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# Impact of sequential herbicide application on growth and yield of wet direct-seeded rice

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**Abstract**
Weed infestation is a major constraint in Direct Seeded Rice (DSR), causing significant yield losses from crop establishment to panicle initiation. Effective and timely weed management is therefore critical for sustaining rice productivity. A field trial was conducted on clay loamy soils at KVK, Kampasagar during the *Rabi* season of 2024–25 to evaluate the performance of JGL 24423 under different weed management practices in wet-direct seeded rice. Sequential herbicide applications, notably Penoxsulam 1.02% + Cyhalofop-butyl 5.1% OD @ 135 g a.i. ha$^{-1}$ at 20 DAS followed by Cyhalofop-butyl 10% EC @ 80 g a.i. ha$^{-1}$ at 45 DAS (T4) recorded the highest plant height (91.83 cm), dry matter accumulation (17,039 kg ha$^{-1}$), tiller density (225.93 m-²), grain yield (7,600 kg ha$^{-1}$) and straw yield (9,436 kg ha$^{-1}$) followed by Penoxsulam 1.02% + Cyhalofop- butyl 5.1% OD @ 135 g a.i. ha$^{-1}$ as PoE at 20 DAS *fb* Fenoxaprop-p-ethyl 6.7% w/w @ 60.38 g a.i. ha$^{-1}$ as PoE at 45 DAS (T5) recorded the plant height (91.50 cm), dry matter accumulation (16,447 kg ha$^{-1}$), tiller density (224.53 m-²), grain yield (7,600 kg ha$^{-1}$) and straw yield (9,436 kg ha$^{-1}$) which were significantly on par with hand weeding with respect to plant height (93.40 cm), dry matter accumulation (17,306 kg ha$^{-1}$), tiller density (448.33 m-²), grain yield (7,600 kg ha$^{-1}$) and straw yield (9,436 kg ha$^{-1}$).

**Keywords:** Growth parameters, sequential application, weed management, wet-direct seeded rice, yield

## 1. Introduction
Rice (*Oryza sativa* L.) is a major staple crop worldwide, sustaining over half of the global population and contributing up to 70% of daily caloric intake in several Asian regions (FAO, 2021) [4]. Cultivated in over 100 countries across tropical and subtropical climates, rice occupies nearly 160 million hectares globally, with Asia accounting for about 90% of production and consumption (IRRI, 2023). India is the second-largest producer, with 43-47.8 million hectares under rice, contributing 135.8 million tonnes at an average yield of 2,838 kg ha$^{-1}$ (DAC and FW, 2022; Indiastat, 2022–2023), though productivity remains lower than in China (4.3 t ha$^{-1}$), Russia (5.2 t ha$^{-1}$), USA (7.5 t ha$^{-1}$), and Australia (10.1 t ha$^{-1}$). Telangana alone contributes 4.66 million hectares, producing 15.87 million tonnes at 3,406 kg ha$^{-1}$. In response to rising labor costs and shortages, rice cultivation is shifting from traditional transplanting to direct-seeded rice (DSR). Wet-direct seeded rice (Wet-DSR), involving sowing pre-germinated seeds in wet puddled soils, offers a labor- and resource-efficient alternative with yields comparable to transplanted rice and enhanced water productivity by 0.3–0.4 kg m-³. However, weed infestation is a major constraint, as absence of standing water and early crop vigor allows aggressive competition, potentially reducing yields by up to 90%. While hand weeding is effective, it is labor-intensive, making chemical control the preferred approach. Sequential application of pre- and post-emergence herbicides provides more comprehensive weed management. Accordingly, this study evaluates different weed control strategies to optimize growth and yield in Wet-DSR.

