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Assessment of Seeding Methods and Weed Management Practices on Weed Dynamics, Crop Performance and Profitability in Rice-Safflower System

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Abstract

Rice–safflower cropping systems face challenges related to crop establishment, rice-residue management and weed competition, which can adversely affect safflower productivity and profitability. A field experiment was conducted at the Research-cum-Instructional Farm of Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh during the *Kharif* and *Rabi* seasons of 2019-20 and 2021-22 to assess the effects of sowing methods and weed management practices in a direct-seeded rice-based cropping system with rice residue retention on weed dynamics and productivity. During the *Kharif* season, rice was sown directly following standard agronomic practices, while during the *Rabi* season, safflower was grown using a split-plot design comprising three sowing methods *namely* zero seed drill, happy seed drill and normal seed drill (with soil preparation only by rotavator) in the main plots and three weed management practices *namely* chemical weed control, hand weeding twice and unweeded check in the subplots, with three replications. The happy seed drill resulted in significantly higher seed and stover yields of safflower (1381 and 3459 kg ha^{-1}, respectively). Hand weeding twice resulted in higher seed and stover yields of safflower (1629 and 4050 kg ha^{-1}, respectively).

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Weed density was lowest in the hand weeding twice treatment, with mean values of 3.61, 3.80 and 4.68 at 30, 60 and 90 days after sowing, respectively and a maximum weed control efficiency of 80.24% compared with unweeded check. Maximum gross returns (7.28 and 8.56 10^3 x ₹ha^{-1}), net returns (4.72 and 5.60 10^3 x ₹ha^{-1}), benefit–cost ratios (2.80 and 2.88), rice equivalent yield (mean value of 3909 and 4614 kg ha^{-1}) system productivity (mean value of 8737 and 9442 kg ha^{-1}) and production efficiency (mean value of 11.64 and 12.28 kg $ha^{-1}day^{-1}$) of safflower were recorded under happy seed drill and hand weeding twice.

Keywords: Carthamus tinctorius L.; direct-seeded rice; rice-residue retention; happy seed drill; zero-tillage; weed density; weed-control efficiency; hand weeding; rice-equivalent yield; crop profitability.

1. Introduction

Rice-based cropping systems are prevalent across various regions of India, ranging from continuous rice to rice followed by a variety of cereals, pulses, oilseeds, vegetables and fibre crops (Deep *et al.*, 2018). Despite the diversity, approximately 30% (11.7 million hectares) of the area under rice production during *Kharif* season in India remains fallow in the subsequent *Rabi* season due to various biotic, abiotic and socioeconomic constraints (Kumar *et al.*, 2019).

Safflower (*Carthamus tinctorius* L.) holds the distinction of being one of the oldest cultivated crops globally (Chapman & Burke, 2007). It is valued for its oil content (35-40%) and high linoleic acid content (75-86%). In India, safflower was cultivated across an area of 48.89 thousand hectares, yielding approximately 0.57 lakh tonnes with a reported productivity of 763 kg ha^{-1} (Ministry of Agriculture and Farmers Welfare, 2022). Recent research on irrigated safflower recorded differences in weed infestation, seed yield and economic returns among tillage and weed-management treatments (Shinde *et al.*, 2026).

In a maize-safflower cropping system, safflower productivity and profitability also varied with tillage and weed-management practices (Reddy *et al.*, 2025). Conservation agriculture, based on three principles—minimum soil disturbance, permanent soil surface cover using crop residues, and diversified crop rotation—offers a promising approach to sustainable agriculture (Hobbs *et al.*, 2008). Crop yields in conservation agriculture systems can match those of conventional systems provided uniform crop stands are achieved and effective weed control measures are implemented.

