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GROWTH AND YIELD OF WHEAT AS AFFECTED BY RICE RESIDUE MANAGEMENT AND IRRIGATION SCHEDULING

Ramanpreet Kaur, J S Deol, Rajni, Simerjeet Kaur* and A S Brar
Department of Agronomy, Punjab Agricultural University, Ludhiana-141 004, India

ABSTRACT

A field experiment was conducted in split-plot design to evaluate the effects of various rice residue management methods (residue removal followed by conventional tillage, Happy Seeder, mouldboard plough + rotavator and residue burning followed by conventional tillage) and irrigation scheduling (20%, 30%, and 40% depletion of available moisture, along with the PAU recommended schedule) on the growth and productivity of wheat. The study found that rice residue management methods did not significantly affect crop growth parameters such as plant height, crop biomass, and tiller density. However, irrigation scheduling had a notable effect on crop performance. The PAU recommended schedule, along with 20% and 30% depletion of available moisture, resulted in highest crop growth, more effective tillers, and higher grain yield compared to the 40% moisture depletion level. Plots with residue management exhibited reduced water contribution from the soil profile compared to plots where residue was removed. In nutshell, wheat sown using the Happy Seeder demonstrated improved crop growth along with more efficient utilization of available water resources.

Keywords: Happy seeder, Residue burning, Residue removal, Rice residue, Water balance

The rice-wheat cropping system (RWCS) is predominant in northwestern India. While this monoculture has made the country self-sufficient in food grain production, it has also led to several critical issues such as soil degradation, a declining water table (Hira *et al*., 2004), yield plateauing (Ladha *et al*., 2003), and challenges in crop residue management, all of which threaten the sustainability of the rice-wheat cropping system. Among these issues, the management of rice residue is particularly concerning in northwestern India. Although wheat residue is commonly used as cattle feed, the high silica and low lignin content of rice straw limit its effectiveness as feed (Anonymous, 2012). The short window between harvesting rice and sowing wheat further complicates residue management. Incorporating rice residue into the soil is time-consuming and energy-intensive. Additionally, the high carbon-to-nitrogen (C:N) ratio of rice residue leads to nitrogen immobilization in the soil, making it less available for the succeeding wheat crop. Consequently, many farmers opt to burn the rice residue to expedite wheat sowing. However, this practice results in harmful gas emissions and degrades soil health.

In-situ rice residue management technologies, such as the Happy Seeder and the incorporation of rice residue into the soil, can enhance the sustainability of the rice-wheat cropping system (RWCS). Incorporating rice residue requires 2-3 additional tillage operations to mix the residue into the soil. To avoid extra tillage, the Happy Seeder allows for direct sowing of wheat in rice residue without any prior tillage (Sidhu *et al.*, 2007). Retaining rice straw as mulch has been reported to improve soil water content and increase wheat grain yield (Rahman *et al.*, 2005; Sidhu *et al*., 2007). The northwestern Indian region typically receives about 115 mm of rainfall during the wheat season (from October-November to March-April). As a result, farmers heavily rely on groundwater to meet the evapotranspiration needs of wheat cultivation. This reliance has led to a concerning groundwater depletion rate of approximately 0.4 meters per year (Brar *et al*., 2012). Consequently, there is an urgent need to implement sustainable practices to manage groundwater over exploitation while ensuring that crop yields are not adversely affected. This includes a thorough evaluation of irrigation scheduling under various zero-tillage conditions and residue management techniques.

To effectively manage irrigation scheduling under different residue management practices in no-till systems, it is crucial to understand the dynamic interplay between soil, plants, and water demands. For example, rice residue mulch can reduce evaporation and enhance water infiltration, potentially decreasing the irrigation water requirements for wheat compared to conventional tillage methods. When soil moisture within the specified root zone reaches a certain depletion level—varying with the crop—irrigation is necessary to replenish it. Optimizing irrigation scheduling in terms of both the amount and timing, based on allowable soil moisture depletion, can improve water use efficiency and prevent excessive water application, as demonstrated

*Corresponding author: simer@pau.edu
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by Meena *et al.* (2015). Keeping in view the challenges of managing rice residue in the rice-wheat cropping system and the declining groundwater levels in Punjab, it becomes imperative to refine irrigation scheduling using soil moisture depletion strategies under various rice residue management techniques. This study was conducted with these considerations in mind.