## 2. Materials and Methods
A field experiment was conducted at KVK, Kampasagar on clay loamy soils during the *Rabi* season of 2024-25. The experimental soil was characterized as clay loam with an alkaline pH, normal electrical conductivity, low organic carbon and nitrogen content, and high phosphorus and potassium levels. Pre-germinated seeds of JGL 24423 were line sown at a rate of 25 kg ha$^{-1}$,

maintaining a spacing of 25 × 10 cm in well-puddled and leveled fields. The recommended nutrient dose of 120 kg N, 26 kg P, and 48 kg K ha$^{-1}$ was applied through urea, single superphosphate, and muriate of potash, respectively. Phosphorus and potassium were applied as basal doses at sowing, while nitrogen was supplied in two equal splits as top dressing at active tillering and panicle initiation stages. All other agronomic and plant protection measures were followed as per recommendations. Five healthy plants were tagged in each plot for recording biometric observations, and the entire net plot was harvested at maturity to determine grain and straw yields. The recorded data were subjected to statistical analysis using analysis of variance (ANOVA) appropriate for a randomized block design. Treatments were replicated thrice

## 3. Results and Discussion

### Weed flora

*Leptochloa chinensis Echinochloa colonum, Echinochloa crusgalli, Cyperus difformis, Cyperus iria, Commelina bhengalensis, Alternanthera sessilis and Xanthium strumarium* were the dominant weeds observed.

### Crop growth parameters (Table-2)

Plant height at harvest was found to be significantly highest with treatment T4 - Penoxsulam 1.02% + Cyhalofop-butyl 5.1% OD @ 135 g a.i. ha$^{-1}$ at 20 DAS followed by Cyhalofop-butyl 10% EC @ 80 g a.i. ha$^{-1}$ at 45 DAS (91.83 cm) followed by T5 – Penoxsulam 1.02% + Cyhalofop-butyl 5.1% OD @ 135 g a.i. ha$^{-1}$ as PoE at 20 DAS *fb* Fenoxaprop-p-ethyl 6.7% w/w @ 60.38 g a.i. ha$^{-1}$ as PoE at 45 DAS (91.50 cm). However, it was found to be on par with treatment T10 - Weed free (HW at 20 & 45 DAS) (93.40 cm) which was 11.6% higher than the weedy check (T11). The reduced competition for nutrients, water, space, and light throughout the crop growth period due to sequential application of herbicides in these treatments resulted in enhanced plant height over the weedy check. Similar results were also reported by Yogananda *et al*. (2022) [8] who observed increased plant height with effective weed control in direct-seeded rice.

Dry matter accumulation at harvest was found to be lowest (5876 kg ha$^{-1}$) with the weedy check (T11) due to heavy weed infestation, which reduced the availability of growth resources, leading to fewer tillers, smaller leaf size, and ultimately poor biomass production. Increments in dry matter accumulation ranged from 41.7% to 53.9% with weed management treatments over the control. Maximum dry matter accumulation was noticed in T4 - Penoxsulam 1.02% + Cyhalofop-butyl 5.1% OD @ 135 g a.i. ha$^{-1}$ at 20 DAS followed by Cyhalofop-butyl 10% EC @ 80 g a.i. ha$^{-1}$ at 45 DAS (17039 kg ha$^{-1}$) followed by T5 - Penoxsulam 1.02% + Cyhalofop-butyl 5.1% OD @ 135 g a.i. ha$^{-1}$ as PoE at 20 DAS *fb* Fenoxaprop-p-ethyl 6.7% w/w @ 60.38 g a.i. ha- 1 as PoE at 45 DAS (16447 kg ha$^{-1}$) it was statistically comparable with T10 - Weed free (HW at 20 & 45 DAS) (17306 kg ha$^{-1}$). The higher dry matter production in these treatments may be attributed to effective weed suppression, which improved resource availability and crop vigour. Similar findings were reported by Choudhary *et al.* (2018) [1].

