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A review on weed flora and weed management strategies in direct seeded rice (DSR)

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Abstract
One of the biggest threats to the successful implementation of direct seeded rice (DSR) system is weed infestation, which can significantly reduce yield by as much as 50% and in some cases, as much as 90%. The diversity and persistence of weed flora in DSR systems often surpass the capacity of a single weed management approach to keep weeds below the economic threshold. Therefore, a combination of various weed management techniques is essential for effective and sustainable control. To address these challenges, herbicides are typically combined with manual and mechanical methods, such as hand weeding, to tackle the "weed demons" in DSR system. Effective weed control during the critical initial stages of crop growth (sowing to 40 days after sowing) is crucial for improving the productivity of direct-seeded rice. While manual and mechanical control measures are effective, they are becoming increasingly impractical due to labor shortages during peak periods and rising labor costs. This has led to delays and increased expenses in weed control practices. Consequently, the integration of herbicide applications both pre-emergence and post-emergence along with the inclusion of mechanical and manual weeding practices, is vital for achieving timely and effective weed control in DSR system.

Keywords: Direct seeded rice, Herbicide, Integrated weed management, weed flora

Introduction
Rice cultivation faces many challenges, especially with traditional methods like puddled transplant rice (PTR). The issues of land scarcity, water shortages, and rising labor costs are driving a need for more efficient and sustainable practices. Some alternatives being explored include direct seeding, which reduces the need for labor and water and the development of more resilient rice varieties that can thrive in diverse conditions. Innovations in irrigation techniques and mechanization are also helping address these challenges. Yogananda *et al.* (2019) also reported that transplanted rice under submerged conditions can indeed face economic challenges due to several factors. Higher labor costs and the non-availability of timely labor can make the practice less viable. Puddling, a process often used in agriculture to make soil more water-retentive, can indeed lead to significant water loss through several mechanisms and managing these factors is crucial to optimizing water use (Rahman, 2019) [18]. Direct seeded rice is indeed an efficient crop establishment method that can help reduce water usage, labor requirements, and production costs in contrast to conventional PTR system of production (Bouman *et al.*, 2007) [6]. In DSR establishment method, seeds can be broadcast, drilled, or dibbled into dry or moist soils for areas with limited water resources (Adnyana *et al.*, 2019) [1] and helps to reduce the strain on water and energy resources, leading to better environmental outcomes (Joshi *et al.*, 2013) [11]. Direct Seeded Rice (DSR) is a valuable approach in modern cropping systems. By skipping the traditional puddling process, it reduces the overall labor and water requirements, making it more efficient. The ability to establish rice early by leveraging pre-monsoon rainfall or supplemental irrigation is a significant advantage, especially in regions where water scarcity or labor shortages are major concerns. This method not only helps in managing resources better but also potentially improves yields by optimizing growing conditions. (Kar *et al.*, 2018) [12]. In DSR, the absence of puddling and transplanting operations means that weeds can establish more readily and compete more aggressively for resources like moisture, nutrients, light, and space.

This competition can drastically reduce the grain yield, sometimes by as much as 75 to 85%. Effective weed management strategies are crucial in DSR to mitigate these losses and ensure successful rice production (Dhanapal *et al.* 2018) [8]. In DSR) system, weeds can be more problematic compared to puddled transplanted rice and If not managed properly, weeds can severely affect rice yield, sometimes even reducing it to zero (Yadav *et al.*, 2013). Using a combination of pre-emergence and post-emergence herbicides, along with manual weeding, can be effective for managing weeds. However, over-reliance on herbicides can lead to resistance issues, where weeds become less responsive to chemical control. In order to mitigate this risk, it's important to integrate other weed management strategies (Chahal and Jhala, 2015) [7]. Integrated weed management refers to the integrated use of cultural, manual, mechanical and/or chemical control methods. Studies revealed that for the success of DSR, weeds can be managed by IWM approaches, which include hand weeding in combination with chemical management and mechanical weeding. Keeping the above facts in view, the IWM strategies followed in effective weed management practices for DSR are reviewed and presented in this article.

