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Effect of weed management practices on system performance of semi-dry rice-based relay cropping system

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Abstract

A field experiment was conducted during 2023-24 and 2024-25 at ICAR–Indian Institute of Rice Research, Rajendranagar, Hyderabad, on sandy clay loam soils to evaluate the effect of weed management practices on the system performance of semi-dry rice-based relay cropping system. The experiment was laid out in a Randomized Block Design with nine treatments, viz., T₁: Seed hardening before sowing *fb* Post Emergence (PoE) application of triafamone + ethoxysulfuron 10 WDG @ 67.5 g *a.i.* ha⁻¹ at 35-40 days after sowing (DAS) of rice, T₂: High seed rate of paddy (45 kg ha⁻¹) followed by PoE application of triafamone + ethoxysulfuron 10 WDG @ 67.5 g *a.i.* ha⁻¹ at 35-40 DAS of rice, T₃: *Sesbania aculeata* @ 25 kg ha⁻¹ co-culture and brown manuring at 35-45 DAS of rice, T₄: Surface Mulching with chopped paddy straw @ 5 t ha⁻¹, T₅: Biodegradable mulch filming, T₆: Pre-Emergence (PE) application of pyrazosulfuronethyl 70% WDG @ 21 g *a.i.* ha⁻¹ *fb* PoE application of triafamone + ethoxysulfuron 10WDG @ 67.5 g *a.i.* ha⁻¹ at 35-40 DAS of rice, T₇: Mechanical weeding twice using weeder at 20-25 DAS and 40-45 DAS, T₈: Weed-free, T₉: Weedy check. Weed management significantly influenced system productivity, production efficiency and economic returns. The weed-free treatment (T₈) recorded the highest system productivity (8792 kg ha⁻¹), production efficiency (41.86 kg ha⁻¹ day⁻¹) and gross returns (₹216045 ha⁻¹), which were statistically comparable with biodegradable mulch (T₅) and paddy straw mulch (T₄). However, maximum net returns (₹139663 ha⁻¹), benefit–cost ratio (3.10) and system profitability (₹665 ha⁻¹ day⁻¹) were recorded with paddy straw mulch (T₄), followed by T₆ and T₇. Moderate performance was observed under T₂, T₆ and T₇, whereas T₁ and T₃ recorded lower values. The weedy check (T₉) resulted in the lowest productivity, efficiency and economic returns. The results indicate that paddy straw mulching is an economically viable and sustainable weed management practice for improving system performance in semi-dry rice-based relay cropping systems.

Keywords: Semi-dry rice, relay cropping, weed management, system performance, productivity, profitability, mulching.

Introduction

Relay cropping in rice is an efficient form of multiple cropping in which the succeeding crop is sown into a standing rice crop before its harvest, enabling timely establishment of the next crop and better utilization of available resources (Tanveer *et al.*, 2017) [7]. In semi-dry rice ecosystems, this approach offers considerable scope to intensify cropping systems, as fields are often left fallow after harvest, particularly during the summer season, leading to underutilization of residual soil moisture and nutrients, greater evaporative losses, and an increased risk of soil degradation. Introducing relay crops into such systems can effectively minimize the fallow period, enhance land-use efficiency, and improve cropping intensity without substantial additional inputs. Relay cropping is particularly advantageous in semi-dry rice systems because it exploits residual soil moisture, available nutrients, and favourable microclimatic conditions created by the standing rice crop. By ensuring continuous ground cover and timely crop establishment, relay cropping helps conserve soil moisture, reduce erosion losses, and improve overall resource-use efficiency. Moreover, inclusion of short-duration crops in relay sequence contributes to diversification and stabilization of production, thereby improving the

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sustainability of rice-based cropping systems and enhancing farm income. Among the crops suitable for relay introduction in semi-dry rice systems, short-duration legumes such as cowpea, black gram, green gram and soybean, as well as millets like foxtail millet and pearl millet, offer significant agronomic and economic advantages. These crops are well adapted to residual moisture conditions, establish quickly, and provide effective ground cover. Their inclusion in relay systems helps suppress weed growth through smothering effects, reduce soil moisture evaporation, improve soil physical condition, and enhance soil fertility, particularly in legume-based systems. In addition, these crops may exhibit better tolerance to herbicide carryover effects from the preceding crop, making them suitable components of intensified rice-based systems (Miller *et al.*, 2018) [4]. Such integration not only improves system resilience but also contributes to higher system productivity and profitability.