The leaf area was significantly highest with treatment T4 - Penoxsulam 1.02% + Cyhalofop-butyl 5.1% OD @ 135 g a.i. ha$^{-1}$ at 20 DAS followed by Cyhalofop-butyl 10% EC @ 80 g a.i. ha$^{-1}$ at 45 DAS (981 cm²) followed by T5 - Penoxsulam 1.02% + Cyhalofop-butyl 5.1% OD @ 135 g a.i. ha$^{-1}$ as PoE at 20 DAS *fb* Fenoxaprop-p-ethyl 6.7% w/w @ 60.38 g a.i. ha$^{-1}$ as PoE at 45 DAS (970 cm²), which was statistically on par with (1000 cm²) with treatment T10 - Weed free (HW at 20 & 45 DAS). The increased leaf area in these treatments may be attributed to efficient weed control both at early and later stages, ensuring better utilization of moisture, nutrients, and light, which promoted greater photosynthetic activity and larger canopy development. The lowest leaf area (790.67 cm²) was recorded under the weedy check (T11).

The number of tillers m-² followed a similar trend, being significantly highest T4 - Penoxsulam 1.02% + Cyhalofop-butyl 5.1% OD @ 135 g a.i. ha$^{-1}$ at 20 DAS followed by Cyhalofop-butyl 10% EC @ 80 g a.i. ha$^{-1}$ at 45 DAS (234 m-²) followed by T5 - Penoxsulam 1.02% + Cyhalofop-butyl 5.1% OD @ 135 g a.i. ha$^{-1}$ as PoE at 20 DAS *fb* Fenoxaprop-p-ethyl 6.7% w/w @ 60.38 g a.i. ha$^{-1}$ as PoE at 45 DAS (231 m-²), which was statistically comparable with (243 m-²) with T10 Weed free (HW at 20 & 45 DAS). The increased tiller density in these treatments can be ascribed to better resource availability owing to reduced crop - weed competition, which promoted higher tiller initiation and survival. The lowest number of tillers (120 m-²) was recorded in the weedy check (T11), where severe weed infestation restricted nutrient and light availability, thereby reducing tillering ability of rice plants. These findings are in line with Dhaker *et al*. (2022) [2], who reported that effective weed management significantly improved tiller density and leaf area in direct-seeded rice.

### Yield (Table-3)

All weed management treatments resulted in significantly higher grain yield over the weedy check. The lowest grain yield **(**1850 kg ha-¹**)** was recorded in T11, which showed a 75.6% reduction compared to the best treatment due to severe competition from uncontrolled weeds for nutrients, moisture, space and light. Among the weed management treatments, the maximum grain yield was obtained with T4 - Penoxsulam 1.02% + Cyhalofop-butyl 5.1% @ OD 135 g a.i. ha$^{-1}$ at 20 DAS followed by Cyhalofop-butyl 10% EC @ 80 g a.i. ha$^{-1}$ at 45 DAS (7403 kg ha$^{-1}$), followed by T5 - Penoxsulam 1.02% + Cyhalofop-butyl 5.1% OD @ 135 g a.i. ha$^{-1}$ as PoE at 20 DAS *fb* Fenoxaprop-p-ethyl 6.7% w/w @ 60.38 g a.i. ha$^{-1}$ as PoE at 45 DAS (7252 kg ha$^{-1}$)**,** which were statistically comparable with T10 - Weed free (HW at 20 & 45 DAS) **(**7600 kg ha-¹**)**. The increment in grain yield under weed management practices was 45.6–53.9% higher compared to the weedy check. This enhancement in yield was attributed to reduced weed density and biomass at all growth stages, which resulted in better utilization of growth resources and improved yield attributes such as number of panicles, spikelets panicle-¹ and tillers m-². These findings are in conformity with those of Sunil *et al.* (2010) [6] and Upasani *et al.* (2012) [7], who reported 50–70% increase in grain yield of rice with sequential herbicide applications over unweeded check.