In a rice-maize rotation, conservation-agriculture and weed-management treatments influenced weed communities and crop productivity (Sahoo *et al.*, 2024). A post-monsoon groundnut study similarly reported lower weed density and dry weight under rice-straw mulching than in unmulched plots (Shin and Zar, 2026). The Happy Seeder is a technology used for sowing crops without burning rice residue. The Happy Seeder is environmentally friendly and can improve soil conditions while saving water, time and labour (Singh *et al.*, 2020; Mooventhan *et al.*, 2018). Sowing with the happy seed drill allows safflower to be drilled into rice stubble without burning, thereby avoiding the air pollution and losses of nutrients and organic carbon associated with burning, while maintaining crop yield (Sidhu *et al.,* 2007; Sidhu *et al.*, 2015). A study conducted at Raipur by Kosariya *and Naik* (2019) reported that the happy seeder method retained paddy straw in the field, eliminated the need for tillage and resulted in higher chickpea yields than conventional methods. A rice-wheat study found lower weed density and biomass under Happy Seeder establishment with retained rice residue than under alternative rice-residue management practices (Kaur *et al.*, 2025).

Weeds can cause serious yield losses when they are not controlled adequately and at the appropriate time (Bhalla *et al.*, 1998; Hosseini, 1997). Safflower requires good weed control for optimum yield, because its seedlings grow slowly for several weeks during the rosette stage and before stem elongation, when safflower competes poorly with weeds. Weed infestation in safflower can reduce yield (Yau & Haidar, 2008). In contrast, growing safflower under weed-free conditions resulted in higher yield attributes and seed yield. Timely implementation of weed-management practices is essential for successful crop cultivation (Ahmed *et al.*, 2005; Dwivedi, 2018; Kumar & Nagaich, 2013). Although sowing methods and weed-control measures have been examined individually, comparative evidence on their combined performance in a rice–safflower system with retained rice residues remains limited within the studies considered here. The objective of this study was to evaluate the effects of sowing methods and weed management on growth, yield attributes and productivity in a rice–safflower cropping system with rice-residue retention.

2. Materials and Methods

2.1 Study Site

A two-year experiment was conducted during *Kharif* and *Rabi* seasons of 2019-20 and 2020-21 at the Research-cum-Instructional Farm of Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh. The farm is located at 21˚4’ N latitude and 81˚35’ E longitude, with an altitude of 290.20 metres above mean sea level. The experimental soil was clay in texture, neutral in reaction, low in organic carbon and available nitrogen, medium in available phosphorus, and high in available potassium.

2.2 Experimental Design and Treatment Details

The study employed a split-plot design with three replications, comprising three main-plot seeding methods: zero seed drill, happy seed drill and normal seed drill (soil preparation using only a rotavator). Three weed-management practices—chemical weed control, hand weeding twice and an unweeded check—were allocated to the subplots.

2.3 Crop Management

During the *Kharif* season, the rice variety ‘Rajeshwari’ was directly sown in the main field following standard agronomic practices without any specific treatment, and safflower was subsequently cultivated during the *Rabi* season.

Sowing was carried out using seed-cum-fertiliser drill, zero-till seed drill and happy seed drill, corresponding to the treatment, in the first fortnight of November using “PBNS-12” safflower cultivar in both experimental years. All recommended nutrients,

comprising 90 kg N + 40 kg P + 30 kg K + 20 kg Sha^{-1}were applied as chemical fertilizers (urea, SSP and MoP), as a basal dose at sowing. The crop was sown in rows spaced 20 cm apart, treated with Bavistin at the rate of 2.5 gkg^{-1} of seed, followed by PSB and Rhizobium culture at 5 g kg^{-1} of seed. Weed-management practices, including hand weeding at 20 and 40 days after sowing and chemical weed control using pendimethalin at 1 $kgha^{-1}$ as pre-emergence were implemented according to the treatment allocations.

2.4 Crop Observations, Weed Dynamics, Economic Analysis and Statistical Analysis

Five randomly selected plants from each plot were assessed for growth parameters, including plant height, number of $branchesplant^{-1}$, dry matter accumulation, number of capitula $plant^{-1}$, number of seeds $capitulum^{-1}$, number of seeds $plant^{-1}$ and 100-seed weight (g), at crop harvest. Seed yield was determined by harvesting from the net plot area separately and weighing them, whereas stover was bundled and weighed separately for each plot. Weed-control efficiency was computed for the different treatments. The economic analysis was conducted in terms of the cost of cultivation. The benefit–cost ratio (B:C) was calculated by dividing gross returns by cost of cultivation. All data collected from the experiment underwent statistical analysis using F-test, following the procedure given by Gomez and Gomez (1984), with critical-difference (CD) values at P = 0.05 used to ascertain the significance of mean treatment differences.