Despite these advantages, the success of semi-dry rice-based relay cropping systems is largely determined by effective crop and weed management. Weed infestation remains one of the major biological constraints in relay systems, as weeds compete aggressively for moisture, nutrients, light and space during the critical establishment period of both rice and relay crops. Poor weed management can reduce crop productivity, lower resource-use efficiency, and adversely affect the economic viability of the system. Therefore, identifying suitable weed management practices is essential for improving weed control, enhancing system productivity, and sustaining profitability in semi-dry rice-based relay cropping systems.

In this context, the present investigation was undertaken to evaluate the effect of different weed management practices on system performance of semi-dry rice-based relay cropping system, with particular emphasis on productivity, production efficiency, and economic returns.

Materials and Methods

The present investigation was conducted at ICAR - Indian Institute of Rice Research (IIRR) (formerly ICAR-Directorate of Rice Research, ICAR-DRR), B block, Agronomy unit, Rajendranagar, Hyderabad, during the *rabi* of 2023-24 and 2024-25. According to Troll's climatic classification, it falls under semi-arid tropics. The site is located at 17.19° N latitude and 78.23° E longitude and at an altitude of 542.3 m above mean sea level. The experiment was laid out in a randomized block design (RBD) with nine treatments, viz., T₁: Seed hardening before sowing *fb* Post Emergence (PoE) application of triafamone + ethoxysulfuron 10 WDG @ 67.5 g *a.i.* ha⁻¹ at 35-40 days after sowing (DAS) of rice, T₂: High seed rate of paddy (45 kg ha⁻¹) followed by PoE application of triafamone + ethoxysulfuron 10 WDG @ 67.5 g *a.i.* ha⁻¹ at 35-40 DAS of rice, T₃: *Sesbania aculeata* @ 25 kg ha⁻¹ co-culture and brown manuring at 35-45 DAS of rice, T₄: Surface Mulching with chopped paddy straw @ 5 t ha⁻¹, T₅: Biodegradable mulch filming, T₆: Pre-Emergence (PE) application of pyrazosulfuronethyl 70% WDG @ 21 g *a.i.* ha⁻¹ *fb* PoE application of triafamone + ethoxysulfuron 10WDG @ 67.5 g *a.i.* ha⁻¹ at 35-40 DAS of rice, T₇: Mechanical weeding twice using weeder at 20-25 DAS and 40-45 DAS, T₈: Weed-free, T₉: Weedy check that are allocated randomly and replicated four times. The soil type of the experimental field was clay loam texture with alkaline pH, low in organic carbon and available nitrogen, medium in available phosphorus and higher in available potassium levels. Semi-dry direct-seeded rice was grown following recommended agronomic practices for the region. The crop was established under semi-dry conditions with

need-based irrigation and recommended nutrient management. The variety used in the experiment was DRRH – 4, a dry direct-seeded aerobic rice hybrid notified and released for commercial cultivation in 2022. Relay crops, cowpea (PGCP-6) and foxtail millet (Suryanandi), were sown into the standing rice crop before harvest to utilize residual soil moisture and nutrients. The relay crops were raised without disturbing the soil, ensuring continuity of the cropping system and efficient resource utilization.

System productivity (kg ha⁻¹) was calculated by converting yields of component crops into rice equivalent yield. System production efficiency (kg ha⁻¹ day⁻¹) was computed based on total system productivity and duration of crops. Economic parameters such as gross returns, net returns, benefit–cost ratio and system profitability (₹ ha⁻¹ day⁻¹) were calculated using prevailing market prices. The data obtained were subjected to analysis of variance (ANOVA) appropriate for RBD. Post-hoc analysis was conducted using the Least Significant Difference (LSD) test. Treatments were assigned letters to indicate significance, where means sharing the same letters were not significantly different.

Results and Discussion

System productivity (kg ha⁻¹)

System productivity of the rice-based cropping system was significantly influenced by different weed management practices during both years and in the pooled analysis. The data related to system productivity was mentioned in Table 1. Among all treatments, T₈ (weed-free) recorded the highest system productivity during 2024, 2025 and the pooled mean. The system productivity under T₈ was 8839, 8744 and 8792 kg ha⁻¹ during 2024, 2025 and the pooled mean, respectively, while it was comparable with T₅ (biodegradable mulch film) (8749, 8612 and 8681 kg ha⁻¹) during both years. In 2025, T₅ was found to be statistically at par to T₄ (paddy straw mulch) (8390 kg ha⁻¹), T₇ (mechanical weeding) (8206 kg ha⁻¹) and T₆ (PE *fb* PoE herbicide) (8180 kg ha⁻¹) and in pooled data, it was at par to T₄ (paddy straw mulch) (8413 kg ha⁻¹). Apart from weedy check, T₃ (brown manuring) (7338, 7177 and 7258 kg ha⁻¹) has recorded lower system productivity, and it was on par with T₁ (seed hardening + PoE herbicide) (7348, 7202 and 7275 kg ha⁻¹) during both the years of study.

