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Effect of establishment methods and irrigation scheduling on leaf area, leaf area index and leaf area duration of wet season rice

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Abstract

Rice cultivation plays a crucial role in global food security but is increasingly constrained by labor shortages and water scarcity. Conventional puddled transplanted rice (TPR) is highly resource-intensive, necessitating the need for efficient crop establishment methods and optimized irrigation strategies. This study aimed to evaluate the effect of different establishment methods and irrigation scheduling on key leaf growth indices viz., leaf area (LA), leaf area index (LAI) and leaf area duration (LAD) which are critical indicators of canopy development and productivity. The field experiment was conducted during *kharif* 2022 and 2023 at the ICAR-Indian Institute of Rice Research (IIRR), Hyderabad, using a strip-plot design with four replications and nine treatment combinations. Three rice establishment methods were assigned to horizontal strips: normal transplanting (NTP-M₁), mechanized SRI (MSRI-M₂) and direct-seeded rice in raised beds (DSR-M₃). Three irrigation scheduling treatments were assigned to vertical strips: AWD with 10 cm depletion (I₁), AWD with 5 cm depletion (I₂) and continuous submergence ± 5 cm (I₃). Results revealed that MSRI (M₂) consistently recorded the highest LA, LAI and LAD, followed by DSR (M₃), while NTP (M₁) showed the lowest values. The superior performance of MSRI was attributed to the use of younger seedlings, wider spacing, uniform mechanical transplanting and intensive cono-weeding, which enhanced canopy expansion, tiller survival and root anchorage. Among irrigation regimes, AWD with 5 cm depletion (I₂) sustained higher LA, LAI and LAD than AWD with 10 cm depletion (I₁) and performed comparably with continuous submergence (I₃), indicating its potential to conserve water without compromising canopy growth. The interaction effect between establishment methods and irrigation scheduling was non-significant; however, individually, MSRI and AWD with 5 cm depletion emerged as the most effective practices. These findings highlight their potential to improve canopy growth indices, enhance water-use efficiency and sustain productivity, offering a viable strategy for sustainable rice cultivation under water-limited environments.

Keywords: Mechanized SRI, direct-seeded rice, alternate wetting and drying, leaf area index, leaf area duration

1. Introduction

Rice (*Oryza sativa* L.), a C3 short-day and semi-aquatic cereal belonging to the Poaceae family, is the most important staple food crop worldwide, serving as the primary source of nutrition and livelihood for over one-third of the global population (Ullah & Datta, 2018) ^[1]. In Asia, more than two billion people derive 60-70% of their daily caloric intake from rice and its products (FAO, 2021) ^[2]. However, over 400 million people in rice-producing regions across Asia, Africa and South America still experience chronic hunger and global food demand is projected to rise by 38% by 2050. To meet the increasing demand and limited water availability, global rice production must increase by 116 million tons by 2035 to ensure food security (GRiSP, 2013; Yamano *et al.*, 2016) ^[4, 3].

Despite its importance, rice cultivation is highly resource-intensive, especially in terms of water use. It requires 3,000-5,000 liters of water to produce one kilogram of grain, making it one of the most water-demanding crops (Chowdhury *et al.*, 2014) ^[5]. Paddy cultivation alone consumes 34-43% of the world's total irrigation water (Bouman *et al.*, 2007) ^[6]. Traditionally, rice is

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cultivated under puddled transplanted rice (TPR) with continuous submergence, a practice that is both labor and water intensive. This system not only results in high water losses through seepage, percolation and evaporation but also contributes to soil degradation and methane emissions (Alam *et al.*, 2020; Subramanian *et al.*, 2023) ^[7, 8]. With increasing competition for water from domestic and industrial sectors, coupled with rural labor shortages due to urban migration, resource-efficient crop establishment methods and optimized irrigation strategies have become essential to sustain rice production (Mallareddy *et al.*, 2023; Vijayakumar *et al.*, 2018) ^[9, 10].