3. Results and Discussion

3.1 Growth Parameters

Analysis of the methods of sowing and weed management in safflower indicated that the highest growth parameters were consistently observed under happy seed drill and hand weeding twice throughout both years of observation. Previous studies by Sidhu *et al.* (2007) and Sidhu (2008) demonstrated that emergence counts was notably higher with happy seeder sowing. Similarly, research by Virk (2016) in soybean showed that plant height was significantly greater in happy seeder sowing than conventional sowing. This observation might be attributed to factors such as lower soil temperature, higher moisture content and weed-free conditions at all the growth stages (Aulakh *et al.,* 2012), resulting in favourable conditions for plant growth.

3.2 Yield Attributes and Yields

Across both years, sowing with the happy seed drill produced significantly higher values for several yield attributes and yield than the other sowing methods (Table 1; Table 2). These attributes included the number of capitula $plant^{-1}$ (24.58), number of seeds $capitulum^{-1}$ (23.32), number of seeds $plant^{-1}$ (566.95), 100-seed weight (5.40 g), seed yield (1381 kg $ha^{-}1$) and stover yield (3459 kg ha^{-1}) observed under happy seeder sowing. These results could be attributed to improvements in growth parameters such as plant height and dry matter accumulation, facilitated by moisture conservation (Jalota *et al.*, 2001; Rathore *et al.*, 1998) and increased availability of nutrients in the root zone due to straw mulching (Yadvinder-Singh *et al.,* 2009). However, the lowest values of these parameters were consistently recorded under the zero seed drill in both years of observation. Kosariya *et al.* (2019) reported that chickpea yielded a higher grain yield under happy seeder (1137.8 kg ha^{-1}). Similarly, Virk (2016) also observed significantly higher seed yield in happy seeder sowing in soybean.

Among the weed management practices, hand weeding twice consistently resulted in the maximum values for the number of capitula $plant^{-1}$(20.52), number of seeds $capitulum^{-1}$(21.42), number of seeds $plant^{-1}$(447.67), 100-seed weight (g) (5.14), seed yield (kg ha^{-1})(1629) and stover yield (kg ha^{-1})(4050) across both observation years. Conversely, the lowest values were consistently observed under the unweeded check. These observations could be attributed to the weed-free periods and reduced competition between weeds and crops. Similar results were observed by Yau and Haidar (2008) who observed that weed competition reduced yield components such as primary branches, petal weight and number of capitula $plant^{-1}$. Additionally, Jalali *et al.* (2012) also reported that weed competition reduced yield components such as primary branches, petal weight and number of capitula $plant^{-1}$. The highest grain yield (3703 kg ha-1) was obtained in the weed-free plot.

3.3 Weed Flora Composition

Predominant weed species observed in the experimental field included *Chenopodium album, Medicago denticulata, Cichorium intybus,* while other species such as *Melilotus indica, Alternanthera sessilis, Echinochloa colona* and *Physalis minima* were observed in lower abundance and grouped as other weeds.

The results revealed lower weed density under the happy seed drill and hand weeding twice treatments at 30, 60 and 90 days during both experimental seasons possibly because of reduced weed competition, especially during critical crop growth stages, as indicated by the increased values of yield attributes. Chemical weed management was observed to control only the initial weed flushes, while hand weeding twice at 20 and 40 DAS significantly reduced weed population. Severe weed competition in the unweeded check was associated with to poor growth and yield attributes, resulting in lower seed yields. These findings are consistent with previous reports by Poonia *and Pithia* (2013), Kaushik *et al.* (2014) and Kour *et al.* (2014). A significantly higher dry weight of weeds was recorded in the unweeded check due to the absence of pre-emergence herbicide application and hand weeding at 30 and 45 DAS, in line with findings by Patel *et al.* (2006), Sharma (2009) and Kour *et al.* (2014). Hand weeding twice at 21 and 45 DAS was associated with a lower total weed count in a related linseed study (Dwivedi & Puhup, 2019).

