also higher under HSW and SSW sowing methods. The surface retention of RCRs in HSW sowing method resulted in moisture conservation, as evident from higher soil moisture content at harvesting. The findings also indicate that HSW sowing technique and IS3 scheduling of irrigation practices resulted in higher grain yield irrigation water productivity. Due to less farming expenses, the increased returns over variable cost of cultivation and benefit-cost ratio were observed in HSW and SSW sowing methods of wheat. The study suggests managing RCRs using happy seeder and super seeder, as well as modified irrigation scheduling strategies, can play an important role in the sustainable enhancement of soil health, crop yield and farm profits.

Conflict of interest

The authors declare no conflict of interest.

REFERENCES

Abdurrahman, M.I., Chaki, S. and Saini, G. (2020). Stubble burning: Effects on health and environment, regulations and management practices. *Environmental Advances*. **2:** 100011. https://doi.org/10.1016/j.envadv.2020.100011.

Anonymous, (2023). Package of Practices for crops of Punjab Rabi (2023-24). Punjab Agricultural University Ludhiana. **40(2).** https://www.pau.edu/content/ccil/pf/pp_rabi.pdf.

Banjara, T.R., Bohra, J.S., Kumar, S., Ram, A. and Pal, V. (2021). Diversification of rice-wheat cropping system improves growth, productivity and energetics of rice in the Indo-Gangetic Plains of India. *Agricultural Research*. **1-10.** https://doi.org/10.1007/s40003-020-00533-9.

Bhatt, R., Singh, P., Hossain, A. and Timsina, J. (2021). Rice wheat system in the northwest Indo-Gangetic plains of South Asia: Issues and technological interventions for increasing productivity and sustainability. *Paddy and Water Environment*. **19(3):** 345-365. http://dx.doi.org/10.1007/s10333-021-00846-7.

Bishnoi, R., Kumar, V., Bishnoi, D.K. and Meena, M.S. (2023). Economics of super seeder technique of wheat cultivation in Haryana. *International Journal of Environment and Climate Change*. **13(9):** 574-582. https://doi.org/10.9734/ijecc/2023/v13i92272.

Bouyoucos, G.J. (1962). Hydrometer method improved for making particle size analyses of soils 1. *Agronomy Journal*. **54(5):** 464-465.

Elabbadi, O.E., Benniou, R., Louahdi, N. and Guendouz, A. (2024). Effect of different tillage operations on soil water storage, water use efficiency and productivity of durum wheat (*Triticum durum* desf.) in semi-arid region. *Indian Journal of Agricultural Research.* **58(4):** 581-587. doi: 10.18805/IJARe.AF-843

Gandhamanagenahalli, A.R., Dass, A., Venkatesh, P., Choudhary, A.K., Upadhyay, P.K., Chandrashekar, A.B. and 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:** 100087. https://doi.org/10.1016/j.farsys.2024.100087.

Gora, M.K., Jat, H.S., Ladha, J.K., Choudhary, M., Sharma, P.C., Yadav, A.K. and Gathala, M.K. (2024). Enhancing productivity, soil health and reducing global warming potential through diverse conservation agriculture cropping systems in India's Western Indo-Gangetic Plains. *Field Crops Research*. **315:** 109476. https://doi.org/10.1016/j.fcr.2024.109476.

Jackson, M.L. (1967). Soil Chemical Analysis, II edn. Prentice Hall of India, New Delhi. pp. 498.

Jat, M.L., Chakarborty, D., Ladha, J.K., Rana, D.S., Gathala, M.K., McDonald, A. *et al.* (2020). Conservation agriculture for sustainable intensification in South Asia. Nat. *Sustain*. **3:** 336-343. https://doi.org/10.1038/s41893-020-0500-2.

Korav, S., Yadav, D.B., Yadav, A., Rajanna, G.A., Parshad, J., Tallapragada, S. and Mahmoud, E.A. (2024). Rice residue management alternatives in rice-wheat cropping system: Impact on wheat productivity, soil organic carbon, water and microbial dynamics. *Scientific Reports*. **14(1):** 1822.https://doi.org/10.1038/s41598-024-52319-6.

Kumar, M., Singh, J., Sharma, S. and Chhina, R.S. (2024). Effect of rice residue management practices and irrigation regimes on root mass density and water productivity of wheat in rice-wheat system in Northern region of India. *Journal of Soil and Water Conservation.* **23(2):** 196-202. http://dx.doi.org/10.5958/2455-7145.2024.00032.6.

Kumar, R. and Singh, U.P. (2018). Performance of zero-till wheat (*Triticum aestivum* L.) with residue and weed management techniques under rice-wheat cropping system. *Agricultural Science Digest-A Research Journal*. **38(2):** 113-117. doi: 10.18805/ag.D-4860.