To overcome the limitations of conventional transplanting, alternative establishment methods such as the Mechanized System of Rice Intensification (MSRI) and Direct-Seeded Rice (DSR) have been promoted. MSRI integrates SRI principles with mechanized transplanting, ensuring younger seedlings, uniform spacing and better soil aeration. These features enhance tillering, canopy expansion and root anchorage while reducing labor dependency. Studies have shown that MSRI can reduce water use by 24%, increase yield by 16% and improve energy efficiency by nearly 27% compared to conventional transplanting (Venkataravana, 2019) ^[12]. Similarly, DSR particularly in raised bed systems eliminates transplant shock, reduces crop duration by 7-10 days, lowers labor and water inputs by up to 30% and enables crop intensification (Vijayakumar *et al.*, 2019; Gathala *et al.*, 2011) ^[11, 13]. However, DSR faces challenges such as severe weed pressure and high intra-plant competition, necessitating precise weed and water management. Alongside establishment methods, irrigation scheduling plays a critical role in rice growth and productivity. Traditional continuous submergence, though effective in weed suppression, is unsustainable under water-limited conditions. Alternate Wetting and Drying (AWD) has emerged as a promising water-saving alternative, capable of reducing water use by 30-45% without compromising yield (Bouman *et al.*, 2007) ^[6]. The “safe AWD” method developed at IRRI maintains soil moisture above critical thresholds to prevent water stress while reducing greenhouse gas emissions and enhancing water productivity (Lampayan *et al.*, 2015) ^[14]. AWD with 5 cm depletion, in particular, has been shown to sustain leaf area index (LAI) and leaf area duration (LAD) by promoting deeper root growth, efficient nutrient uptake and delayed leaf senescence (Selvakumar *et al.* (2020b) ^[16]. Recent advances in IoT and sensor-based AWD systems further improve precision irrigation, reducing energy costs and enhancing sustainability (Pham *et al.*, 2021) ^[15].

The performance of rice under different establishment and irrigation methods can be effectively assessed through leaf growth indices such as leaf area (LA), leaf area index (LAI) and leaf area duration (LAD). These indices are fundamental determinants of canopy development, photosynthetic efficiency and biomass accumulation. LA represents the total photosynthetic surface available, LAI indicates the ratio of leaf area to ground area and LAD integrates both the magnitude and persistence of canopy cover over time (Watson, 1952; Constable & Hodgson, 1990; Nayak, 2018) ^[17, 18, 19]. A higher and sustained LAI during the vegetative and reproductive phases ensures greater photosynthate accumulation for grain filling, while LAD provides a measure of canopy longevity and efficiency in intercepting solar radiation. Variations in establishment methods and irrigation regimes strongly influence these indices by affecting seedling vigor, tiller survival, canopy expansion and leaf senescence. Despite their importance,

comprehensive evaluations of the combined effects of establishment methods and irrigation scheduling on leaf growth dynamics under semi-arid tropical conditions remain limited. Therefore, this study evaluated the effects of establishment methods and irrigation regimes on leaf area, leaf area index and leaf area duration of rice, with the aim of identifying resource-efficient practices to sustain canopy development and productivity under water-limited conditions.

