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RESEARCH ARTICLE

Optimizing growth and yield of wheat through strategic residue and weed management under rice-wheat cropping system

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Abstract

Rice residue management and weed control strategies are critical components in sustainable rice farming systems, influencing crop growth and production. The experiment was conducted at the Sher-e-Kashmir University of Agricultural Science and Technology research farm from the *rabi* season of 2022 to rainy reason of 2024 using a split-plot design. This study explores the effects of different rice residue management practices *viz.,* RM_1- Conventional tillage; RM_2- Residue retention on the soil surface (Happy Seeder); RM_3- Residue incorporation in the soil (Super Seeder); RM_4- Surface seeding 7 DBH (Days before sowing); RM_5- Surface seeding JBH (Just before sowing) and weed management practices *viz.,* WM_1- Pinoxaden 50 g ha^{-1} + Metribuzin 175 g ha^{-1}(PoE); WM_2- Clodinafop-Propargyl 60 g ha^{-1} + Metsulfuron-methyl 4 g ha^{-1}(PoE); WM_3- Weedy check on growth parameters *viz.,* plant height, numbers of tillers, dry matter accumulation, crop growth, yield attributes *viz.,* numbers of effective tillers, numbers of grains $spike^{-1}$ and yield of wheat. The rice residue incorporation in the soil (RM_3) was found to be over all superior under different growth parameters yield attributes and yield of wheat grain wherein, under different chemical control (WM_2) Clodinafop-propargyl 60 g ha^{-1} + Metsulfuron-methyl 4 g ha^{-1}(PoE) recorded significantly higher growth parameter, yield attributes and yield of wheat. Overall, the findings suggest that strategic rice residue management, in conjunction with appropriate weed control methods, can optimize the growth and production of wheat, thereby, promoting sustainable wheat production.

Keywords: growth; happy seeder; residue incorporation; Super Seeder; weed management; yield

Introduction

The rice-wheat cropping system (RWCS) is a dominant agricultural practice in Asia, spanning an area of approximately 13.5 million hectares, with 57 % of this concentrated in South Asia. A significant portion of the Indo-Gangetic Plains, known for its fertile soils and conducive climate, falls within this region, making it a hub for rice-wheat cultivation. India plays a pivotal role in this system, with 9.2 million hectares dedicated to rice-wheat cropping, substantially contributing to the nation's food security and agricultural output. In fiscal year 2024, India had an estimated 47.6 million hectares of land for rice cultivation (1). The production of rice was the highest with around 138 million metric tons in fiscal year 2024 across India among the other food grains (2). This yields an average productivity of approximately 2900 kg per hectare. In fiscal year 2024, India produced approximately 110.6 million metric tons of wheat (3). The area under wheat cultivation was around 31.45 million hectares, resulting in an average yield of approximately 3520 kg per hectare. This extensive production system underscores its critical role in meeting the food demands of the country's growing population.

The rice-wheat cropping system ensures food security and provides livelihood opportunities for millions of farmers. However, it is essential to maintain its sustainability and productivity in the face of challenges like soil degradation, declining water resources, inefficient residue management and increasing weed infestations. By adopting innovative residue management techniques and effective weed control strategies, the system can be optimized to meet future demands while minimizing its environmental footprint. Despite its importance, the sustainability and productivity of the rice-wheat system are under threat from several challenges. Two key issues are inefficient management of rice residues and widespread weed infestations, which adversely affect soil quality, environmental health and wheat crop yields.

Open field burning of rice residues is a common practice due to its convenience and low cost. However, this method has severe environmental and health consequences. It releases significant amounts of greenhouse gases, including carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), contributing to global warming. Additionally, harmful pollutants such as particulate matter, carbon monoxide (CO) and polycyclic aromatic hydrocarbons (PAHs) are emitted, deteriorating air quality and posing serious respiratory health risks (4). In India, agricultural residue burning has been linked to 44000 - 98000 particulate matter exposure-related premature deaths annually between 2003 and 2019 (5). Moreover, this practice leads to the loss of essential nutrients and soil organic matter, adversely affecting soil health and agricultural productivity (6).

Agronomically, residue burning depletes soil organic matter, a critical component for maintaining soil fertility. Organic matter enhances soil properties such as structure, water retention, nutrient availability and microbial activity. Its loss through burning accelerates soil degradation, ultimately reducing long-term agricultural productivity. Consequently, sustainable rice residue management practices are urgently needed to safeguard environmental quality while improving soil health and resource efficiency. Innovative residue management techniques have emerged as viable alternatives to burning. These include conventional tillage, retaining residues on the soil surface using tools like the Happy Seeder, incorporating residues into the soil using the Super Seeder and surface seeding methods where residues are managed either several days before sowing (7 DBH) or immediately before sowing (JBH). Each approach offers unique advantages for optimizing residue use, enhancing soil health and reducing operational costs. For example, retaining residues on the surface acts as a natural mulch, conserving moisture, regulating soil temperature and suppressing weed growth. Similarly, incorporating residues into the soil increases organic carbon content and enhances nutrient cycling, creating an ideal environment for wheat cultivation.