Similarly, significantly higher straw yield was recorded with T4 - Penoxsulam 1.02% + Cyhalofop-butyl 5.1% OD @ 135 g a.i. ha$^{-1}$ at 20 DAS followed by Cyhalofop-butyl 10% EC 80@ g a.i. ha$^{-1}$ at 45 DAS (9368 kg ha-¹) and T5 - Penoxsulam 1.02% + Cyhalofop-butyl 5.1% OD@ 135 g a.i. ha$^{-1}$ as PoE at 20 DAS *fb* Fenoxaprop-p-ethyl 6.7% @ w/w 60.38 g a.i. ha$^{-1}$ as PoE at 45 DAS (8912 kg ha-¹)**,** which was statistically on par with T10 - Weed free (HW at 20 & 45 DAS) **(**9436 kg ha-¹**).** The lowest straw yield **(**3923 kg ha-¹**)** was obtained in the weedy check **(**T11**),** which was 46.0% lower than the best treatment. The improvement in straw yield under effective weed management practices may be ascribed to reduced crop–weed competition, enhanced vegetative growth and higher biomass accumulation. These results are in agreement with the findings of Lipishmita

(2016) [5], who also reported substantial increases in straw yield of direct- seeded rice due to hand weeding and sequential herbicide application. The harvest index (HI) varied between treatments, with the highest **(**45.64%**)** recorded under T8 - Triafamone 20% + Ethoxysulfuron 10% WG @ 44+22.5 g a.i. $ha^{-1}$ at 2-4 leaf stage of the weeds (15-20 DAS) *fb* Fenoxaprop-p-ethyl 6.7% w/w @ 60.38 g a.i. $ha^{-1}$ as PoE at 45 DAS followed by T9 - Triafamone 20% + Ethoxysulfuron 10% WG @ 44+22.5 g a.i. $ha^{-1}$ at 2-4 leaf stage of the weeds (15-20 DAS) *fb* Quinclorac 25% SC @ 250 g a.i. $ha^{-1}$ as PoE at 45 DAS (45.09%) while the lowest **(**32.06%**)** was observed under the weedy check **(**T11**).** The higher HI values in effective weed management treatments suggest better partitioning of assimilates towards grain yield as compared to vegetative biomass.

**Table 1:** Sequential Herbicide combinations applied in Wet Direct Seeded Rice

| T. No | Treatment Details |
|---|---|
| T1 | Metsulfuron methyl 10% + chlorimuron ethyl 10% WP 4 g a.i. $ha^{-1}$ + bispyribac sodium 10% SC 25 g a.i. $ha^{-1}$(TM) at 2-4 leaf stage of weeds (15-20 DAS) *fb* Cyhalofop-butyl 10% EC 80 g a.i. $ha^{-1}$ as PoE at 45 DAS. |
| T2 | Metsulfuron methyl 10% + chlorimuron ethyl 10% WP 4 g a.i. $ha^{-1}$ + bispyribac sodium 10% SC 25 g a.i. $ha^{-1}$(TM) at 2-4 leaf stage of weeds (15-20 DAS) *fb* Fenoxaprop-p-ethyl 6.7% w/w 60.38 g a.i. $ha^{-1}$ as PoE at 45 DAS. |
| T3 | Metsulfuron methyl 10% + chlorimuron ethyl 10% WP 4 g a.i. $ha^{-1}$ + bispyribac sodium 10% SC 25 g a.i. $ha^{-1}$(TM) at 2-4 leaf stage of weeds (15-20 DAS) *fb* Quinclorac 25% SC 250 g a.i. $ha^{-1}$ as PoE at 45 DAS. |
| T4 | Penoxsulam 1.02% + Cyhalofop-butyl 5.1% OD 135 g a.i. $ha^{-1}$ as PoE at 2-4 leaf stage of the weeds (15-20 DAS) *fb* Cyhalofop-butyl 10% EC 80 g a.i. $ha^{-1}$ as PoE at 45 DAS. |
| T5 | Penoxsulam 1.02% + Cyhalofop-butyl 5.1% OD 135 g a.i. $ha^{-1}$ as PoE at 2-4 leaf stage of the weeds (15-20 DAS) *fb* Fenoxaprop-p-ethyl 6.7% w/w 60.38 g a.i. $ha^{-1}$ as PoE at 45 DAS. |
| T6 | Penoxsulam 1.02% + Cyhalofop-butyl 5.1% OD 135 g a.i. $ha^{-1}$ as PoE at 2-4 leaf stage of the weeds (15-20 DAS) *fb* Quinclorac 25% SC 250 g a.i. $ha^{-1}$ as PoE at 45 DAS. |
| T7 | Triafamone 20% + Ethoxysulfuron 10% WG 44+22.5 g a.i. $ha^{-1}$ at 2-4 leaf stage of the weeds (15-20 DAS) *fb* Cyhalofop-butyl 10% EC 80 g a.i. $ha^{-1}$ as PoE at 45 DAS. |
| T8 | Triafamone 20% + Ethoxysulfuron 10% WG 44+22.5 g a.i. $ha^{-1}$ at 2-4 leaf stage of the weeds (15-20 DAS) *fb* Fenoxaprop-p-ethyl 6.7% w/w 60.38 g a.i. $ha^{-1}$ as PoE at 45 DAS. |
| T9 | Triafamone 20% + Ethoxysulfuron 10% WG 44+22.5 g a.i. $ha^{-1}$ at 2-4 leaf stage of the weeds (15-20 DAS) *fb* Quinclorac 25% SC 250 g a.i. $ha^{-1}$ as PoE at 45 DAS. |
| T10 | Weed free (HW at 20 & 45 DAS) |
| T11 | Weedy check |