Higher system productivity under T₈, T₅ and T₄ could be attributed to effective weed suppression in rice, which improved growth, yield and nutrient uptake of the main crop and also exerted beneficial residual effects on the succeeding crop. Better weed control under these treatments likely reduced crop–weed competition, improved resource use efficiency and enhanced overall system productivity. Similar results were also reported by Sahoo *et al.* (2024) [6].

System production efficiency (kg ha⁻¹ day⁻¹)

System production efficiency of the rice-based cropping system varied significantly due to different weed management practices during both years and in the pooled analysis. The data related to system production efficiency was mentioned in Table 1. Among the treatments, T₈ (weed free) recorded the highest system production efficiency which was statistically comparable with T₅ (biodegradable mulch film). Weed free registered 42.09, 41.64 and 41.86 kg ha⁻¹ day⁻¹ during both the years, whereas T₅ registered higher system production efficiency of 41.66 and 41.01 kg ha⁻¹ day⁻¹ during 2024 and 2025, respectively, with a pooled mean of 41.34 kg ha⁻¹ day⁻¹. In 2025 and pooled, T₈ was statistically at par with T₄ (paddy straw mulch) (39.95 kg ha⁻¹

day⁻¹), whereas in pooled it was also at par to T₇ (mechanical weeding) (39.08 kg ha⁻¹ day⁻¹) and T₆ (PE fb PoE herbicide) (38.95 kg ha⁻¹ day⁻¹). Apart from weedy check, T₃ (brown manuring) (34.94, 34.18 and 34.56 kg ha⁻¹ day⁻¹) has recorded lower system production efficiency and it was on par to T₁ (seed hardening + PoE herbicide) (34.99, 34.29 and 34.64 kg ha⁻¹ day⁻¹) during both the years of study. These results were in conformity with Das *et al.*

System profitability (₹ ha⁻¹ day⁻¹)

System profitability of the rice-based cropping system during both the years was recorded higher in T₄ (paddy straw mulch) (653, 678, 665 ₹ ha⁻¹ day⁻¹) and T₆ (PE fb PoE herbicide) (613, 644, 628 ₹ ha⁻¹ day⁻¹) which were at par to T₂ (high seed rate + PoE herbicide) (641 ₹ ha⁻¹ day⁻¹) in 2024 and T₇ (mechanical weeding) (647, 625 ₹ ha⁻¹ day⁻¹) in 2025 and pooled. Lower

system profitability was recorded in T₃ (brown manuring) (522, 521, 521 ₹ ha⁻¹ day⁻¹) which was at par to T₁ (seed hardening + PoE herbicide) (529 ₹ ha⁻¹ day⁻¹ each). Higher system profitability under T₄ could be attributed to its ability to maintain higher system productivity with relatively lower cost of cultivation, resulting in greater net returns per unit time. Although T₈ and T₅ recorded higher system productivity, their profitability was comparatively lower due to higher expenditure involved in maintaining weed free conditions and biodegradable mulch application. The better profitability under T₆, T₇ and T₂ might be due to favorable balance between yield gain and cost of weed management. In contrast, lower profitability under T₉ was mainly due to poor crop performance and lower returns under severe weed competition. The data related to system profitability was mentioned in Table 1.

Table 1: Systemics of rice-cowpea/foxtail cropping system as influenced by different weed management practices