Weed management is another critical factor influencing wheat productivity in the rice-wheat system. Weeds compete with crops for essential resources like water, nutrients and light, often causing significant yield reductions. In conservation agriculture systems, where residues are retained, weed pressure can be exceptionally high due to favourable conditions created by organic mulch. Therefore, combining effective weed control measures with residue management is essential to maximize wheat productivity.

Weed control in wheat farming employs various cultural, mechanical and chemical approaches. Among these, chemical herbicides are widely used due to their high efficiency and ease of application. Post-emergence (PoE) herbicides such as Pinoxaden, Metribuzin, Clodinafop-Propargyl and Metsulfuron-Methyl have effectively controlled specific weed species. When combined these herbicides target a broad spectrum of grassy and broadleaf weeds, reducing competition and improving wheat growth. For instance, Clodinafop-Propargyl (60 g ha^{-1}) combined with Metsulfuron methyl (4 g ha^{-1}) has shown superior weed control and significantly improved yield attributes in wheat.

To evaluate the combined effects of residue and weed management practices, a study was conducted at the Sher-e-Kashmir University of Agricultural Science and Technology research farm between the *Rabi* season of 2022 and the rainy season of 2024. The study employed a split-plot design to test five residue management practices and three weed control strategies, focusing on their influence on the growth parameters of wheat.

Materials and Methods

Experiment sites weather conditions

The research was conducted for two years, i.e., 2022-23 and 2023-24, at the research farm SKUAST-Jammu division of Agronomy, which lies between 32°20' N Latitude and 74°45' E' Longitude above mean sea level. Amongst the different weather parameters, temperature and relative humidity did not show much seasonal variations to impact the growth and development of wheat. In contrast, a considerable variation in the rainfall was recorded during *Rabi* 2022-23 and 2023-24. The total rainfall received (Fig. 1.) during *Rabi* 2022-23 was 223.4 mm which was 22.7 mm lower than the seasonal normal rainfall. During the growing seasons of 2023-24, the wheat crop received 259.8 mm of rainfall which was 13.7 mm higher than the seasonal normal rainfall. The climate of the experimental site is characterized by hot and dry conditions in early summer, followed by a hot and humid climate during *Kharif* and cold winters in *Rabi*. The soil of the experimental field was classified as sandy clay loam, having low carbon content (4.41 g kg^{-1}), pH (7.96), 219 kg ha^{-1} of available nitrogen, 12.5 kg ha^{-1} of available nitrogen, 12.5 kg ha^{-1} of available phosphorus and 140 kg ha^{-1} of available potassium.

Experimental design

The experiment was carried out during the *Rabi* season of 2022-23

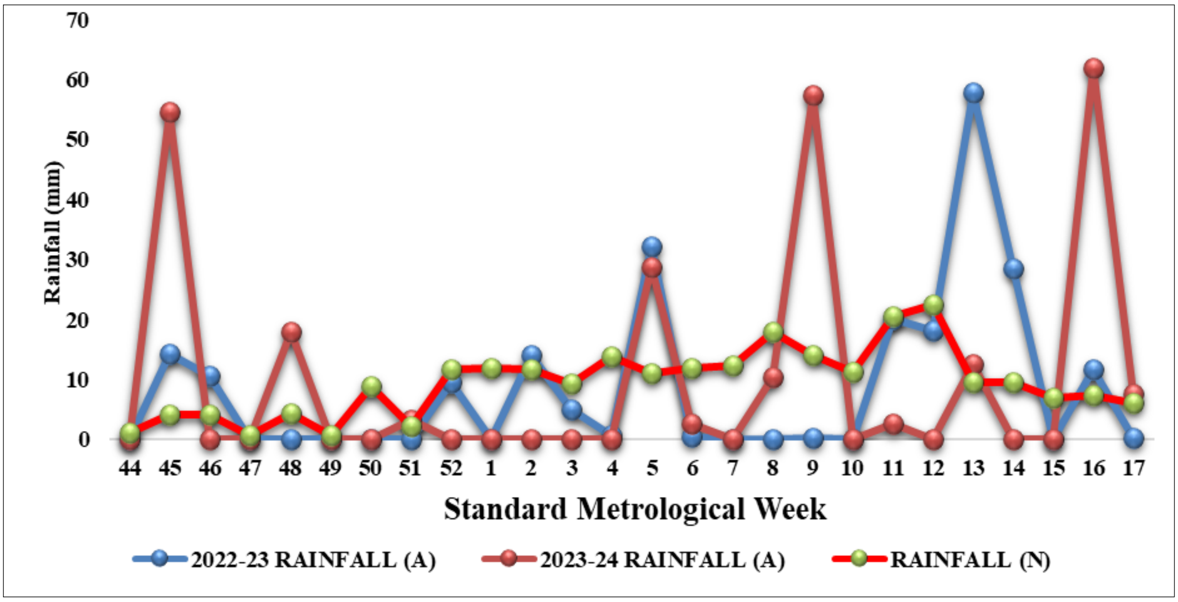

Fig. 1. Standard metrological week graph for rainfall.