MATERIALS AND METHODS

A two-year field study was conducted during 2019-20 and 2020-21 at the Students' Research Farm of the Department of Soil Science, Punjab Agricultural University, Ludhiana, Punjab, India. The maximum and minimum temperatures, as well as the rainfall during the growing season, are presented in Figures 1 and 2. The soil at the experimental site was sandy loam with 0.36% organic carbon, a pH of 7.40, and available nutrient levels of 189 kg ha^{-1} nitrogen, 22.5 kg ha^{-1} phosphorus, and 183.5 kg ha^{-1} potassium. The experiment was laid out in a split-plot design with three replications. The main plots comprised four methods of rice straw management: residue removal followed by conventional tillage, PAU Happy Seeder, mouldboard plough followed by rotavator, and residue burning followed by conventional tillage (farmers' practice). The previous rice crop was harvested using a combine fitted with a super straw management system (Super SMS technology) for all treatments. Rice straw was manually removed under the residue removal method, and controlled burning was done in the burning plots. In the conventional method, the seedbed for wheat was prepared by ploughing twice, followed by planking, and sowing was done using the *pora* method. With the Happy Seeder, wheat was sown directly into standing rice stubble and loose straw without prior seedbed preparation. The subplots featured four irrigation schedules: irrigation at 20%, 30%, and 40% depletion of available soil moisture, along with the Punjab Agricultural University (PAU) recommended irrigation schedule, which served as the control.

Wheat variety *Unnat* PBW 343 was sown at a rate of 100 kg ha^{-1} in rows spaced 22.5 cm apart on November 20th in both years of the study. Fertilizer application was done at the rates of 125 kg ha^{-1} nitrogen (N), 60 kg ha^{-1} phosphorus (P_2O_5), and 30 kg ha^{-1} potassium (K_2O), using urea, diammonium phosphate, and muriate of potash, respectively. The entire amount of phosphorus and potassium was incorporated at sowing. The first split of urea was applied at the first irrigation, and the second split was applied at the second irrigation. In the conventional method, urea was applied after irrigation, while in the Happy Seeder method, it was applied a day before irrigation. At harvest, the following parameters were measured: plant height (cm), total and effective tiller density (number per square meter), crop biomass (g per square meter), grains per spike, and thousand grain weight. The grain yield was recorded from the net plot area and expressed in quintals per hectare (q ha^{-1}).

Available soil moisture was measured by subtracting soil moisture at the permanent wilting point from soil moisture at field capacity. Irrigations were applied at 20%, 30%, and 40% depletion of available soil moisture. In the PAU recommended irrigation scheduling, the crop was sown after pre-sowing irrigation, and the first irrigation was given four weeks after sowing in both years of the study. During the first year, only one irrigation was applied due to frequent rainfall. In contrast, four irrigations were applied during the 2020-21 season. The second irrigation was given four weeks after sowing, while the third and fourth irrigations were applied six and four weeks after sowing, respectively. The fifth and final irrigation was applied in the first week of April. Each irrigation depth was maintained at 75 mm. To apply the desired depth, a measured amount of water was delivered to the treatment plot using a water meter installed at the inlet. Effective rainfall was calculated using the USDA soil conservation formula (Dhaliwal *et al.*, 2013).

$$ER = Rtot \left(125 - \frac{0.2Rtot}{125}\right)$$

Volumetric soil moisture was measured using a Delta-T Devices PR2 soil moisture profile probe (Delta-T Devices, UK) with access tubes extending to a depth of 100 cm. Soil moisture measurements were taken at fixed depths of 0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm, 40-60 cm, and 60-100 cm, thrice a week. The amount of irrigation water applied to each plot was measured using a water meter installed at the irrigation inlet of the experimental field. The water balance equation for the root zone depth of 1 meter was calculated as:

$$I + P = ETc + D + R + Wg \pm \Delta s$$

where, I is irrigation (mm), P is precipitation (mm), ETc is crop evapotranspiration (mm), D is soil water drainage (mm) i.e. water in soil profile above field capacity (θv), R in runoff (mm), Wg is water used through capillary rise (mm), ∆s is change in soil water storage during the growing season (mm). The amount of irrigation (I) water applied and rainfall (P) received were directly measured. The drainage (D) was calculated as the excess water that drained from the 1 m soil profile. Runoff (R) was considered zero as each plot was bunded with 30 cm ridges. Since, water table was below 4 m depth, the capillary rise (Wg) was also assumed as zero.