Associated weed flora under DSR

Weed infestation is one of the significant challenges in rice production. The diverse weed flora, including aquatic, semi-aquatic, and terrestrial species, can thrive under various agro-climatic conditions, cropping sequences, tillage practices, and irrigation regimes. Among different species of weeds in rice fields, grasses are the most problematic, followed by sedges and broad-leaf weeds. These weeds compete with rice plants for resources such as nutrients, water and light, leading reduction in yields and overall production losses worldwide. Effective weed management is crucial for maintaining rice productivity and ensuring food security. The predominant weeds associated with DSR in Asia has been presented in Table 1.

Table 1: The predominant weed associated with DSR in Asia (Singh *et al*., 2016)

Scientific Name	Common Name	Family
Grasses		
Echinochloa crus-galli	Barnyard grass	Poaceae
Echinochloa colona	Wild rice	Poaceae
Eleusine indica	Goosegrass	Poaceae
Leptochloa chinensis	Sprangletop	Poaceae
Digitaria sanguinalis	Large crab grass	Poaceae
Brachiaria ramosa	Signal grass	Poaceae
Cynodon dactylon	Bermuda grass	Poaceae
Dactylotenium aegyptium	Crow foot grass	Poaceae
Sedges		
Fimbristylis miliacea	Globefingerush	Cyperaceae
Cyperus difformis	Small flower umbrella sedge	Cyperaceae
Cyperus iria	Flat sedge	Cyperaceae
Cyperus rotundus	Purple nut sedge	Cyperaceae
Broad-leaf weeds		
Alternanthera sessilis	*Khaki weed*	Amarathaceae
Ammania baccifera	*Redstem*	Lythraceae
Caesulia axillaris	Pink node flower	Asteraceae
Celosia argentia	Quail grass	Amarathance
Cleome viscosa	Cleome	Capparaceae
Commelina benghalensis	Wandering jaw	Commelinaceae
Commelina communis	Dayflower	Commelinaceae
Cyanotis axillaris	Creeping cradle	Commelinaceae
Digera arvensis	Digera kondra	Amarathaceae

In transplanted rice, weeds generally emerge later because the rice seedlings are already established when they are transplanted into the field. The rice plants are larger and more competitive, making it easier to manage weeds. In DSR, weeds emerge alongside the crop because both the rice and the weeds start growing at the same time. This simultaneous emergence leads to greater competition between the crop and weeds, making weed management more challenging. Among the various types of weeds, grasses are the most problematic, followed by sedges, with broadleaf weeds being comparatively less troublesome but still impactful. The spread and dominance of various weed flora in India under direct seeded rice system has been given in Table 2.

Table 2: Dominant weed flora associated with direct seeded rice cultivation in India

Location and soil description of site	Dominant weed flora	Reference
Agronomic Research Farm, University of Agriculture Faisalabad, Lyallpur soil series (Aridisol-fine-silty, mixed, hyperthermic Ustalfic, Haplargid in USDA classification and Haplic Yermosols in FAO classification). The pH of 7.6	**Grasses:** *Echinochloa crus-galli, Echinochloa colona, Eluesine indica, Leptochloa chinensis, Dactyloctenium aegyptium* **Sedges:** *Cyperus iria, Cyperus rotundus*) **Broad leaved weeds:** *Trianthema portulacastrum, Portulaca oleracea, Ipomoea aquatica*).	Khaliq *et al.* (2012) [13]
Regional Agricultural Research Station (RARS) Parwanipur, Nepal. Soil was an Inceptisol formed on Himalayan residium	**Dominant weed flora:** *Echinochloa crusgalli, Echinochloa colona, Cynodon dactylon, Cyperus iria, Cyperus rotundus, Fimbristylis*	Bhurer *et al.* (2013) [5]