and 2023-24. The research was laid out in split plot design consisting of five residue management practices *viz.*, RM_1- Conventional tillage; RM_2-Residue retention on the soil surface (Happy Seeder); RM_3- Residue incorporation (Super Seeder); RM_4- Surface seeding 7 days before harvesting (DBH) of rice crop ; RM_5- Surface seeding just before harvesting (JBH) of rice crop as a main plots and three weed management practices *viz.,* WM_1- Pinoxaden 50 g ha^{-1} + Metribuzin 175 g ha^{-1}(PoE); WM_2- Clodinafop-propargyl 60 g ha^{-1} + Metsulfuron-methyl 4 g ha^{-1}(PoE) and WM_3- Weedy check as sub plots. The experiment included 15 treatment combinations and was replicated thrice.

Management of crop

The wheat crop under treatment (RM_1), the conventional tillage method, was sown after the rice crop was harvested with a combine and the residue of the harvested crop was removed from the field. The field was then ploughed twice with the help of a tractor drawn tiller, followed by a single pass of rotavator to pulverize and level the field; a seed drill was used for sowing of the wheat crop. There was no requirement for land preparation in the treatment RM_2, RM_3, RM_4andRM$_5$. The crop under treatment RM_2 was sown with the help of a Happy seeder and in treatment RM_3, a Super Seeder was used for sowing the wheat crop. The crop under surface seeding (RM_4 and RM_5) in Fig. 2 & 3 was sown by broadcasting the wheat seeds in standing rice. In treatment RM_4 after the broadcasting of wheat seed rice crop was harvested by using combine harvester after 7 days (Fig. 2). In treatment RM_5 the wheat seed was broadcasted along with that rice crop was harvested using combine harvester (Fig. 3). Wheat variety 'DBW-222' was sown using a seed rate of 100 kg ha^{-1} for residue management treatments RM_1, RM_2 and RM_3 and 125 kg ha^{-1} for RM_4 and RM_5 treatments. Further, the wheat crop was grown by adopting all the recommended packaging of cultivation, except for the agronomic management practices under investigation as experimental treatments. The fertilizer application was done by supplementing 100:50:25:: N:P:K kg ha^{-1} (recommended dose) for conventional tillage treatment (RM_1) and additional 25 kg ha^{-1} of N in all the other residue management treatments (RM_2, RM_3, RM_4 and RM_5) using urea, DAP and MOP as nutrient source to adjust their requirements.

Herbicide application

Fig. 3. Treatment RM_5: Surface seeding of wheat in standing rice crop.

Herbicide application was done with the help of a knapsack sprayer fitted with a flat fan nozzle using a spray volume of 500 L ha^{-1}. All the herbicides are post-emergence and have been applied as per their recommended time of application. Pinoxaden @ 50 g ha^{-1} was tank mixed with metribuzin @ 175 g ha^{-1}whereas clodinafop-propargyl @ 60 g ha^{-1} + metsulfuron-methyl @ 4 g ha^{-1} (ready mix) were applied to the treatments as per the technical programme of the experiment.

Parameter recorded

Growth parameters

The growth parameters *viz.,* plant height (cm), Numbers of tillers (m^{-2}), dry matter accumulation (g m^{-2}) were recorded periodically at different intervals. The crop growth rate (g m^{-2} day^{-1}) was recorded and calculated at 60-90, 90-120 DAS and 120 DAS - at harvest.

The plant height of the wheat crop was recorded from 5 tagged plants by measuring the crop from the ground level to the uppermost tip of the crop and the mean value was calculated. The number of tillers in the treatments RM_1, RM_2 and RM_3 was counted from 1m row length in the direction of wheat sown randomly from the fourth row. Whereas, in the treatments RM_4 and RM_5 were taken by throwing the quadrant of 0.25m x 0.25 m in all such plots from the south side of the plots, leaving a 0.50m distance from the bund.

(i) Germinated wheat seeds in 7 days befor harvesting (RM_4)

(ii) Harvesting of rice crop in 7 days befor harvesting (RM_4)

Fig. 2. Treatment RM_4: Germinated wheat seeds and harvesting of rice crop using combin harveaster.