Data were analyzed using the analysis of variance (ANOVA) technique to determine the statistical significance of the effects of the applied treatments. For observations on weeds, the data on weed population and biomass were square root transformed before analysis; however, the original values are presented in parentheses for clarity. Significant treatment effects were identified by ANOVA, and means were separated using Fisher's protected least significant difference (LSD) test at a significance level of $p \leq 0.05$.

RESULTS AND DISCUSSION

In the experiment, different methods of rice residue management did not significantly affect plant height in either year (Table 1). During the 2019-20 season, the impact of irrigation scheduling treatments on plant height at harvest was not significant due to frequent rainfall (Fig. 1). However, in the 2020-21 season, plant height was significantly greater under 20% and 30% depletion of available soil moisture, as well as the PAU recommended irrigation schedule, compared to the 40% depletion treatment. This increased plant height may be attributed to higher soil moisture availability to roots, which improves nutrient availability and enhances the net photosynthesis rate. This, in turn, may have increased the availability of photosynthates, thereby promoting better growth and development of the crop.

The influence of rice residue management systems on crop biomass at harvest was not significant. During the 2019-20 season, frequent rainfall events resulted in non-significant differences in crop biomass across various irrigation scheduling methods. However, in the 2020-21 season, higher dry matter was observed when irrigation was applied at 20% depletion of available soil moisture, in contrast to 40% depletion. Interestingly, the 20% depletion strategy yielded results similar to the 30% depletion approach recommended by PAU. This notable impact of water availability on biomass production can be attributed to improved nutrient uptake under higher moisture conditions, as opposed to the water-stressed conditions associated with lower irrigation intensities, as suggested by previous studies (Liu *et al.*, 2018; Si *et al.*, 2020) and align with the observations made by Asif *et al.* (2010) and Ram *et al.* (2013).

Tiller density was not significantly affected by different methods of rice residue management. During the 2019-20 season, irrigation scheduling did not impact tiller density at harvest due to frequent rainfall events (Fig. 1). However, in the 2020-21 season, a 20% depletion of available soil moisture resulted in significantly higher tiller density compared to other irrigation schedules, while the 40% depletion treatment recorded the lowest tiller density. The higher tiller density associated with more frequent irrigation is likely due to better plant height and increased dry matter accumulation, which contribute to improved overall plant growth.

Yield and yield attributes

Across all treatments, the number of effective tillers observed during the 2019-20 cropping season exceeded those in the 2020-21 season. This difference can be attributed to the higher and more evenly distributed rainfall, as well as the lower mean temperatures throughout the cropping period, as shown in Figures 1 and 2. Interestingly, rice residue management methods did not significantly affect the number of effective tillers, grains per spike, or thousand-grain weight in either year. However, residue removal/burning and the mould board plough combined with a rotavator resulted in

Table 1. Effect of methods of rice straw management and irrigation scheduling on growth parameters at harvest of wheat

Treatments	Final Plant height (cm)		Crop biomass at harvest (g m^{-2})		Tiller density at harvest (No. m^{-2})	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Rice residue management						
Residue removal+conventional tillage	97.25	91.87	757.71	666.17	428.85	428.85
Happy seeder	99.54	97.01	811.27	709.01	455.64	455.64
MB plough+ rotavator	98.33	95.2	792.35	693.88	446.17	446.17
Residue burning+conventional tillage	96.27	90.97	748.35	658.67	424.17	424.17
LSD ($p \leq 0.05$)	NS	NS	NS	NS	NS	NS
Irrigation scheduling						
20% depletion of available soil moisture	97.71	97.30	780.06	681.65	439.95	457.14
30% depletion of available soil moisture	97.52	93.73	778.29	711.43	438.53	438.53
40% depletion of available soil moisture	96.88	88.25	771.91	635.92	437.14	409.95
PAU recommendation	97.29	95.78	779.42	698.74	439.21	449.21
LSD ($p \leq 0.05$)	NS	6.64	NS	55.41	NS	34.63