	dichotoma, Phyllanthus niruri	
Rice Research Station, Moncompu, Alappuzha, Kerala, The soil of the experimental site was silty clay with pH 6.17	**Sedges**: *Fimbristylis miliacea, Cyperus difformis, Cyperus iria, Sehoeonopheetus pungens* **Broad-leaved weeds:** *Monochoria vaginalis, Ludwigia perennis* and *Sphenoclea zeylanica*	Raj *et al.* (2013) [19]
Chaudhary Charan Singh Haryana Agricultural University, Regional Research Station, Karnal, India. The soil was clay loam in texture, with slight alkaline reaction (pH 8.2)	**Dominant weed flora:** *Cyperus iria, C. difformis, Fimbristylis miliacea, Eclipta alba, E. glabrescens, Leptochloa chinensis, Dactyloctenium aegyptium, Ammannia baccifera* and *Digiteria arvensis*	Ganie *et al.* (2014) [9]
Crop Research Center of GBPUA & T, Pantnagar. The soil was loamy, medium in organic matter (0.67%), with pH 7.5.	**Grasses:** *Cyperus rotundus* and *Cyperus compressus* **Sedges:** *Echinochloa crus-galli, Echinochloa colona, Dactyloctenium aegyptium, Digitaria ciliaris, Eleushine indica, Eragrostis spp.* and *Acrachne racemosa* **Broadleaved weeds:** *Phyllanthus niruri, Euphorbia hirta, Trianthema portulacastrum and Ammannia baccifera*	Singh *et al.* (2014) [27]
Tamil Nadu Rice Research Institute, Aduthurai, The soil of the experimental field was clay with slightly alkaline pH (8.2),	**Predominant weed flora:** *Echinochloa crusgalli, Echinochloa colona, Leptochloa chinensis, Cyperus difformis, Cyperus iria, Fimbristylis miliacea, Eclipta alba, Ammannia baccifera, Bergia capensis* and *Ludwigia parviflora*	Parthipan and Ravi (2016) [16]
Anbil Dharmalingam Agricultural College and Research Institute, Tiruchirapalli, The soil of the experimental field was sandy clay loam with pH of 8.8.	**Grasses:** *Cynodon dactylon, Echinochloa colona*, and *Panicum repens* **Sedges:** *Cyperus rotundus* and *Cyperus difformis* **Broad-leaved weeds:** *Ammannia baccifera*.	Nivetha *et al.* (2017) [15]
Bangladesh Agricultural University as well as in farmers' fields at Digarkanda village of Mymensingh district, Sonatala series of dark grey floodplain with pH 6.5	**Dominant weed flora:** *Echinochloa crus-galli, Cyperus difformis* and *Alternanthera philoxeroides*	Akter *et al.* (2018) [2]
Zonal Agricultural Research Station, Mandya, Karnataka. The soil of experimental site was red sandy loams soil pH of 6.5.	**Grasses:** *Echinochloa colonum L.* (barnyard grass), *Cynodon dactylon, Digitaria sanguinalis* and *Panicum repens* **Sedges:** *Cyperus rotundus* **Broad leaf weeds:** *Digera arvensis, Physalis minima, Ageratum conyzoides, Portulaca oleracea, Commelina Benghalensis, Trianthema portulacastrum, Parthenium hysterophorus, Abutilon indicum*	Yoganada *et al.* (2019)
Division of Agronomy, ICAR-Indian Agricultural Research Institute, New Delhi, sandy loam with pH 7.9	**Dominant weed flora:** *Echinochloa crus-galli, Leptochloa chinensis, Digera arvensis, Eclipta alba, Trianthema portulacastrum, Cyperus iria*, and *C. rotundus*	Sen *et al.* (2020) [24]

1. Chemical control

In direct-seeded rice (DSR) systems, effective weed management is crucial for ensuring optimal crop yields. Employing multiple strategies in tandem, rather than relying on a single method, often yields the best results in controlling weeds. Some of the strategies are discussed below and these should be used in conjunction rather than in isolation. Many research works conducted related to different weed management in DSR indicated that herbicide may be considered to be a viable alternative or supplement to hand weeding.