The plant samples for estimation of dry matter accumulated in treatments RM_4 and RM_5 were taken by throwing the quadrant of 0.25 m^2 from the west side of the plots, leaving 0.5 m length from the bund. Whereas, in the treatments RM_1, $RM_2$and $RM_3$the samples were taken from third row by cutting and RM_3, the sample were taken from the third row by cutting a 1m row length from the south direction of the plots. The sample plants were cut close to the soil surface in each plot and kept in paper bags. The samples were air dried and shifted in the oven for drying at a temperature of 60 ± 5 ˚C for 72 hrs or until a constant weight was reached.

The cumulative crop growth rate or the increase in plant material per unit land area per unit time was determined using the formula given and expressed as g m^{-2} day^{-1}(7).

$$CGR= \frac{(W_2 - W_1)}{(t_2 - t_1)}$$

W1- Total dry matter of crop plants at the time interval t_1

W_2- Total dry matter of crop plants at the time interval t_2

Yield and yield attributes

Number of effective tillers

The number of effective tillers in treatment RM_4 and RM_5 was counted from the area covered by the quadrant measuring 0.25 m, thrown randomly from the south side in the net plot. However, in treatments RM_1, $RM_2$and RM_3 it was counted from 1m running row length from three spots of net plot area of each treatment, averaged and converted to work out number of effective tillers m^{-2}.

Numbers of grains $spike^{-1}$

The number of grains $spike^{-1}$ were recorded by randomly selecting 10 effective spikes from each plot at maturity. The spikes were properly dried in the sun and threshed by beating with stick to separate the grains from the spikes. The grains obtained were counted and averaged to workout number of grains $spike^{-1}$.

Test weight (1000 grain weight)

Random sample of grains was drawn from the yield of each net plot and 1000 grains were counted, weighted and expressed in gram (g).

Grain yield

The threshed grains of wheat obtained from each net plot in all the treatments were sun dried to near 12 % moisture and weighed separately as per the treatment and finally expressed as grain yield in kg ha^{-1} by multiplying with conversion factor given below:

Straw yield

The straw yield was worked out by deducting the grain yield from the biological yield obtained from net plot of each treatment and converted into straw yield in kg ha^{-1}.

Statistical analysis

All observations were statistically analyzed using analysis of variance (ANOVA). The results were tested for treatment means by applying the F-test of significance, based on the null hypothesis (8). Wherever necessary, standard errors (SE) along with critical differences (CD) at the 5 % level of significance were computed to distinguish treatment effects from chance effects.

Results

Effect of rice residue and weed management practice on growth parameters

Plant height, numbers of tillers, dry matter accumulation and crop growth rate

Experimental results presented in Table 1 revealed that different rice residue and weed management significantly influenced the plant height and number of tillers of wheat at different intervals. Under different rice residue management practice at 30 DAS, treatment RM_4 recorded significantly higher plant height of wheat and which was statistically at par with the treatments RM_5. The lowest plant height was registered in treatment RM_2 which was statistically at par with treatment RM_1 and RM_3. Whereas a change in the trend of plant height was recorded at 60 DAS, treatment RM_4 produced significantly taller plants and which was statistically at par with the treatment RM_3. Besides this, the lowest plant height was registered in the treatment RM_1 which was statistically at par with the treatment RM_5 followed by RM_2 in both the years of study. This might be due to the reason that surface seeding technique not only promotes an earlier start for wheat but also minimizes soil disturbance, contributing to better soil structure and health (9). Sowing of wheat directly into the standing rice and use rice residue as mulch, helps to maintain moisture levels in the soil, which is critical for seed germination and early plant growth (10).

Experimental results presented in Table 1 and 2 revealed that different rice residue and weed management significantly influenced the Numbers of tillers, dry matter accumulation and crop growth rate (CGR) of wheat at different intervals represented in Fig. 4 describe that under different rice residue management practice the significantly higher number of tillers and dry matter accumulation and CGR was registered with treatment RM_3 which was statistically at par with treatment RM_4 and RM_2. While the lowest was recorded with treatment RM_1. This effect occurs due to positive correlation between residue management and crop performance as incorporation of rice residue enhanced soil biota which increase the mineralization process and constant supply of nutrient boosted the cell division and cell expansion also improved soil health resulting from organic matter addition, which promoted better roots systems and increased the overall plant density (11, 12).

Among the different weed management significantly highest plant height number of tillers, dry matter accumulation and crop growth rate were recorded with treatment WM_2 however the lowest plant height was recorded with statement WM_3 at all periodic intervals in both the year of experiment this might be due to fact that application of Clodinafop-propargyl 60 g ha^{-1} + Metsulfuron-methyl 4 g ha^{-1}PoE provide broad spectrum control of weeds and this gave the crop early advantage over weeds and improved access to nutrients and water, consequently helped the crop in achieving higher plant height (13).