2. Materials and Methods

The field experiment was carried out during *kharif* 2022 and 2023 at the ICAR- Indian Institute of Rice Research (IIRR), Agronomy unit, Rajendranagar, Hyderabad to study the effect of different establishment methods and irrigation scheduling on leaf growth indices of rice. The experimental site is geographically located at an altitude of 542.3 m above mean sea level located at 17.19°N latitude and 78.23°E longitude in Southern Telangana Agro-climatic Zone of Telangana. According to Troll's climatic classification, it falls under semi-arid tropics (SAT). The soil at the experimental site was clay loam in texture, neutral in reaction with pH of 7.8 and electrical conductivity of 0.42 dSm⁻¹. The fertility status of the soil was low in organic carbon (0.48%) and available nitrogen (223 kg ha⁻¹), higher in available phosphorus (47 kg ha⁻¹) and available potassium (502 kg ha⁻¹). The experiment was laid out in a strip plot design with four replications. It comprised nine treatment combinations, with three rice establishment methods assigned as horizontal strips and three irrigation scheduling treatments as vertical strips. Establishment methods consist of normal transplanting (NTP-M₁), mechanised SRI (MSRI- M₂) and direct seeded rice (DSR) in raised bed system. Irrigation scheduling consists of AWD water management with 10 cm depletion of water (I₁), AWD water management with 5 cm depletion of water (I₂) and Submergence condition $\pm$ 5 cm (I₃). In DSR, pregerminated seeds were sown with a drum seeder at 40 kg ha⁻¹, while in MSRI, 18 day old seedlings were mechanically transplanted at 25 kg ha⁻¹ and in NTP, 25 day old seedlings were manually transplanted at 30 kg ha⁻¹. The crop spacing was 20 × 15 cm (NTP), 23.8 × 15 cm (MSRI) and 20 × 10 cm (DSR). Fertilizer management included nitrogen applied in three equal splits viz., basal, tillering and the remaining at panicle initiation. Full dose of phosphorus and potassium was applied as basal dose at the time of sowing or transplanting. In wet DSR, a pre-emergence application of Pretilachlor (Sofit) 30 EC @ 1.25 L ha⁻¹ was applied at 3 DAS, followed by two cono-weeding at 18 and 35 DAS and a post-emergence application of Bispyribac sodium 10% EC @ 250 ml ha⁻¹ at 47 DAS (2-3 leaf stage of weeds) using a hand-operated knapsack sprayer with 750 L ha⁻¹ of spray solution. In MSRI, four cono-weedings were carried out at 15 day intervals from 15 DAT, while in NTP, two hand weedings were performed at 20 and 45 DAT. Chloropyriphos 50% EC @ 2.5 ml L⁻¹ of water was sprayed at 45 DAS as prophylactic measure against stem borer. To ensure uniform crop establishment, common irrigation was provided until 30 DAS in DSR and 15 DAT in transplanted rice, after which irrigation schedules were imposed as per treatments using field water level sensors. In all treatments, irrigation was applied to a depth of 5 cm whenever the specified depletion level was reached and it was withheld 10 days prior to harvest. To minimize seepage losses, buffer channels were constructed between experimental plots. Leaf area was measured from five randomly selected hills per plot at 40, 70 and 100 DAS using a LICOR LI-3100 automatic leaf area meter.

Leaf area index (LAI) was computed as the ratio of leaf area to

ground area occupied by the plant, following Watson (1952) ^[17].

$$LAI = \frac{\text{Leaf area (cm}^2\text{)}}{\text{Ground area (m}^2\text{)}}$$

The Leaf Area Duration (LAD), which represents the persistence of leaf area over time, was calculated using the formula suggested by Watson (1952) ^[17].

$$LAD = \frac{LAI_1 + LAI_2}{2} (t_2 - t_1)$$

Where,

LAD = Leaf Area Duration between time T_2 and T_1

LAI_1 = Leaf Area Index at time T_1

LAI_2 = Leaf Area Index at time T_2

$T_2 - T_1$ = time interval (days).

The data were statistically analyzed following the procedure outlined by Gomez and Gomez (1984) ^[20]. Whenever treatment differences were found significant based on the F-test, critical differences (CD) were computed at the 5% probability level and presented accordingly. Non-significant differences were denoted as “NS.”

3. Results and Discussion

3.1 Leaf area (cm² m⁻²)

The data pertaining to leaf area at different growth stages viz., 40, 70, 100 DAS and at harvest was analysed and presented in the Table 4.3. The results indicate that leaf area was significantly influenced by different establishment methods and irrigation scheduling, while their interaction effect was found non-significant at all growth stages during both years and in the pooled mean. Leaf area plays a crucial role in determining the photosynthetic efficiency and biomass accumulation of rice.

Among the establishment methods, MSRI (M_2) recorded a significantly higher leaf area than both DSR (M_3) and NTP (M_1) at 40 DAS during both years and in the mean. At 70 DAS, MSRI (M_2) registered a significantly higher leaf area than NTP (M_1), but was at par with DSR (M_3) during both years and in the mean. At 100 DAS, MSRI (M_2) exhibited a significantly higher leaf area than both DSR (M_3) and NTP (M_1) in 2022 and in the mean, whereas in 2023, it was at par with DSR (M_3). The superior leaf area in MSRI was might be due to multiple synergistic factors. The use of younger seedlings (18 days) transplanted at the optimal phyllochron stage minimised transplant shock and promoted early vigour and tiller initiation. The slightly wider row spacing (23.8×15 cm) improved light interception and reduced intra-hill competition, facilitating canopy expansion. In contrast, NTP used older seedlings that experienced delayed establishment and DSR, although free from transplant shock, faced higher plant density (20×10 cm),