Location and soil description of site	Chemical control	Inference	Reference
Zonal Agricultural Research Station, Brahmavar. The soil of the experimental site was sandy loam in texture and pH was acidic (5.04).	Pre-emergence application of bensulfuron methyl 0.6% G @ 60 g *a.i.* ha-1 + pretilachlor 6% G @ 600 g *a.i.* ha-1	Pre-emergent application of bensulfuron methyl 0.6% G @ 60 g a.i. ha-1 + pretilachlor 6% G @ 600 g a.i. ha-1 recorded higher grain yield and straw yield. This was on par with bispyribac sodium @ 25 g a.i. ha-1.	Manjunatha *et al.* (2012) [14]
Agricultural College and Research Institute, Madurai, Clay loamy soil with ph of 7.2	post emergence mixture of fenoxaprop + ethoxysulfuron on 30 DAS	post emergence mixture of fenoxaprop + ethoxysulfuron on 30 DAS recorded significantly higher grain yield of 6278 kg ha-1 and SPAD value	Ramachandiran and Balasubramanian (2012) [20]
Crop Research Center of GBPUA & T, Pantnagar. The soil was loamy, with pH 7.5.	Bispyribac-sodium at 25 g/ha at the 1-3 leaf stage, followed by its lower dose, 20 g/ha	Recorded the lowest weed density and biomass at the 1-3 leaf stage or at the 4-6 leaf stage of the	Singh *et al.* (2014)

	applied at the 4-6 leaf stage	weeds during both years	
Chaudhary Charan Singh Haryana Agricultural University, Regional Research Station, Karnal, India. The soil was clay with pH of 8.2	Pendimethalin 1.0 kg/ha pre-emergence (PE) fb bispyribac-sodium 25 g/ha + ready-mix chlorimuron + metsulfuron 4 g/ha post-emergence (POE) at 30 DAS fb one hand weeding (HW) 60 DAS	Produced more grain yield as compared to other treatment combinations.	Ganie *et al.* (2014) [9]
Division of Agronomy, Sher-eKashmir University of Agricultural Sciences and Technology of Jammu, soil was sandy clay loam in texture	Bispyribac sodium @ 30 g ha-1 at 30 DAS (PoE)	highest grain yield (3.50 t ha-1) was recorded with hand weeding twice at 20 and 40 DAS which was statistically at par with fenoxaprop + ethoxysulfuron 60 + 15 g ha-1 (3.48 t ha-1) and bispyribac-sodium 25 g ha-1 (3.13 t ha-1).	Sharma *et al.* (2016) [25]
agronomic research farm, University of Agriculture Faisalabad, The pH of saturated soil paste was 8.1	Sequential application of pendimethalin @ 900 g ha-1 (PE) *fb* bispyribac sodium @ 30 g ha-1 at 15 DAS	Maximum number of productive tillers per m2 (346), no. of kernels per panicle (87.33), biological yield (17.8 t ha-1) and grain yield (4.12 t ha-1)	Ali *et al.* (2019) [3]
ICAR-Indian Institute of Rice Research, Hyderabad, Telangana, India, The soil was clay loam pH 8.07.	Application of florpyrauxifen benzyl + cyhalofop @ 180 g ha-1	Highest grain yield (4.1 and 3.4 t ha-1) was in plots treated with florpyrauxifen-benzyl + cyhalofop-butyl at 180 g ha-1	Sreedevi *et al.* (2020)
Integrated Farming System Research Station, Karamana, Thiruvananthapuram of KAU, India and soil was sandy clay loam with a pH of 4.84,	Tank mix combination of bispyribac sodium + fenoxaprop-p-ethyl @ 25 + 60 g ha-1	Recorded with the highest number of panicle (312.65 m-2), number of grains (154.3 panicle-1), filled grains (73.85%) and grain yield (5.13 t ha-1).	Sekhar *et al.* (2020) [23]
Mata Gujri College, Fatehgarh Sahib (Punjab), The soil was alluvial having clay loam in texture with normal soil reaction (7.9)	Bispyribac-sodium @ 25 g ha-1 + carfentrazone @ 20 g ha-1 (PoE) & bispyribac-sodium @ 25 g ha-1 + ethoxysulfuron @ 18 g ha-1 (PoE)	Registered more number of grains (136 no. panicle-1) and grain yield (5.47 t ha-1)	Singh and Kumar (2020)
Kole lands during 2019-20 and 2020-21, in a farmer's field at Alappad in Thrissur district, North Kerala, is clayey with pH of 4.6	Tank mixture of cyhalofop-butyl + penoxsulam and chlorimuron-ethyl + metsulfuron-methyl	Resulted in the high grain yield in this treatment, which was more than 100% greater than that in the unweeded control	Reddy *et al.* (2021) [21]
Birsa Agricultural University, Ranchi, Jharkhand, India, soil was acidic in nature with pH 5.2	Pretilachlor 750 g ha-1 *fb* bispyribac-sodium 25 g ha-1 being similar	Recorded maximum weed management index (5.11) and agronomic management index (4.11) at 60 DAS and higher net returns (93376/ha) and B:C (3.13)	Barla *et al.* (2021) [4]
CCS HAU Regional Research Station, Karnal.	Application of triafamone + ethoxysulfuron- 30% WG at 35+17.5, 40+20 and 45+22.5 g ha-1 doses.	Resulted in complete control of *Cyperus difformis* and *Fimbristylis miliaceae* and number of effective tillers.	Yadav *et al.* (2019)
Zonal Agricultural Research Station, Mandya, The soil of experimental site was red sandy loams with soil pH of 6.5.	Pre-emergence application of bensulfuron-methyl 0.6% + pretilachlor 6% GR 10 kg ha-1 *fb* post-emergence application of bispyribac-sodium 25 g ha-1.	Recorded significantly higher grain yield (4.60 t/ha), net monetary returns (Rs. 39,340 /ha) and B: C ratio (2.32)	Yogananda *et al.* (2019)
Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh, The soil was sandyloam with neutral soil reaction.	Oxadiargyl 80 g ha-1 at 3 DAS *fb* bispyribac-sodium 25 g ha-1 at 25 DAS	Registered the lowest weed dry matter next to two hand weeding at 20 and 35 DAS	Tiwari *et al.* (2020)