Treatments	System productivity (kg ha ⁻¹)			System production efficiency (kg ha ⁻¹ day ⁻¹)			System profitability (₹ ha ⁻¹ day ⁻¹)		
	2024	2025	Pooled	2024	2025	Pooled	2024	2025	Pooled
T ₁	7348 ^e	7202 ^c	7275 ^c	34.99 ^e	34.29 ^c	34.64 ^c	529 ^d	529 ^{cd}	529 ^c
T ₂	8315 ^{cd}	7851 ^b	8083 ^b	39.59 ^{cd}	37.39 ^b	38.49 ^b	641 ^{ab}	604 ^{abc}	622 ^{ab}
T ₃	7338 ^e	7177 ^c	7258 ^c	34.94 ^e	34.18 ^c	34.56 ^c	522 ^d	521 ^{de}	521 ^c
T ₄	8436 ^{bc}	8390 ^{ab}	8413 ^{ab}	40.17 ^{bc}	39.95 ^{ab}	40.06 ^{ab}	653 ^a	678 ^a	665 ^a
T ₅	8749 ^{ab}	8612 ^a	8681 ^a	41.66 ^{ab}	41.01 ^a	41.34 ^a	579 ^c	585 ^{bcd}	582 ^b
T ₆	8076 ^{cd}	8180 ^{ab}	8128 ^b	38.46 ^{cd}	38.95 ^{ab}	38.7 ^b	613 ^{abc}	644 ^{ab}	628 ^{ab}
T ₇	8030 ^d	8206 ^{ab}	8118 ^b	38.24 ^d	39.08 ^{ab}	38.66 ^b	603 ^{bc}	647 ^{ab}	625 ^{ab}
T ₈	8839 ^a	8744 ^a	8792 ^a	42.09 ^a	41.64 ^a	41.86 ^a	596 ^c	576 ^{bcd}	586 ^b
T ₉	6527 ^f	6441 ^d	6484 ^d	31.08 ^f	30.67 ^d	30.88 ^d	433 ^e	442 ^e	438 ^d
S.Em	120.49	208.22	133.00	0.57	0.99	0.63	13.89	24.30	15.16
CD (LSD=0.05)	361.20	624.18	398.68	1.72	2.97	1.90	41.64	72.84	45.43
CV	3.03	5.29	3.36	3.03	5.29	3.36	4.84	8.37	5.25

System Economics

System gross returns (₹ ha⁻¹)

System gross returns of the rice-based cropping system during both the years were recorded higher in T₈ (weed free) (216452, 215638, 216045 ₹ ha⁻¹) which was at par to T₅ (biodegradable mulch film) (213894, 212496, 213195 ₹ ha⁻¹). In 2025 and pooled, T₈ was at par to T₄ (paddy straw mulch) (206421, 206872, 206647 ₹ ha⁻¹), whereas in 2025 it was also at par to T₇ (mechanical weeding) (202512 ₹ ha⁻¹) and T₆ (PE fb PoE herbicide) (201301 ₹ ha⁻¹) also. Lower system profitability was recorded in T₃ (brown manuring) (179448, 176496, 177972 ₹ ha⁻¹) which was at par to T₁ (seed hardening + PoE herbicide) (179471, 176705, 178088 ₹ ha⁻¹ day⁻¹ each) during both the years of the study. Higher system gross returns under T₈, T₅ and T₄ could be attributed to higher system productivity and better overall crop performance under effective weed management, which increased total economic output from the cropping system. Similar findings were reported by Devasinghe, D., *et al.* (2011) [3]. The data related to the system gross returns was mentioned in Table 2.

System net returns (₹ ha⁻¹)

Among the treatments, T₄ (paddy straw mulch) recorded the highest system net returns and remained superior over the rest of the treatments. It registered ₹137051 (2024), ₹142276 (2025) and ₹139663 ha⁻¹ (pooled mean), indicating its economic superiority in improving profitability of the rice-based cropping system. T₆ (PE fb PoE herbicide), T₇ (mechanical weeding twice) and T₂ (high seed rate fb PoE herbicide) recorded comparatively higher system net returns and were statistically comparable with T₄. The lower system net returns were recorded

under T₉ (weedy check), which registered ₹90977 (2024), ₹92828 (2025) and ₹91903 ha⁻¹ (pooled mean) which was *fb* T₃ (brown manuring) (109579, 109400, 109489 ₹ ha⁻¹) and it was at par to T₁ (seed hardening + PoE herbicide) (111011, 111019, 111015 ₹ ha⁻¹) during both the years. In 2025, T₃ was also at par to T₈ (weed free) (121042 ₹ ha⁻¹) and T₅ (biodegradable mulch film) (122899 ₹ ha⁻¹). Higher system net returns under T₄ could be attributed to its ability to maintain higher system productivity with lower cost of cultivation, resulting in greater net income from the cropping system. Although T₈ and T₅ recorded higher system productivity and gross returns, their net returns were comparatively lower due to higher expenditure involved in maintaining weed-free conditions and biodegradable mulch application. These results were in conformity with Dash, S., *et al.* (2024) [2]. The data related to system net returns were mentioned in Table 2.