leading to greater competition and reduced leaf expansion per plant. MSRI's mechanical transplanting ensured uniform spacing and depth, optimising root anchorage and resource distribution. Weed management further enhanced its performance; MSRI received four timely cono-weedings, which improved soil aeration and nutrient mineralisation. NTP, with only two hand weedings, provided limited soil disturbance and aeration. In contrast, DSR employed a combined chemical and physical weed management strategy. Pretilachlor as a pre-emergence herbicide, two cono-weedings and a post-emergence application of Bispyribac sodium. While this approach was effective for weed suppression, it did not offer the consistent soil aeration and stimulation of root growth associated with frequent mechanical weeding. Additionally, AWD water management under MSRI supported deeper root growth and improved water and nutrient use efficiency, contributing to sustained leaf development. Overall, the integration of early seedling vigour, precise transplanting, intensive weeding and optimal spacing enabled MSRI to outperform both NTP and DSR in terms of leaf area and canopy development. These results align with the findings of Mohanasundar and Perumal (2021) ^[21], Singh *et al.* (2021) ^[22], Selvakumar *et al.* (2020b) ^[16], Nayaka *et al.* (2019) ^[23] and Rajnesh *et al.* (2018) ^[24].

At 40 DAS, the effect of irrigation scheduling on leaf area was non-significant. However, at 70 and 100 DAS, AWD with 5 cm depletion (I_2) recorded significantly higher leaf area over AWD with 10 cm depletion (I_1), while remaining statistically at par with submergence conditions (I_3) during both years and in mean. The superior performance of AWD with 5 cm depletion (I_2) might be due to the maintenance of optimal soil moisture, which enhanced root growth, nutrient availability and uptake resulting in increased tillering, delayed leaf senescence with higher photosynthetic rate (Selvakumar *et al.* 2020b, Thakur *et al.*, 2014) ^[16, 25]. Controlled moisture conditions and improved soil aeration under AWD with 5 cm depletion encouraged increased tillering, enhanced leaf production and stimulated cell division and elongation, collectively contributing to greater leaf expansion, increased leaf area per metre square and higher LAI (Theerthana *et al.*, 2021; Abul, 2014) ^[26, 27]. In contrast, reduced LAI under AWD 10 cm (I_1) might be due to lower turgor pressure caused by moisture stress, which restricted cell expansion and leaf development. The positive influence of optimal irrigation on leaf area index and photosynthetic efficiency has been well documented in earlier studies (Constable and Hodgson, 1990; Ramesh *et al.*, 2006) ^[18, 28]. These results were in accordance with the findings of Rahman *et al.* (2020), Sridhar *et al.* (2019) ^[44] and Duttarganvi *et al.* (2016) ^[30].

The interaction effect between establishment methods and irrigation scheduling on leaf area per meter square was found to be non-significant at all growth stages during both years and in the mean.

Table 1: Leaf area of rice as influenced by different establishment methods and irrigation scheduling during kharif 2022 and 2023

Treatment	Leaf area (cm ² m ⁻²)								
	40 DAS			70 DAS			100 DAS		
	2022	2023	Mean	2022	2023	Mean	2022	2023	Mean
Horizontal factor: Establishment methods (M)									
M ₁ : Normal transplanting	11912	12012	11962	30367	30180	30274	51883	51635	51759
M ₂ : Mechanised SRI	14885	14502	14693	34496	34144	34320	60443	59457	59950
M ₃ : DSR in raised bed system	14058	13763	13911	33266	33373	33320	56765	56273	56519
S.Em±	141	196	108	458	462	396	790	1255	521
CD (P= 0.05)	486	677	375	1584	1598	1371	2733	4343	1802