Effect of rice residue and weed management practice on yield attributes of wheat

Experimental data with respect to yield attributes of wheat *viz.,* Numbers of effective tillers and number of grains $spike^{-1}$

Table 1. Effect of rice residue and weed management practices on periodic plant height (cm) and number of tillers (m^{-2}) of wheat during 2022-23 (Y_1) and 2023-24 (Y_2)

Treatment details	Plant height (cm)								Number of tillers (m^{-2})					
	30 DAS		60 DAS		90 DAS		At harvest		60 DAS		90 DAS		At harvest	
Main plot	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2
RM_1	22.78	24.52	47.42	48.37	80.65	82.21	91.58	92.87	281.00	283.11	320.88	323.11	319.88	322.56
RM_2	21.98	23.37	49.21	50.21	82.97	84.65	94.42	95.51	292.67	295.33	335.11	337.11	335.22	339.33
RM_3	23.48	24.27	50.08	51.19	84.43	85.79	95.03	96.51	304.88	308.22	348.66	350.22	350.66	354.33
RM_4	25.78	26.00	51.73	52.53	86.20	87.60	96.69	98.20	299.44	302.11	340.11	342.00	342.66	347.88
RM_5	24.90	25.94	47.78	49.45	81.74	83.14	93.24	94.13	287.11	290.22	326.87	330.22	328.77	334.11
SEm (±)	0.72	0.52	0.78	0.81	1.07	1.01	0.76	0.94	4.49	4.99	5.32	5.28	5.89	5.23
CD (5 %)	2.21	1.72	2.60	2.69	3.54	3.34	3.12	3.12	14.89	16.52	17.63	17.49	19.53	17.33
Sub plot														
WM_1	23.82	25.61	47.85	49.01	80.09	82.38	90.95	92.93	289.67	295.86	333.93	338.33	334.33	340.60
WM_2	23.89	25.74	53.54	55.92	91.80	94.39	102.28	104.57	332.86	336.46	371.06	376.13	375.40	379.47
WM_3	23.65	23.11	46.34	46.12	77.71	77.26	89.34	88.84	256.53	255.06	307.13	298.00	296.60	294.67
SEm (±)	0.66	0.73	0.91	0.68	1.15	0.66	1.02	1.14	7.69	7.58	7.42	7.65	7.07	7.10
CD (5 %)	NS	NS	2.72	2.02	3.38	1.97	2.80	3.39	22.87	22.52	22.04	22.75	21.01	21.79

RM_1- Conventional tillage; RM_2- Residue retention on the soil surface (Happy Seeder); RM_3- Residue incorporation in the soil (Super Seeder); RM_4- Surface seeding 7 DBH; RM_5- Surface seeding JBH WM_1- Pinoxaden 50 g ha^{-1} + Metribuzin 175 g ha^{-1} (PoE); WM_2- Clodinafop-propargyl 60 g ha^{-1} + Metsulfuron-methyl 4 g ha^{-1} (PoE); WM_3- Weedy check

Table 2. Effect of rice residue and weed management practices on periodic dry matter accumulation (g m^{-2}) and Crop growth rate (g m^{-2} day^{-1}) of wheat during 2022-23 (Y_1) and 2023-24 (Y_2)

Treatment details	Dry matter accumulation (g m^{-2})						Crop growth rate (g m^{-2} day^{-1})					
	60 DAS		90 DAS		At harvest		30 -60 DAS		60-90 DAS		120 DAS - At harvest	
Main plot	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2
RM_1	252.55	263.77	662.25	692.22	926.67	950.34	7.52	7.83	13.65	14.28	0.69	0.92
RM_2	266.66	278.88	691.77	724.00	1005.57	1022.04	8.02	8.37	14.20	14.83	1.15	1.18
RM_3	286.11	300.22	730.00	748.66	1061.52	1098.46	8.63	9.05	14.79	14.95	1.34	1.40
RM_4	272.22	288.77	713.33	737.00	1030.34	1076.09	8.13	8.58	14.70	14.94	1.15	1.18
RM_5	258.44	270.74	670.00	699.33	968.03	989.09	7.70	8.07	13.71	14.29	1.13	1.28
SEm (±)	6.36	7.36	13.53	12.19	19.18	26.91	0.20	0.25	0.27	0.17	0.13	0.06
CD (5 %)	19.65	24.39	44.82	40.39	63.52	89.14	0.67	0.80	0.89	0.57	0.61	0.24
Sub plot												
WM_1	260.46	282.72	628.33	666.86	961.76	976.06	7.52	8.17	12.26	12.81	1.00	1.11
WM_2	306.06	328.66	908.00	960.73	1266.20	1340.27	8.02	9.63	20.06	21.07	1.28	1.32
WM_3	235.06	230.06	544.68	533.13	767.32	765.28	6.93	6.77	10.32	10.10	0.98	0.98
SEm (±)	7.97	8.26	6.32	6.90	8.40	17.31	0.27	0.28	0.35	0.39	0.09	0.05
CD (5 %)	NS	NS	18.77	20.52	24.97	51.43	0.80	0.81	1.02	1.16	0.26	0.16