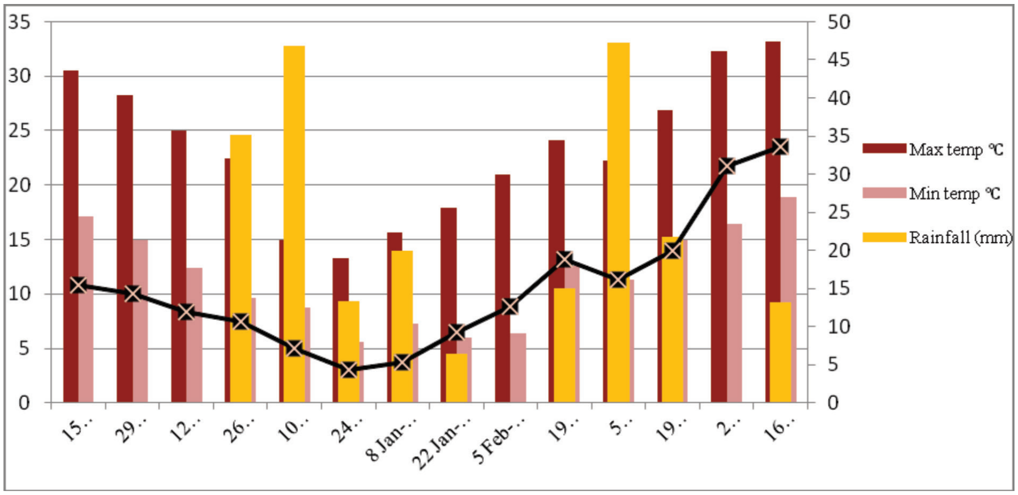

Fig. 1. Graphical representation of meteorological data at Ludhiana (2019-20)

numerically lower grains per spike compared to the Happy Seeder method.

In the 2019-20 season, different irrigation schedules did not significantly affect the number of effective tillers, grains per spike, or thousand-grain weight. However, in the 2020-21 season, the highest number of effective tillers (337.08 per square meter) was recorded with irrigation applied at a 20% depletion of available moisture. This result was statistically comparable to those obtained with a 30% depletion of available moisture (318.33 per square meter) and in line with the PAU recommendation (323.96 per square meter). Similarly, the 20% depletion of available soil moisture resulted in significantly more grains per spike compared to the 40% depletion, and was on par with the 30% depletion and PAU recommendation for the 2020-21 season. The notable impact of water availability on effective tiller density and grains per spike can be attributed to improved nutrient uptake by roots under higher moisture conditions, as opposed to water-stressed conditions. This finding is consistent with the previous research of Liu *et al.* (2018) and Si *et al.* (2020), and aligns with observations made by Khan *et al.* (2007), Asif *et al.* (2010), Gill *et al.* (2015), and Meena *et al.* (2015).

The ultimate goal of all agronomic practices is to maximize grain yield, which results from various physiological, growth, and yield-related factors. Any stress experienced by the crop, whether during its vegetative or reproductive stages, can significantly

Table 2. Effect of methods of rice straw management and irrigation scheduling on yield attributes and grain yield of wheat

Treatments	Effective tillers (No. m^{-2})		No. of grain/ spike		1000 grain weight (g)		Grain yield (q ha^{-1})	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Rice residue management								
Residue removal+conventional tillage	329.38	312.71	40.05	37.7	36.61	36.61	47.50	45.85
Happy seeder	362.29	345.63	41.77	41.65	40.45	40.45	50.45	50.58
MB plough+ rotavator	328.75	312.08	40.24	38.64	37.54	37.54	48.59	47.31
Residue burning+conventional tillage	328.13	311.46	39.24	37.18	36.12	36.12	48.36	46.08
LSD ($p \le 0.05$)	NS	NS	NS	NS	NS	NS	NS	2.58
Irrigation scheduling								
20% depletion of available soil moisture	340.75	337.08	41.67	40.65	38.46	39.48	49.04	49.56
30% depletion of available soil moisture	333.17	318.33	39.6	38.56	37.48	37.46	49.54	8.73
40% depletion of available soil moisture	333	302.5	38.78	36.56	36.51	35.51	47.40	44.13
PAU recommendation	340.63	323.96	41.34	39.4	38.27	38.27	48.92	48.42
LSD($p \le 0.05$)	NS	23.68	NS	1.48	NS	NS	NS	1.27