Vertical factor: Irrigation scheduling (I)									
I ₁ : AWD 10cm depletion	13285	13230	13257	31233	30828	31031	54578	54288	54433
I ₂ : AWD 5cm depletion	13978	13681	13829	33950	33745	33848	58512	57678	58095
I ₃ : Submergence $\pm$ 5cm	13592	13366	13479	32946	33124	33035	56002	55400	55701
S.Em $\pm$	187	266	186	510	581	421	731	658	671
CD (P= 0.05)	NS	NS	NS	1766	2009	1456	2531	2278	2323
Interaction (M x I)									
S.Em $\pm$	360	325	190	1044	930	812	1190	2362	1042
CD (P= 0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

3.2 Leaf area index

The data on leaf area index (LAI) recorded at 40, 70 and 100 DAS was analyzed and presented in the Table 4.4. LAI was significantly influenced by different establishment methods and irrigation scheduling, while their interaction effect was non-significant at all growth stages during both years and in the mean. The rate of photosynthesis influenced by LAI, with higher crop productivity depending on maintaining a high LAI throughout the vegetative phase. LAI increases after germination, peaks at flowering and then declines due to senescence (Nayak, 2018) ^[19]. Total leaf area per unit ground area indicates the available source for photosynthate production, which accumulates in the developing sink. Active leaf growth before flowering supports photosynthate accumulation for grain filling. The decline in leaf growth after flowering, may result from ineffective tiller death, reducing solar radiation and photosynthetic activity.

Among the establishment methods, MSRI (M₂) consistently recorded significantly higher LAI compared to both DSR (M₃) and NTP (M₁) at all stages, except at 70 DAS where it was

statistically at par with DSR. However, by 100 DAS, MSRI surpassed both DSR and NTP, particularly in 2022 and in the mean, indicating its superior ability to sustain canopy development during the reproductive phase. This divergence in LAI between 70 and 100 DAS can be attributed to several physiological and management factors. MSRI employed younger seedlings (18 days), wider spacing (23.8 $\times$ 15 cm) and precise mechanical transplanting, all of which supported stronger tiller retention, delayed senescence and improved light interception. In contrast, DSR with closer spacing (20 $\times$ 10 cm), experienced higher intra-plant competition leading to early leaf senescence and reduced functional leaf area. NTP with older seedlings and manual planting suffered from transplant shock and uneven spacing, further compromising canopy development. Additionally, MSRI included four timely cono-weedings, which improved soil aeration and microbial activity enhancing nutrient uptake and sustaining leaf growth. DSR although managed with herbicides and two cono-weedings, lacked the intensity and soil stimulation provided in MSRI, while NTP's limited hand weeding offered

Table 2: Leaf area index of rice as influenced by different establishment methods and irrigation scheduling during kharif 2022 and 2023

Treatment	Leaf area index								
	40 DAS			70 DAS			100 DAS		
	2022	2023	Mean	2022	2023	Mean	2022	2023	Mean
Horizontal factor: Establishment methods (M)									
M ₁ : Normal transplanting	1.19	1.20	1.20	3.04	3.02	3.03	5.19	5.16	5.18
M ₂ : Mechanised SRI	1.49	1.45	1.47	3.45	3.41	3.43	6.04	5.95	6.00
M ₃ : DSR in raised bed system	1.41	1.38	1.39	3.33	3.34	3.33	5.68	5.63	5.65
S.Em $\pm$	0.01	0.02	0.01	0.05	0.05	0.04	0.08	0.13	0.05
CD (P= 0.05)	0.05	0.07	0.04	0.16	0.16	0.14	0.27	0.43	0.18
Vertical factor: Irrigation scheduling (I)									
I ₁ : AWD 10cm depletion	1.33	1.32	1.33	3.12	3.08	3.10	5.46	5.43	5.44
I ₂ : AWD 5cm depletion	1.40	1.37	1.38	3.40	3.37	3.38	5.85	5.77	5.81
I ₃ : Submergence $\pm$ 5cm	1.36	1.34	1.35	3.29	3.31	3.30	5.60	5.54	5.57
S.Em $\pm$	0.02	0.03	0.02	0.05	0.06	0.04	0.07	0.07	0.07
CD (P= 0.05)	NS	NS	NS	0.18	0.20	0.15	0.25	0.23	0.23
Interaction (M x I)									
S.Em $\pm$	0.04	0.03	0.02	0.10	0.09	0.08	0.12	0.24	0.10
CD (P= 0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