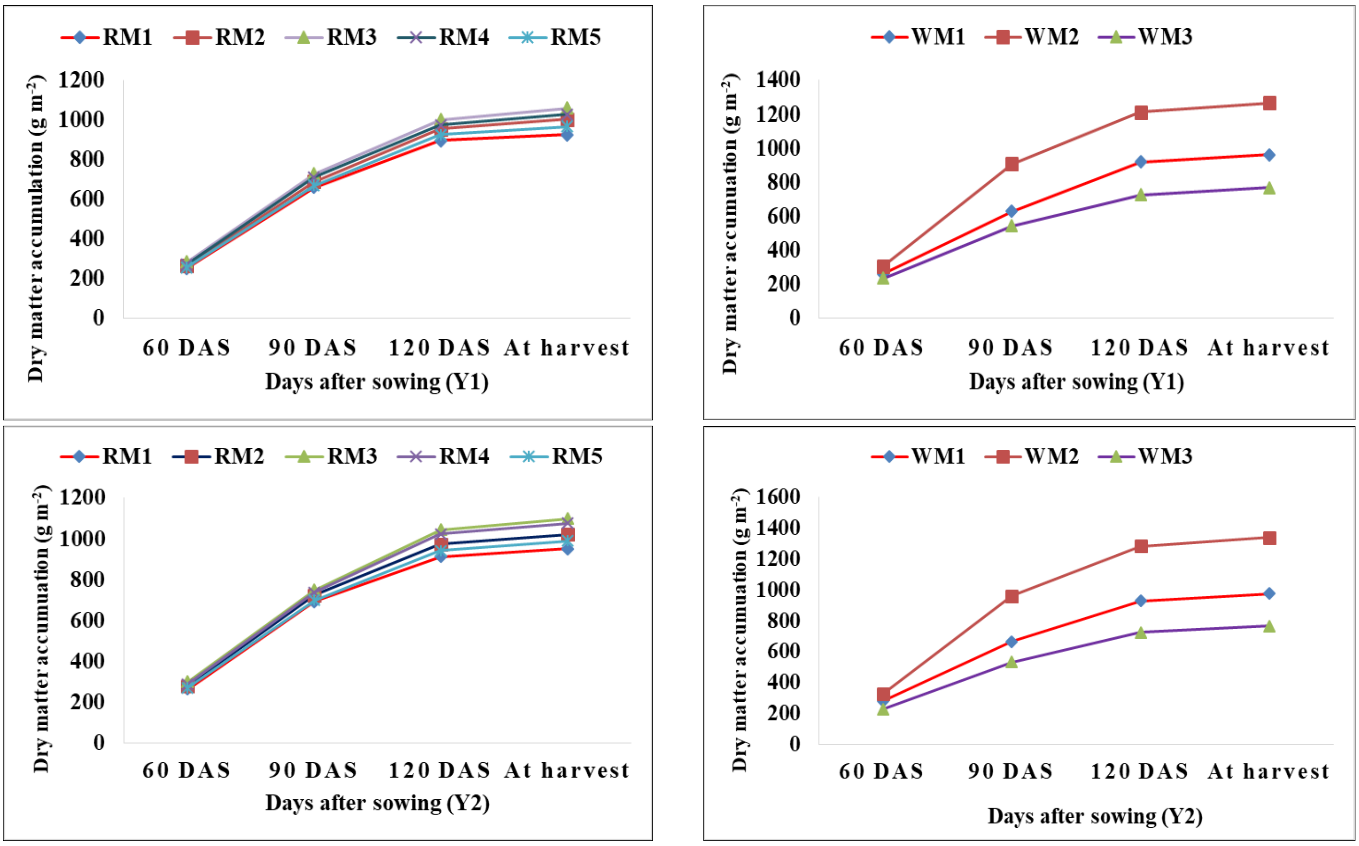

Fig. 4. Effect of rice residue and weed management practices on periodic dry matter accumulation (g m^{-2}) of wheat during 2022-23 (Y_1) and 2023-24 (Y_2).