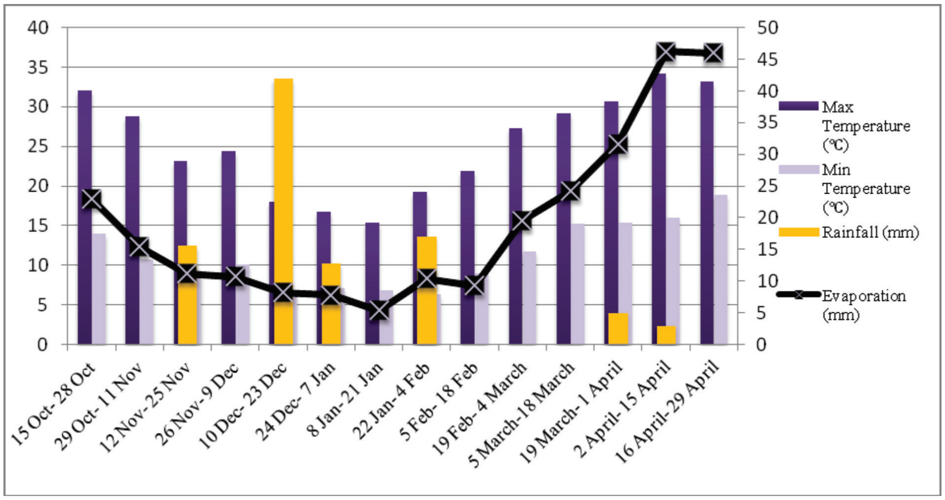

Fig. 2. Graphical representation of meteorological data at Ludhiana (2020-21)

reduce the final yield. In the first year, rice residue management methods did not have a significant impact on wheat grain yield. However, in the second year, the highest grain yield was achieved with the Happy Seeder technology, outperforming other residue management systems. This highlights the effectiveness of Happy Seeder as a climate-resilient technology with promising potential for the future. Wheat grown with Happy Seeder showed a higher growth rate, compensating for any initial slow growth during the early stages. This observation is consistent with Singh *et al.* (2011), who reported that while wheat under rice straw mulch experienced initial slow growth, it recovered during later stages. Additionally, the lower mean soil temperature under Happy Seeder may have helped prevent terminal heat stress, as suggested by Akter and Islam (2017). In contrast, other studies by Hernanz *et al.* (2002) and Bhattacharyya *et al.* (2008) found no significant difference in wheat grain yield between zero tillage and conventional methods.

During the 2020-21 season, significantly higher grain yields were observed when crop residues were retained on the surface. This increase is primarily attributed to enhanced photosynthesis, improved translocation of photosynthates, a larger sink, and a more robust reproductive phase. Retaining straw on the surface helps regulate soil temperature and moisture, contributing to the higher grain yield. Rice residues act as mulch, which aids in weed suppression, improves soil structure, and reduces soil evaporation and runoff losses. These findings are consistent with the results documented by Singh *et al.* (2009) and Sidhu *et al.* (2007).

The application of irrigation scheduling significantly impacted wheat grain yield during the 2020-21 season. Specifically, a 20% depletion of available soil moisture resulted in the highest grain yield, which was statistically comparable to a 30% depletion of available soil moisture and aligned with the PAU recommendation. This yield was significantly higher than that obtained with a 40% depletion of available soil moisture. In contrast, during the 2019-20 season, irrigation scheduling had a non-significant effect on grain yield, likely due to more favourable rainfall distribution. The reduction in grain yield associated with decreased irrigation intensity can be attributed to limited water and nutrient uptake by the roots, which leads to accelerated leaf senescence, a shorter growth period, reduced photosynthesis, and slow translocation of assimilates, ultimately resulting in poor grain development. These observations are consistent with the findings of Asch *et al.* (2005) and Farooq *et al.* (2009). Similar results were also reported by Ram *et al.* (2013) and Yousaf *et al.* (2014) regarding decreased wheat grain yield under water-stressed conditions.