minimal aeration benefits. The uniform canopy structure in MSRI allowed better light penetration and air movement, maintaining leaf turgor and chlorophyll content for a longer duration. Root systems under MSRI also developed more deeply under AWD with 5 cm depletion, improving nutrient absorption during critical growth stages. Collectively, these factors enhanced LAI sustainability in MSRI during the grain-filling phase. These findings are supported by Suryakala (2024) ^[31], Venkataravana (2019) ^[12] and Thirupathi (2017) ^[32], who reported significantly higher LAI under MSRI compared to drum-seeding and conventional transplanting methods.

At 40 DAS, the effect of irrigation scheduling on leaf area index was found to be non-significant. However, at 70 and 100 DAS, AWD with 5 cm depletion (I₂) recorded significantly higher LAI

over AWD with 10 cm depletion (I₁) but was statistically at par with submergence conditions (I₃) during both years and in mean. The higher LAI in AWD with 5 cm depletion might be due to optimal soil moisture balance, which maintains higher relative water content, ensuring vigorous tiller production and leaf expansion (Kishore, 2016) ^[33]. Moderate water stress under AWD 5 cm depletion encouraged deeper root growth, improving nutrient uptake and photosynthesis, which led to better leaf expansion and canopy coverage. Enhanced nutrient availability in AWD with 5 cm depletion stimulated tillering, which in turn increased LAI. Studies by Poddar *et al.* (2022) ^[34], Madhurya *et al.* (2022) ^[35], Ram *et al.* (2022) ^[36] and Kishore *et al.* (2017a) ^[37] support this finding, indicating that AWD with 5 cm depletion significantly enhances LAI due to improved moisture

regulation and nutrient absorption. Conversely, AWD with 10 cm depletion (I_1) recorded lower LAI values due to increased water stress, which reduced nutrient availability, negatively affecting leaf expansion and chlorophyll synthesis. Gautam *et al.* (2019) [38], Reddy (2022) [39], Liang *et al.* (2016) [40] reported similar results, highlighting that prolonged irrigation intervals in AWD systems limit nutrient uptake, reducing LAI and overall canopy development.

The interaction effect between establishment methods and irrigation scheduling on the leaf area index of rice was found non-significant at all growth stages during both years and in the mean.

3.3 Leaf area duration (days)

The data on leaf area duration (LAD), computed for 0-40 DAS, 40-70 DAS and 70-100 DAS, was analyzed and presented in the Table 4.5. LAD was significantly influenced by different establishment methods and irrigation scheduling during both years and in the mean, while the interaction effect was found to be non-significant. The results showed that LAD increased with crop age, reaching its peak between 70-100 DAS in all treatments. This reflects the persistence and magnitude of leaf area throughout the crop's growth cycle, maximizing light interception, which is closely linked to grain yield.

Among the establishment methods, MSRI (M_2) recorded the significantly highest LAD values, over DSR (M_3) and NTP (M_1) at all computations during both years and in the mean. The

superior LAD in MSRI (M_2) might be due to enhanced root growth, which facilitated efficient nutrient and water uptake. This in turn supported the development of more tillers per hill with larger leaf areas. The increased leaf area contributed to a higher leaf area index, which when integrated over time resulted in a higher LAD. These combined factors allowed MSRI (M_2) to maintain a larger and more persistent leaf area throughout the growing season, ultimately leading to higher LAD values compared to other establishment methods. The results were in accordance with the findings of Bhavya and Kumar (2018) [41] and Praneeth *et al.* (2017) [42].

At 0-40 DAS, the effect of irrigation scheduling on LAD was non-significant. However, at 40-70 DAS and 70-100 DAS, AWD with 5 cm depletion (I_2) recorded significantly higher LAD values compared to AWD with 10 cm depletion (I_1) and submergence conditions (I_3). The higher LAD under AWD with 5 cm depletion might be due to the optimized water balance, which facilitated deeper root development and improved nutrient and water absorption. This ensured sustained canopy growth and extended the photosynthetic phase, leading to better tiller retention and enhanced LAD values. AWD with 10 cm depletion resulted in lower LAD values due to prolonged drying intervals, which led to early leaf senescence and reduced leaf persistence. Studies by Choudhary (2021) [43], Selvakumar *et al.* (2020b) [16] and Sridhar *et al.* (2019) [44] also found that AWD with moderate depletion levels maintained superior LAD values, thereby supporting higher yield potential.