Table 3. Effect of rice residue and weed management practices on yield attributes and yield of wheat during 2022-23 (Y_1) and 2023-24 (Y_2)

Treatment details	Number of effective tiller (m^{-2})		No. of grain spikes^{-1}		Grain yield (kg ha^{-1})		Straw yield (kg ha^{-1})	
Main plot	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2
RM_1	310.66	314.55	37.55	38.11	4140.44	4297.45	5041.34	5152.64
RM_2	322.77	327.66	38.88	39.11	4556.21	4691.23	5359.65	5471.35
RM_3	339.44	342.55	40.00	40.66	4904.87	4948.21	5663.23	5706.33
RM_4	331.33	334.22	39.33	40.00	4331.33	4418.57	5278.43	5371.54
RM_5	317.77	319.66	38.44	38.55	4255.77	4392.66	5157.11	5265.78
SEm (±)	5.41	5.45	0.44	0.52	128.62	124.35	110.11	91.26
CD (5 %)	17.93	18.05	1.48	1.73	425.99	411.83	364.67	302.24
Sub plot								
WM_1	324.13	329.93	38.93	39.40	37.81	38.96	4320.86	4583.13
WM_2	366.46	372.66	41.66	42.80	40.12	40.98	5953.05	6049.60
WM_3	282.60	280.60	35.93	35.66	36.26	36.20	3039.27	3016.13
SEm (±)	3.29	4.76	0.29	0.28	1.04	0.91	37.49	58.19
CD (5 %)	9.79	14.14	0.88	0.87	3.06	2.70	111.39	172.89

presented in Table 3. were significantly affected by rice residue and weed management practices while, 1000 grain weight was only significantly affected by weed management practices. Under rice residue management practices, the significantly higher number of effective tillers and number of grains spike^{-1} were registered with treatment RM_3 which was statistically at par with RM_4 and RM_2 over RM_1. This was due to incorporation of rice residue fasten the process of mineralisation which improved the soil microbial activity (14). This process promotes in addition of substantial organic matter which helps in replenishing major nutrient and enhanced translocation of photosynthates from source to sink which led to significant enhancement in yield attributes (15).

Among the weed management practices application of Clodinafop-propargyl 60 g ha^{-1} + Metsulfuron-methyl 4 g ha^{-1}PoE (WM_2) proved to be superior to other weed management practices in terms of yield attributes. The reason for the notable increase in yield attributes is that application Clodinafop-propargyl 60 g ha^{-1} + Metsulfuron-methyl 4 g ha^{-1} (PoE) significantly improved all growth parameter characteristics, creating the ideal environment by significantly reducing inter-generic competition through wide spectrum weed control, which in turn improved plant growth. The Reduced crop weed competition improved source formation, increasing net photosynthesis and improved carbohydrate translocation, which raised sink realisation (16, 17).

Effect of rice residue and weed management practice on yield of wheat

Data with respect to grain yield, straw yield and harvest index of wheat in Table 3. Indicate that treatment RM_3 produced significantly higher grain and straw yield as well as numerically better harvest index which was statistically at par with RM_2 over RM_1. The reason ascribed that addition of crop residue with additional fertilization might have improved the soil health and consequently higher uptake of available nutrients from the soil and increased the number of effective tillers, length of ear-head number of spikelet's spike^{-1} and 1000 grain weight which ultimately attributed to increase in grain yield (13). Similar results were also reported in previous works (18, 19).

Among the weed management practices, the data revealed that application of Clodinafop-propargyl 60 g ha^{-1} + Metsulfuron-methyl 4 g ha^{-1} PoE (WM_2) proved to be superior over other weed management practices in terms of grain yield, straw yield and harvest index. The reason for the notable increase in grain and straw yield under this treatment was due to complete suppression of mixed weed flora growth. This improved plant growth, increased LAI and yield qualities, which in turn increased the yield of wheat grain and straw. Moreover, reduced crop weed competition during critical period exerts an important regulation function which led to significant enhancement in yield of wheat crop. Similar results were also reported in previous works (18, 19).

Correlation between effective tillers, grain per spike and grain yield

The correlation between effective tillers, grain per spike and grain yield show a very strong positive correlation (0.98) (Fig. 5). This indicates that as the number of effective tillers increases, the grain yield also increases significantly. Similarly, the number of grains per spike also has a strong correlation (0.97) with grain yield, implying that more grains per spike contribute positively to higher yield. The correlation between the number of effective tillers and grains per spike is nearly perfect (1.00). This suggests that an increase in tillers is directly linked to an increase in grains per spike.

The findings indicate that higher tiller density and increased grains per spike are major contributors to maximizing wheat yield. Treatments RM_3 (residue incorporation) and WM_2 (Clodinafop-propargyl + Metsulfuron-methyl), which recorded highest numbers of effective tiller and grains per spike, also recorded the highest yields. This suggests that optimized residue management and effective weed control significantly enhance growth parameters and final yield.