Table 1. Growth parameters (at harvest stage) and yield attributes of safflower as influenced by different methods of sowing and weed management practices in rice-safflower system

Treatment	Growth parameters												Yield attributes								
	Plant height (cm)			Branches plant^{-1}			Dry matter accumulation (g plant^{-1})			Number of capitula plant^{-1}			Number of seeds capitulum^{-1}			Number of seeds plant^{-1}			100 seed weight (g)		
	19-20	20-21	Mean	19-20	20-21	Mean	19-20	20-21	Mean	19-20	20-21	Mean	19-20	20-21	Mean	19-20	20-21	Mean	19-20	20-21	Mean
Methods of sowing																					
Zero seed drill	92.38	94.65	93.51	6.69	6.70	6.70	38.99	39.22	39.11	13.56	14.93	14.24	16.01	18.70	17.36	218.80	280.35	249.57	4.49	4.60	4.55
Happy seed drill	110.71	112.02	111.37	7.65	7.80	7.73	44.77	45.34	45.06	24.55	24.61	24.58	22.72	23.32	23.02	558.08	575.82	566.95	5.38	5.43	5.40
Normal seed drill (soil preparation only by rotavator)	100.18	102.24	101.21	7.28	7.29	7.28	41.91	42.34	42.13	17.27	18.22	17.74	18.26	21.84	20.05	316.76	398.18	357.47	4.81	4.90	4.86
SEm±	0.95	0.87	0.65	0.14	0.12	0.12	0.92	0.98	0.95	0.11	0.30	0.10	1.32	1.15	0.90	25.15	24.09	19.94	0.18	0.17	0.14
CD (P≤0.05)	3.75	3.42	2.57	0.55	0.48	0.46	2.78	2.94	2.86	0.45	1.17	0.39	-	-	-	98.75	94.60	78.28	-	-	-
Weed management practices																					
Chemical weed control	102.47	103.37	102.92	7.19	7.22	7.20	39.90	41.35	40.63	18.29	19.12	18.71	18.87	21.17	20.02	356.53	414.78	385.66	4.88	4.91	4.89
Hand weeding twice	109.60	111.55	110.57	7.53	7.62	7.57	41.47	42.92	42.19	20.29	20.75	20.52	20.14	22.70	21.42	418.23	477.12	447.67	5.12	5.15	5.14
Unweeded check	91.21	94.00	92.60	6.91	6.95	6.93	38.31	39.76	39.04	16.78	17.89	17.34	17.99	19.99	18.99	318.88	362.45	340.67	4.68	4.88	4.78
SEm±	1.29	1.07	0.64	0.15	0.13	0.11	0.48	0.49	0.48	0.26	0.13	0.14	0.57	0.89	0.37	10.95	14.48	8.39	0.18	0.10	0.10
CD (P≤0.05)	3.97	3.29	1.98	0.47	0.40	0.34	1.49	1.47	1.48	0.79	0.42	0.42	-	-	-	33.74	44.63	25.86	-	-	-

Table 2. Yields, Total weed density at 30, 60 and 90 DAS of safflower as influenced by different methods of sowing and weed management practices in rice-safflower system