Table 3: Leaf area duration of rice as influenced by different establishment methods and irrigation scheduling during kharif 2022 and 2023

Treatment	Leaf area duration (days)								
	0-40 DAS			40-70 DAS			70-100 DAS		
	2022	2023	Mean	2022	2023	Mean	2022	2023	Mean
Horizontal factor: Establishment methods (M)									
M ₁ : Normal transplanting	23.82	24.02	23.92	63.42	63.29	63.35	123.38	122.72	123.05
M ₂ : Mechanised SRI	29.77	29.00	29.39	74.07	72.97	73.52	142.41	140.40	141.41
M ₃ : DSR in raised bed system	28.12	27.53	27.82	70.99	70.70	70.85	135.05	134.47	134.76
S.Em±	0.28	0.39	0.22	0.72	0.67	0.55	1.28	1.52	0.87
CD (P= 0.05)	0.97	1.35	0.75	2.48	2.31	1.90	4.44	5.26	3.02
Vertical factor: Irrigation scheduling (I)									
I ₁ : AWD 10cm depletion	26.57	26.46	26.51	66.78	66.09	66.43	128.72	127.67	128.20
I ₂ : AWD 5cm depletion	27.96	27.36	27.66	71.89	71.14	71.52	138.69	137.13	137.91
I ₃ : Submergence ± 5cm	27.18	26.73	26.96	69.81	69.73	69.77	133.42	132.79	133.10
S.Em±	0.37	0.53	0.37	0.94	0.96	0.67	1.24	1.41	1.18
CD (P= 0.05)	NS	NS	NS	3.25	3.34	2.30	4.30	4.88	4.08
Interaction (M x I)									
S.Em±	0.72	0.65	0.38	1.71	1.42	1.23	1.91	4.09	2.12
CD (P= 0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

The interaction effect on leaf area duration of rice due to different establishment methods and irrigation scheduling was found non-significant at all the growth stages during both the years and in mean.

4. Conclusion

The present study demonstrated that establishment methods and irrigation scheduling significantly influenced leaf growth indices (LA, LAI and LAD) of rice, whereas their interaction effects were non-significant. Among establishment methods, mechanized SRI (MSRI) consistently outperformed both direct-seeded rice (DSR) and normal transplanting (NTP), recording higher LA, LAI and LAD across growth stages. This superiority might be due to the use of younger seedlings, precise mechanical transplanting, wider spacing and intensive cono-weeding, which

collectively enhanced canopy expansion, tiller survival and sustained photosynthetic activity. With respect to irrigation, alternate wetting and drying (AWD) with 5 cm depletion maintained significantly higher LA, LAI and LAD than AWD with 10 cm depletion and was statistically comparable to continuous submergence, highlighting its potential to conserve water while sustaining canopy development. These results establish that while combined treatment effects were non-significant, individually MSRI and AWD with 5 cm depletion are resource-efficient practices that enhance canopy growth indices and water use efficiency under semi-arid tropical conditions. The findings underline the potential of integrating mechanized transplanting with precision water management to promote sustainable rice cultivation in water-limited environments.

Future Line of Work

Future research should focus on establishing stronger physiological linkages by relating leaf growth indices with chlorophyll content, photosynthetic rate and radiation use efficiency to better quantify their contribution to yield. Multi-season and multi-location trials are essential to validate the consistency and adaptability of MSRI and AWD practices across diverse agro-ecological zones. Additionally, exploring the interactions of establishment methods and AWD under abiotic stresses such as drought, salinity and high temperature will provide valuable insights for developing climate-resilient management practices. Together with these biological assessments, economic evaluations through cost-benefit analyses are required to determine the profitability, feasibility and scalability of MSRI and AWD technologies for farmers in resource-constrained regions, ensuring their wider adoption for sustainable rice cultivation.

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