2. Integrated Weed Management options

A single approach to weed control is often insufficient and can lead to issues like weed resistance, environmental harm, and shifts in weed populations. Because weed communities respond dynamically to management practices, it's essential to adopt a diverse set of strategies. Farmers are showing keen interest in comprehensive weed management that reduces reliance on herbicides and cost. Integrated Weed Management (IWM) addresses these concerns by combining various ecologically and economically viable methods, considering their economic, environmental, and social impacts. This comprehensive approach aims to minimize the negative effects of weeds on agriculture and natural ecosystems while promoting long-term sustainability.

Location and description of soil	IWM strategies	Inference	Reference
Chaudhary Charan Singh Haryana Agricultural University, Regional Research Station, Karnal, India. The soil was clay loam in texture with slight alkaline reaction (pH 8.2)	Pendimethalin @ 1.0 kg ha-1 (PE) *fb* bispyribac-sodium @ 25 g ha-1 + (ready-mix) chlorimuron + metsulfuron 4 g ha-1 (PoE) at 30 DAS *fb* one HW at 60 DAS	Recorded significantly lower weed density (130 no. m-2) and weed biomass (85 g m-2) at 60 DAS	Ganie *et al.* (2014) [9]
N.E. Borlaug Crop Research Centre, G.B. Pant University of Agriculture & Technology Pantnagar, U.S. Nagar, Uttarakhand, silty clay loam pH of 7.3	Hand weeding twice at 20 and 40 DAS and fenoxaprop + ethoxysulfuron 60 + 15 g ha-1 and bispyribac-sodium 25 g ha-1	Hand weeding twice at 20 and 40 DAS produced higher yield (3.48 t ha-1) at par with fenoxaprop + ethoxysulfuron 60 + 15 g ha-1 and bispyribac-sodium 25 g ha-1	Pratap *et al.* (2016) [17]
Agricultural Research Farm, Institute of Agricultural Sciences, BHU, Varanasi, UP. The soil was sandy clay loam with pH 7.40	Penoxsulam 35 g/ha at 10 DAS fb one HW at 35 DAS	Effective control of weeds, to obtain higher yield and net return in direct seeded rice.	Sanodiya and Singh