Treatment	Yields						Total weed density (number m^{-2})									Weed control efficiency (%)		
	Seed yield (kgha^{-1})			Stover yield (kgha^{-1})			30 DAS			60 DAS			90 DAS					
	19-20	20-21	Mean	19-20	20-21	Mean	19-20	20-21	Mean	19-20	20-21	Mean	19-20	20-21	Mean	19-20	20-21	Mean
Methods of sowing																		
Zero seed drill	953	1006	980	3123	3161	3142	5.26 (31)	4.80 (26)	5.04 (28)	6.96 (53)	6.06 (42)	6.53 (47)	8.40 (79)	7.60 (65)	8.01 (72)	41.25	43.78	42.46
Happy seed drill	1363	1398	1381	3436	3482	3459	4.61 (24)	3.58 (14)	4.14 (19)	6.29 (43)	5.48 (33)	5.90 (38)	7.57 (65)	6.61 (50)	7.11 (58)	48.66	51.92	50.22
Normal seed drill (soil preparation only by rotavator)	1194	1216	1205	3259	3269	3264	6.73 (47)	5.64 (35)	6.22 (41)	7.65 (62)	6.90 (53)	7.29 (58)	9.37 (95)	8.56 (82)	8.98 (89)	30.24	34.26	32.16
SEm±	14.46	16.68	13.86	13.79	18.83	11.05	0.10	0.11	0.10	0.05	0.14	0.06	0.12	0.07	0.09	-	-	-
CD (P≤0.05)	56.77	65.48	54.43	54.16	73.92	43.37	0.39	0.40	0.33	0.21	0.57	0.25	0.48	0.29	0.34	-	-	-
Weed management																		
Chemical weed control	1233	1252	1243	3503	3519	3511	4.63 (22)	3.81 (15)	4.25 (18)	7.33 (54)	6.43 (41)	6.90 (47)	8.23 (68)	7.30 (54)	7.79 (61)	42.23	47.18	44.60
Hand weeding twice	1620	1638	1629	4026	4074	4050	4.02 (17)	3.14 (10)	3.61 (13)	4.24 (18)	3.31 (11)	3.80 (14)	5.03 (26)	4.31 (18)	4.68 (22)	77.92	82.78	80.24

Treatment	Yields						Total weed density (number m^{-2})									Weed control efficiency (%)		
	Seed yield ($kgha^{-1}$)			Stover yield ($kgha^{-1}$)			30 DAS			60 DAS			90 DAS					
	19-20	20-21	Mean	19-20	20-21	Mean	19-20	20-21	Mean	19-20	20-21	Mean	19-20	20-21	Mean	19-20	20-21	Mean
Unweeded check control	656	730	693	2289	2318	2304	7.96 (64)	7.06 (51)	7.53 (57)	9.34 (87)	8.70 (76)	9.03 (82)	12.09 (146)	11.16 (125)	11.64 (136)	-	-	-
SEm±	10.64	16.71	9.31	9.56	14.75	8.62	0.11	0.14	0.08	0.08	0.12	0.07	0.09	0.13	0.07	-	-	-
CD (P≤0.05)	32.77	51.50	28.69	29.45	45.46	26.58	0.33	0.43	0.24	0.24	0.38	0.20	0.29	0.39	0.21	-	-	-

Figures in parenthesis are original values and have been transformed ($\sqrt{X+0.5}$ before statistical analysis

Table 3. Economics, Rice equivalent yield, System productivity and Production efficiency of safflower as influenced by different methods of sowing and weed management practices in rice-safflower system

Treatment	Net returns (10^3 x ₹/ha)			B:C ratio			Rice equivalent yield ($kg\ ha^{-1}$)			System productivity ($kg\ ha^{-1}$)			Production efficiency ($kg\ ha^{-1}\ day^{-1}$)		
	19-20	20-21	Mean	19-20	20-21	Mean	19-20	20-21	Mean	19-20	20-21	Mean	19-20	20-21	Mean
Main plot- Methods of sowing															
Zero seed drill	2.55	2.73	2.64	1.98	1.97	1.98	2709	2839	2774	7528	7676	7602	8.42	8.63	8.53
Happy seed drill	4.66	4.78	4.72	2.85	2.75	2.80	3873	3946	3909	8692	8783	8737	11.48	11.79	11.64
Normal seed drill (soil preparation only by rotavator)	3.69	3.69	3.69	2.39	2.28	2.33	3393	3430	3411	8212	8267	8239	10.28	10.50	10.39
SEm±	0.08	0.09	0.07	0.028	0.029	0.026	-	-	-	-	-	-	-	-	-
CD (P≤0.05)	0.30	0.35	0.29	0.110	0.113	0.100	-	-	-	-	-	-	-	-	-
Sub plot- Weed management															
Chemical weed control	4.01	4.06	4.03	2.66	2.55	2.60	3504	3533	3518	8323	8370	8346	11.37	11.36	11.37
Hand weeding twice	5.60	5.60	5.60	2.97	2.79	2.88	4605	4623	4614	9424	9460	9442	12.12	12.44	12.28
Unweeded check control	1.28	1.55	1.41	1.60	1.66	1.63	1866	2059	1962	6685	6896	6790	6.70	7.12	6.91
SEm±	0.06	0.09	0.05	0.020	0.030	0.017	-	-	-	-	-	-	-	-	-
CD (P≤0.05)	0.17	0.27	0.15	0.061	0.092	0.052	-	-	-	-	-	-	-	-	-