**Table 2:** Growth parameters in wet DSR as influenced by sequential application of herbicides

| Treatment | Plant height (cm) | Dry matter (kg $ha^{-1}$) | Leaf area ($cm^2$) $hill^{-1}$ | Number of tillers $m^{-2}$ |
|---|---|---|---|---|
| T1 | 88.50 | 12800 | 920 | 214 |
| T2 | 87.37 | 11410 | 890 | 207 |
| T3 | 84.70 | 10968 | 875 | 209 |
| T4 | 91.83 | 17039 | 981 | 234 |
| T5 | 91.50 | 16447 | 970 | 231 |
| T6 | 88.43 | 15460 | 950 | 229 |
| T7 | 89.40 | 16411 | 965 | 230 |
| T8 | 88.50 | 15672 | 954 | 225 |
| T9 | 88.27 | 15374 | 940 | 223 |
| T10 | 93.40 | 17306 | 1000 | 243 |
| T11 | 83.67 | 5876 | 791 | 120 |
| S.E (m) ± | 2.91 | 632 | 34.98 | 7.15 |
| CD (P = 0.05) | 8.58 | 1864 | 103.19 | 21.11 |

**Table 3:** Yield of Wet-Direct Seeded Rice as influenced by by sequential application of herbicides

| T. No | Grain yield (kg $ha^{-2}$) | Straw yield (kg $ha^{-2}$) | Harvest Index |
|---|---|---|---|
| T1 | 5726 | 7526 | 43.25 |
| T2 | 4842 | 6392 | 43.12 |
| T3 | 4558 | 6226 | 42.27 |
| T4 | 7403 | 9368 | 44.14 |
| T5 | 7252 | 8912 | 44.89 |
| T6 | 6886 | 8528 | 44.59 |
| T7 | 7196 | 8963 | 44.56 |
| T8 | 6916 | 8216 | 45.64 |
| T9 | 6869 | 8363 | 45.09 |
| T10 | 7600 | 9436 | 44.61 |
| T11 | 1850 | 3923 | 32.06 |
| S.E (m) ± | 223 | 293 | 1.12 |
| CD (P = 0.05) | 657 | 863 | 3.31 |

## 4. Conclusion

Effective weed management significantly enhanced growth and yield in wet direct-seeded rice. Sequential applications of penoxsulam + cyhalofop-butyl with either cyhalofop-butyl or fenoxaprop-p-ethyl were on par with manual weeding, while the weedy check recorded the lowest productivity.

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