Conclusion

The study highlights the significance of effective rice residue management and weed control strategies in enhancing wheat growth and yield. Among the residue management practices, Residue incorporation in the soil (RM_3 - Super Seeder) demonstrated superior performance across various growth parameters, yield attributes and overall wheat productivity. Similarly, among the weed management treatments, Clodinafop-propargyl 60 g ha^{-1} + Metsulfuron-methyl 4 g ha^{-1} (PoE) (WM_2) recorded the highest growth parameters, yield attributes and wheat yield. These findings suggest that integrating residue incorporation with effective weed control measures can significantly improve wheat productivity, contributing to sustainable farming practices. The study underscores the importance of adopting strategic residue and weed management approaches to enhance soil health, optimize crop growth and ensure long-term agricultural sustainability.

Authors' contributions

HS, BRB, RP and NS carried out the field experiment, collection and analysis of data, participated in the sequence alignment and drafted the manuscript. JSM and SKM participated in the design of the study, supervised the whole research and helped in compiling the manuscript. FF and CL conceived the study and participated in data collection, compiling and analysis. All authors read and approved the final manuscript.

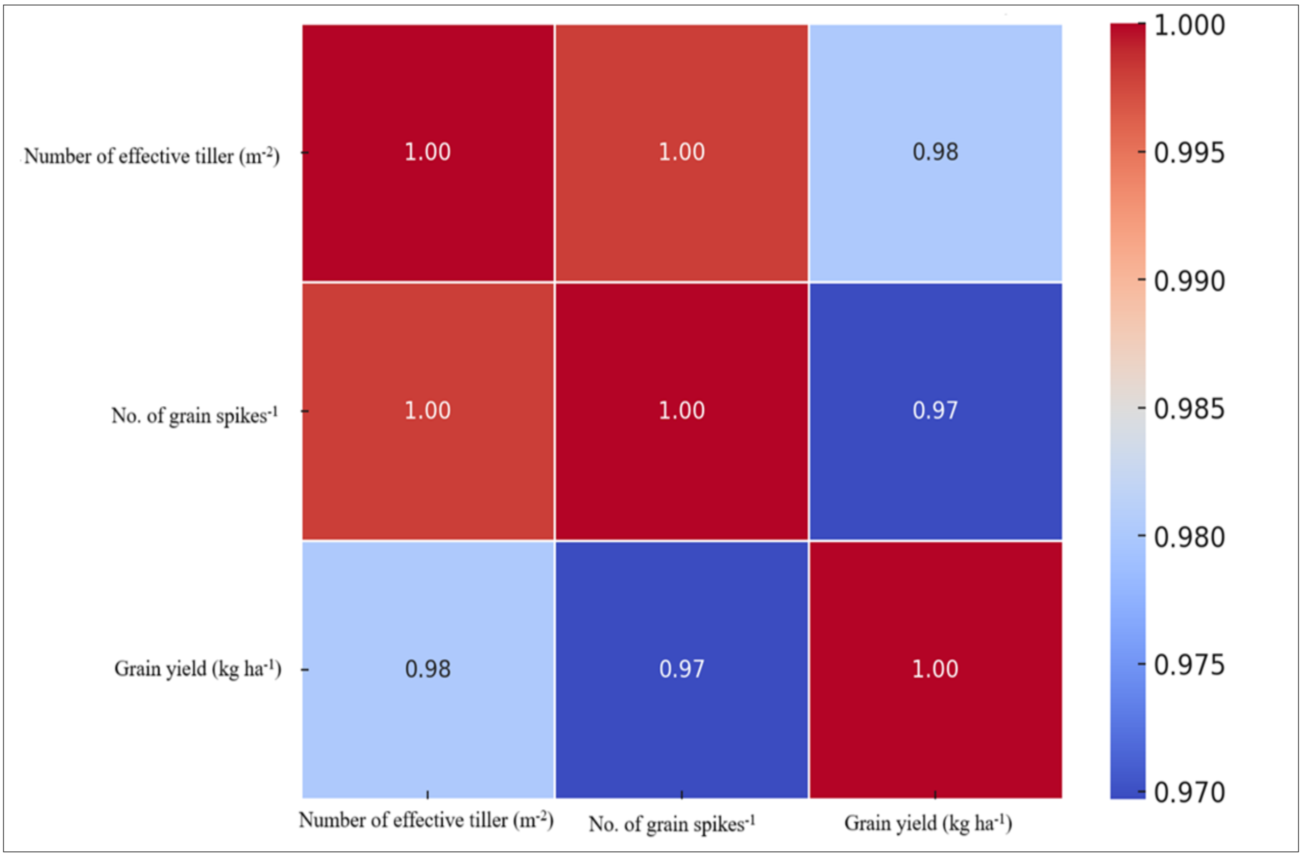

Fig. 5. Correlation matrix between effective tillers, grain per spike and grain yield.

Compliance with ethical standards

Conflict of interest: All the authors do not have any conflict of interest to declare.

Ethical issues: None

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