Additionally, these treatments increased weed-control efficiency and improved the weed index, contributing to higher yields (Table 2; Fig. 1). Rahman *et al.* (2005) reported reduced weed growth in no-till wheat under rice-straw mulching, consistent with the weed-suppression effects observed in residue-retaining systems.

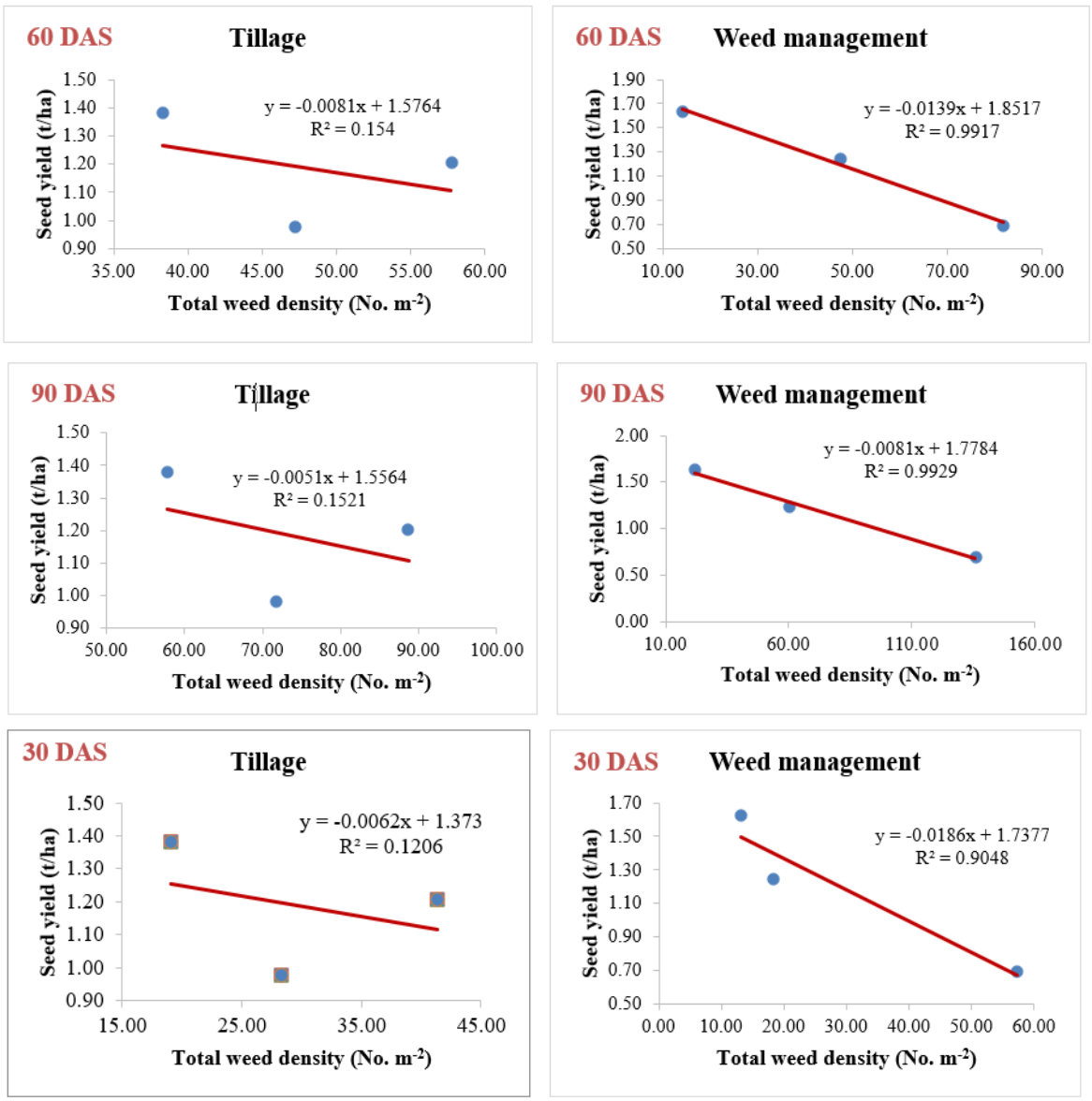


Fig. 1. Relationship between grain yield (t/ha) and total weed density (Total weed density (No. m^{-2}) safflower as influenced by different methods of sowing and weed management in rice-safflower system (mean of two years)

3.4 Economics of Safflower

Sowing safflower with happy seed drill resulted in the highest gross returns (Mean 7.2810^3 x ₹ ha^{-1}) and net returns (Mean 4.7210^3 x ₹ ha^{-1}), whereas the lowest returns were recorded under zero seed drill during both years of observation. This could be attributed to higher seed and straw yields of safflower. Similar results were reported by Kosariya and Naik (2019), who found the happy seed drill to be more economical than other drills. Happy seeder technology can reduce cultivation costs and enable farmers to sow crops immediately after rice harvesting without additional tillage, potentially avoiding delayed sowing (Pandit *et al.*, 2010).

Among the weed management practices, the maximum gross returns (Mean 8.5910^3 x ₹ ha^{-1}) and net returns (Mean 5.6010^3 x ₹ ha^{-1}) were noted under hand weeding twice, whereas the minimum returns were recorded under unweeded check during both the years. Rathod *et al.* (2016) also reported higher gross returns, net returns and benefit–cost ratios with two hand weedings at 20 and 40 DAS in chickpea.

3.5 System Analysis of Safflower

Analysis of rice equivalent yield, system productivity and production efficiency of safflower under different sowing methods and weed management practices showed the highest rice-equivalent yield (3909 and 4614 kg ha^{-1}) system productivity (8737 and 9442 kg ha^{-1}) and production efficiency (11.64 and 12.28 kg $ha^{-1}day^{-1}$) under the happy seed drill and hand weeding twice treatments (Table 3). Conversely, the lowest values were recorded under the zero seed drill and unweeded check treatments during both the years. Kumar *et al.* (2020) similarly reported that different combinations of crop establishment methods and residue management led to higher annual system productivity and production efficiency in rice-chickpea, rice-safflower and rice-lentil rotations.