System B: C ratio

System B: C ratio differed significantly due to different weed management practices during both years and in the pooled analysis. T₄ (paddy straw mulch) recorded higher ratio of 3.10, 3.11, 3.10, respectively, during both years of study, which was at par to T₆ (PE fb PoE herbicide) (2.99, 3.05, 3.02) and T₂ (high seed rate + PoE herbicide) (3.07, 2.91, 2.99). In 2025 and pooled, T₇ (mechanical weeding) (3.04, 2.99) was also found to be at par to T₄. Lower B:C ratio among the treatments was recorded in T₅ (biodegradable mulch film) (2.39, 2.37, 2.38), T₈ (weed free) (2.44, 2.43, 2.44) and T₉ (weedy check) (2.45, 2.44, 2.44), which were at par to each other. Higher system B:C ratio under T₄ could be attributed to higher net returns with relatively lower cost of cultivation, resulting in better economic efficiency

of the cropping system. Although T₈ and T₅ recorded higher productivity and gross returns, their B:C ratio remained lower due to the higher cost of weed management. The higher B:C ratio under T₆, T₇ and T₂ might be due to comparatively lower

cost of cultivation coupled with better returns. Nagargade, M., *et al.* (2024) [5]. The data related to the system B: C ratio was mentioned in Table 2.

Table 2: System returns of rice-cowpea/foxtail cropping system as influenced by different weed management practices

Treatments	System gross returns (₹ ha ⁻¹)			System net returns (₹ ha ⁻¹)			System B:C ratio		
	2024	2025	Pooled	2024	2025	Pooled	2024	2025	Pooled
T ₁	179471 ^e	176705 ^c	178088 ^c	111011 ^d	111019 ^{cd}	111015 ^c	2.73 ^c	2.69 ^b	2.71 ^b
T ₂	203616 ^{cd}	193124 ^b	198370 ^b	134556 ^{ab}	126837 ^{abc}	130697 ^{ab}	3.07 ^{ab}	2.91 ^a	2.99 ^a
T ₃	179448 ^e	176496 ^c	177972 ^c	109579 ^d	109400 ^{de}	109489 ^c	2.67 ^c	2.63 ^{bc}	2.65 ^b
T ₄	206421 ^{bc}	206872 ^{ab}	206647 ^{ab}	137051 ^a	142276 ^a	139663 ^a	3.1 ^a	3.11 ^a	3.10 ^a
T ₅	213894 ^{ab}	212496 ^a	213195 ^a	121524 ^c	122899 ^{bcd}	122212 ^b	2.39 ^d	2.37 ^d	2.38 ^c
T ₆	197501 ^{cd}	201301 ^{ab}	199401 ^b	128691 ^{abc}	135264 ^{ab}	131978 ^{ab}	2.99 ^{ab}	3.05 ^a	3.02 ^a
T ₇	196002 ^d	202512 ^{ab}	199257 ^b	126632 ^{bc}	135915 ^{ab}	131274 ^{ab}	2.94 ^b	3.04 ^a	2.99 ^a
T ₈	216452 ^a	215638 ^a	216045 ^a	125082 ^c	121042 ^{bcd}	123062 ^b	2.44 ^d	2.43 ^{cd}	2.44 ^c
T ₉	158347 ^f	157425 ^d	157886 ^d	90977 ^e	92828 ^e	91903 ^d	2.45 ^d	2.44 ^{cd}	2.44 ^c
S.Em	2917	5103	3183	2917	5103	3183	0.04	0.07	0.05
CD (LSD=0.05)	8743	15296	9541	8743	15296	9541	0.13	0.22	0.14
CV	3.00	5.27	3.28	4.84	8.37	5.25	3.18	5.33	3.36

Conclusion

The results of the present study clearly demonstrated that weed management practices significantly influenced system productivity, production efficiency and economic returns of the semi-dry rice-cowpea/foxtail millet relay cropping system. Among the treatments, weed-free (T₈) and biodegradable mulch (T₅) recorded higher system productivity and production efficiency, indicating the importance of effective weed control in maximizing biological performance. However, economic analysis revealed that paddy straw mulch (T₄) was superior, recording the highest system profitability (₹665 ha⁻¹ day⁻¹), net returns (₹139663 ha⁻¹) and benefit-cost ratio (3.10), owing to its lower cost of cultivation coupled with sustained productivity. Treatments involving integrated herbicide application (T₆), mechanical weeding (T₇) and higher seed rate with herbicide (T₂) also performed well and were economically comparable with T₄, suggesting their feasibility as alternative weed management options. In contrast, brown manuring (T₃) and seed hardening with herbicide (T₁) were less effective, while the weedy check (T₉) resulted in significantly lower productivity and economic returns due to severe weed competition. Overall, the study indicates that paddy straw mulching is a cost-effective, sustainable and economically viable weed management practice for improving system performance in semi-dry rice-based relay cropping systems.

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