Water use studies

The study of different water balance components is essential for understanding movement of water in to and out of soil, plant and atmospheric system. It helps in irrigation scheduling to the crops by avoiding excess losses while maintaining high yield levels. The data on water balance components are presented in Table 3. The irrigation water applied varied considerably between methods of rice residue management during 2020-21, the irrigation water applied to residue removal/burning and mould board plough+rotavator was higher as compared to Happy Seeder method. This could be due to lower losses due to evaporation under Happy Seeder due to presence of crop residue on soil surface. However, during 2019-20, the amount of irrigation water applied was found almost similar

Table 3. Effect of methods of rice straw management and irrigation scheduling on water balance component of wheat

Treatments		Irrigation water applied (mm)		Rainfall received (mm)		Effective rainfall (mm)		Soil profile contribution (mm)		Runoff (mm)		Drainage (mm)	
		2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Residue removal + conventional tillage	$I_{20\%}$	175	450	219	90.4	142.3	77.3	32.4	23.2	0	0	80.3	159.0
	$I_{30\%}$	175	300	219	90.4	142.3	77.3	32.7	18.2	0	0	83.5	66.4
	$I_{40\%}$	175	150	219	90.4	142.3	77.3	32.9	14.4	0	0	83.1	42.4
	I_{Rec}	175	300	219	90.4	142.3	77.3	32.7	22.7	0	0	83.5	71.1
Happy seeder	$I_{20\%}$	175	375	219	90.4	142.3	77.3	32	22.6	0	0	79.4	108.4
	$I_{30\%}$	175	225	219	90.4	142.3	77.3	31.8	17.0	0	0	85.5	68.5
	$I_{40\%}$	100	150	219	90.4	142.3	77.3	31.4	12.2	0	0	10.9	56.3
	I_{Rec}	175	300	219	90.4	142.3	77.3	31.8	16.7	0	0	85.5	61.1
Mould board *fb* rotavator	$I_{20\%}$	175	450	219	90.4	142.3	77.3	32	22.6	0	0	84.8	152.3
	$I_{30\%}$	175	300	219	90.4	142.3	77.3	31.9	17.9	0	0	85.0	70.0
	$I_{40\%}$	100	150	219	90.4	142.3	77.3	32	14.5	0	0	9.8	42.0
	I_{Rec}	175	300	219	90.4	142.3	77.3	31.6	20.8	0	0	81.8	65.0
Residue burning + conventional tillage	$I_{20\%}$	175	450	219	90.4	142.3	77.3	29.9	22.6	0	0	88.7	163.8
	$I_{30\%}$	175	300	219	90.4	142.3	77.3	31.5	17.5	0	0	85.7	69.1
	$I_{40\%}$	175	150	219	90.4	142.3	77.3	31.4	14.6	0	0	85.9	45.2
	I_{Rec}	175	300	219	90.4	142.3	77.3	32.7	21.7	0	0	83.5	65.9

under all residue management methods. This might be due to frequent rainfall during crop season (Fig. 1). During 2020-21, the amount of water applied reduced with increase in irrigation intensity with the highest being under 20% depletion of available soil moisture followed by 30% depletion of available soil moisture and PAU recommendation. During 2019-20, lower amount of irrigation water applied could be due to higher and frequent rainfall received during 2019-20 as compared to the next year. The higher amount of soil profile water was used in residue removal, mould board+rotavator and burning as compared to Happy Seeder during both the years. The perusal of the data revealed that irrigation scheduling affected soil profile contribution considerably. It was found that 40% depletion of available soil moisture used more soil profile as compared to 30% depletion of available soil moisture 20% depletion of available soil moisture and PAU recommendation. This might be due to water stress condition under 40% depletion of available soil moisture that led to higher utilization of moisture from soil profile. A total of 219 mm rainfall was received during 2019-20 crop season, out of which 142.3 mm was effective. During 2020-21, 90.4 mm rainfall was received, out of which 77.3 mm was effective. The higher losses due to drainage were recorded under residue removal, mould board+ rotavator and burning as compared to Happy Seeder during both the years. The drainage varied considerably among different irrigation scheduling options. It was found that 20% depletion of available soil moisture resulted in higher losses due to drainage as compared to 30% depletion of available soil moisture and PAU recommendation, while found least under 40% depletion of available soil moisture during both the years.

CONCLUSION

The study highlighted the promise of Happy Seeder technology as a climate-resilient approach, particularly in the second year of experimentation. This technology appears to enhance grain yield by maintaining a favourable growth rate (thus compensating for early growth setbacks) and mitigating the terminal heat stress through lowered soil temperatures. Retaining crop residues on the surface has also shown potential benefits, contributing to improved photosynthesis, better nutrient translocation, and a more robust reproductive phase, ultimately resulting in higher grain yield.

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