4. Conclusions

The field experiment demonstrated that sowing methods and weed-management practices influenced safflower growth, yield, weed suppression and profitability in the rice–safflower system with retained rice residues. Among the three sowing methods, the happy seed drill produced the highest mean seed yield (1,381 kg ha^{-1}) and stover yield (3,459 kg ha^{-1}). It also recorded a mean rice-equivalent yield of 3,909 kg ha^{-1}, system productivity of 8,737 kg ha^{-1} and a benefit–cost ratio of 2.80. Among the weed-management practices, hand weeding twice at 20 and 40 days after sowing resulted in the highest mean seed yield (1,629 kg ha^{-1}), stover yield (4,050 kg ha^{-1}) and weed-control efficiency (80.24%). It was also associated with a mean rice-equivalent yield of 4,614 kg ha^{-1}, system productivity of 9,442 kg ha^{-1} and a benefit–cost ratio of 2.88. These results indicate that the happy seed drill and two hand weedings performed favourably within their respective treatment comparisons. However, the reported main effects do not establish the performance of every combination of sowing method and weed management. Additional experiments across locations and seasons would help assess the wider applicability of the observed responses.

5. Limitations

The study was conducted at a single research farm over two experimental seasons using one safflower cultivar and a limited set of sowing and weed-management treatments. Consequently, the findings may not extend to different soil types, climates or production systems. Long-term effects of rice-residue retention were not assessed. Further multi-location and multi-season trials, with explicit interaction analyses and consistent reporting, would strengthen the evidence.

Declaration of AI Use

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

Competing Interests

Authors have declared that no competing interests exist.

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