Leharwan, M., Kumar, Y., Kumar, R., Saraswat, P.K., Kumar, R., Veetil, A.K.T. and Kumar, S. (2023). Assessing the effects of conservation tillage and in-situ crop residue management on crop yield and soil properties in rice-wheat cropping system. *Sustainability.* **15(17):** 12736. https://doi.org/10.3390/su151712736.

Li, C., Hu, Y., Zhang, F., Chen, J., Ma, Z., Ye, X. and Mellouki, A. (2017). Multi-pollutant emissions from the burning of major agricultural residues in China and the related health-economic effects. *Atmospheric Chemistry and Physics*. **17(8):** 4957-4988. https://doi.org/10.5194/acp-17-4957-2017.

Meena, R., Tripathi, S.C., Sharma, R.K., Chhokar, R.S., Chander, S. and Jha, A. (2018). Role of precision irrigation scheduling and residue-retention practices on water-use efficiency and wheat (*Triticum aestivum*) yield in North-Western plains of India. *Indian Journal of Agronomy*. **63(2):** 186-196.

Mehta, C.R., Badegaonkar, U.R., Singh, P.L. and Singh, K.K. (2023). Integrated straw management in India. doi: 10.13140/RG.2.2.29826.29125.

Olsen, S.R., Cole, C.V., Waternabe, F.S., Dean, L.A. (1954). 'Estimation of available phosphorous in soil by extraction with sodium bicarbonate. Circular. 939. p. 919. (US Department of Agriculture).

Prajapat, A.L., Saxena, R., Choudhary, R.R. and Kumhar, M. (2020). Consumptive use, water use efficiency, moisture depletion pattern of wheat under semi-arid eastern plain zone of Rajasthan. *Agricultural Science Digest-A Research Journal*. **40(4):** 387-391. doi: 10.18805/ag.D-5092.

Puniya, R., Bazaya, B.R., Kumar, A., Sharma, B.C., Nesar, N.A., Bochalya, R.S. and Mehta, S. (2023). Effect of residue and weed management practices on weed flora, yield, energetics, carbon footprint, economics and soil quality of zero tillage wheat. *Scientific Reports*. **13(1):** 19311. https://doi.org/10.1038/s41598-023-45488-3.

Radheshyam, Jat, S.L., Jat, M.L., Parihar, C.M., Jat, H.S., Singh, A.K., Bijarniya, D. and Kumar, M. (2024). On-farm evidence on breaking yield barriers through optimizing wheat cropping system in indo gangetic plain. *European Journal of Agronomy (TSI)*. **159:** 1-12. https://doi.org/10.1016j.eja.2024.127256.

Saini, J. and Bhatt, R. (2020). Global warming-causes, impacts and mitigation strategies in agriculture. *Curr. J. Appl. Sci. Technol.* **39(7):** 93-107. doi: 10.9734/CJAST/2020/v39i730580.

Sapkota, A., Haghverdi, A., Avila, C.C. and Ying, S.C. (2020). Irrigation and greenhouse gas emissions: A review of field-based studies. *Soil Systems*. **4(2):** 20. https://doi.org/10.3390/soilsystems4020020.

Sidhu, H.S., Singh, M., Singh, Y., Blackwell, J., Lohan, S.K., Humphreys, E. and Singh, S. (2015). Development and evaluation of the Turbo Happy Seeder for sowing wheat into heavy rice residues in NW India. *Field Crops Research*. **184:** 201-212. https://doi.org/10.1016/j.fcr.2015.07.025.

Singh, A., Chhabra, V., Mehta, C.M., Kaur, G. and Sreethu, S. (2023). Evaluation of different paddy straw management technologies for their economic viability in rice-wheat system. *Plant Science Today*. **10(4):** 180-185. https://doi.org/10.14719/pst.2463.

Singh, V., Gupta, R.K., Kalia, A., Al-Ansari, N., Alataway, A., Dewidar, A.Z. and Mattar, M.A. (2023). Soil type and integrated nitrogen nutrient-rice straw residue management techniques affect soil microbes, enzyme activities and yield of wheat crop. *Heliyon*. **9(6):** https://doi.org/10.1016/j.heliyon.2023.e16645.

Subbiah, B.V. and Asija, G.L. (1956). A rapid method for the estimation of available nitrogen in soils. *Curr. Sci.* **25:** 259-260.

Tripathi, S., Singh R.N., Sharma, S.K. (2015) Quantification and Characterization of Soil Physico-Chemical Properties Influenced by Wheat (*Triticum aestivum*) Residue Burning in India. *J Global Ecol Env.* **2(3):** 155-160 https://www.ikprress.org/index.php/JOGEE/article/view/191.

Walkley, A., Black, I.A. (1934). An examination of the degtjare method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci.* **37:** 29-38.