College of Agriculture, Dapoli Dist. Ratnagiri, The soil of was sandy clay loam with pH of 5.80.	Application of oxadiargyl (PE) along with 1 HW at 20/30 DAS/DAT	Recorded significantly higher grain yield over the integration of oxadiargyl (PE) and 1 HW at 40/60 DAS/DAT as well as pre and post emergence application herbicides	Shendage *et al.* (2019) [26]
Research farm of Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal, Puducherry, sandy clay loam in texture, near neutral in reaction (pH: 6.94)	Pendimethalin @ 1000 g ha-1 at 3 DAS *fb* bispyribac-sodium @ 25 g ha-1 at 20 DAS *fb* manual weeding at 40 DAS	Resulted in better rice growth, yield parameters and higher rice grain yield (3.86 t/ha).	Saravanane (2020) [22]
Regional Research Station, Tamil Nadu Agricultural University, Paiyur, The soil was sandy loam in texture with pH 8.1	Application of pyrazosulfuron-ethyl at 20 g/ha at 3 DAS fb cono-weeding on 25 DAS	Recorded the higher grain yield 6.25 t/ha.	Sivakumar *et al.* (2020)
Institute of Agricultural sciences, BHU, Varanasi, Uttar Pradesh, India, Sandy clay loam in texture with pH 7.80.	Hand weeding at 20 and 40 DAS and pyrazosulfuron @ 20 g ha-1 (PE) *fb* bispyribac sodium @ 25 g ha-1 at 15-20 DAS	Resulted in significantly higher N, P and K uptake by grain and straw of rice and was comparable with application of pyrazosulfuron @ 20 g ha-1 (PE) *fb* bispyribac sodium @ 25 g ha-1 at 15-20 DAS	Hemalatha *et al.* (2020) [10]
Kusma, Boarijore Blockand Bhaluka, Sundarpahadi block of Godda, Kjharkhand. Soil of the sites was light sandy loam in texture,with pH 7.2	Sesbania (Sesbania broadcasted on the same day DSR is established and Sesbania killed by application of 2, 4-D @ 500 g a.i. /ha at 25-30 DAS	Reduced the weed infestation and improves crop productivity of DSR in rainfed agro-ecosystem.	Singh *et al.* (2022)

Conclusion

Effective weed management is crucial for maximizing yield and sustainability in direct-seeded rice (DSR) cultivation. By delaying weeding, the competition between weeds and the rice plants intensifies, leading to increased weed biomass which negatively impacts yield. A well-rounded approach that combines these strategies is key to achieving sustainable weed control and higher productivity in direct-seeded rice systems. Combining chemical methods with other weed management practices, such as mechanical weeding, cultural practices, and crop rotations, to achieve long-term weed control and enhance productivity. Weed flora of DSR system varies with respect to soil types and locations. Integrated weed management technologies also varies according to locations and weed flora present in the fields. From the above review, it was inferred that mostly the application of bensulfuron-methyl 0.6% + pretilachlor 6% GR 10 kg ha-1 *fb* post-emergence application of bispyribac-sodium 25 g ha-1 under chemical control method. Application of pyrazosulfuron-ethyl @ 20 g ha-1 at 3 DAS *fb* cono weeding on 25 DAS or pyrazosulfuron-ethyl 10% WP @ 20 g ha-1 at 3 DAS *fb* cono-weeding at 25 DAS or pendimethalin @ 1000 g ha-1 at 3 DAS *fb* bispyribac-sodium @ 25 g ha-1 at 20 DAS *fb* manual weeding at 40 DAS performed better in weed control as IWM strategies.

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