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WEEDS IN DIRECT SEEDED RICE AND THEIR HERBICIDAL CONTROL: A REVIEW

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Abstract: *Rice (Oryza sativa L.) is an important staple crop in India, where it is mainly grown by manual transplanting of seedlings into puddled soil. The conventional method of rice growing is not only water-demanding but also cumbersome and laborious. Growing water crisis, water-intensive nature of rice cultivation and escalating labour costs drive the search for alternative planting methods to improve water productivity in rice. Direct seeded rice (DSR), is gaining popularity because of its low-input demand. In DSR, weeds are the main biological constraint. Weed flora composition is dynamic and can change drastically with a shift from puddled rice to direct seeded rice and also the adoption of direct seeded rice has resulted in a change in the relative abundance of weed species. In absence of proper weed control under direct seeded rice, weeds are responsible for 35-100 per cent yield reduction. Initial thirty to seventy days are considered critical for crop weed competition. Herbicides are used to manage weeds in DSR systems, sequential applications of a pre-emergence herbicides followed by post-emergence herbicides should be used to control weeds in DSR with integration of other non-chemical weed control methods to provide effective and sustainable weed control.*
Keywords*: Weeds, Direct Seeded Rice, Weed Shift, Herbicides, yield losses.*

Introduction: Rice (*Oryza sativa* L.) is a major food grain crop of the world and more than half of the population subsists on it. It is the main livelihood of rural population living in subtropical and tropical Asia and hundreds of millions people living in Africa and Latin America. In India, rice is the second important food crop next to wheat. India is the second largest rice producing country in the world. Rice is being cultivated by three principal methods viz., transplanting, dry seeding and wet seeding. Transplanting is the traditional system of rice cultivation and it is in vogue in many rice growing areas. Expansion in the irrigated area, introduction of early maturing rice cultivars, availability of selective herbicides for weed management together with increasing transplanting cost and declining profitability of transplanted rice production system have encouraged rice farmers to shift from transplanting to direct seeding[1]. In addition, in order to check the declining water table, a new technique of direct-seeding is now fast replacing traditional transplanted rice. In direct-seeded upland rice, weeds pose serious competition to the crop in early stage and cause heavy reduction in rice yield. Weeds are a major constraint to the success of DSR in general[2,3]. The conversion from transplanted to direct seeded rice results in more aggressive weed flora and increases reliance on herbicides for weed control. Research has shown that, in the absence of effective weed control options, yield losses are greater in DSR than in transplanted rice[4]. Weeds are more problematic in DSR than in puddled transplanting rice because (1) emerging DSR seedlings are less competitive with concurrently emerging weeds and (2) the initial flush of weeds is not controlled by flooding in DSR [5].

Changes in Weed Population Dynamics and Weed Species Shift: Weeds are dynamic and the composition and competition by weeds is dependent on soil, climate, cropping and management factors. Rice fields can be colonized by terrestrial, semi-aquatic or aquatic plants depending on the type of rice culture and season. The total number of weeds species in a field largely depends on the associated environment and cropping systems (Table-1). It is usually lower (10-15) in highly productive and intensive systems. Weed flora composition can change drastically with a shift from conventional transplanting rice (CTR) to some form of alternative rice establishment methods[6]. More species-rich vegetation and diverse weed flora in DSR than in CTR have been observed[7]. The adoption of direct seeded rice has resulted in a change in the relative abundance of weed species in rice crops. In particular *Echinochloa spp*., *Ischaemum rugosum*, *Cyperus difformis* and *Fimbristylis miliacea* are widely adapted to conditions of DSR. A total of 46 species were present in transplanted rice in 1989, and, after 3 years (six seasons of rice) of Wet-DSR, 21 new weed species were added to the weed flora [8,9]. Analysis of spectrum of weed flora revealed that grasses are more problematic, constituting 60%, followed by sedges (25%) and broad-leaf weeds (15%) among the weed population. In a study conducted in Modipuram, India, the number of species of grasses, broadleaves, and sedges was 6, 4, and 4, respectively, in CTR, whereas, in DSR, it increased to 15 grass species, 19 broadleaf species, and the number of sedge species remained unaffected[6]. This clearly shows that some new grass and broadleaf species that were not adapted to CTR appeared in DSR. Higher numbers and more diverse flora in DSR could result in lower efficacy of weed management strategies, including herbicides. In addition, adopting DSR may result in weed flora shifts toward more difficult-to-control and competitive grasses and sedges. Shifts in weed flora were reported in Malaysia when rice crops shifted from CTR to Dry- and Wet-DSR [10].

Table-1: Weed species shift and weed population dynamics due to changes in the method of rice establishment

Weed Flora	Method of establishment and year		
	Transplanted (1979)	Dry seeded (1987)	Wet seeded (1989)
No. of species	21	50	57
No. of genera	18	38	44
No. of families	13	22	28

In a long-term and more detailed field study conducted in Malaysia, weedy rice and *L. chinensis* were absent in Wet-DSR plots at the start of the experiment in 1989. However, *L. chinensis* appeared after only 2 years (in 1991) and weedy rice after 4 years (in 1993) of experimentation. By 2001, weedy rice, *Echinochloa spp., L. chinensis, and Fimbristylis miliacea* became the dominant species[8,9]. In Vietnam also, shifts toward more difficult-to-control grass weed species (*E. crus-galli*, *L. chinensis*, and weedy rice) were observed with the introduction of DSR [11]. *E. crus-galli, Commelina diffusa Burm. f., Cyperus rotundus L.*, *Cyperus iria* and *L. chinensis* were dominant in non-weeded Dry-DSR plots in comparison with *C. iria*, *Echinochloa colona* and *Caesulia axillaris Roxb.* in CTR plots after four seasons of rice cropping[12]. Direct seeding also favors sedges such as *Cyperus difformis, C. iria, C. rotundus, and F. miliacea*[13]. The major weed flora of experimental field consisted of: *Echinochloa crusgalli*., *Dactyloctenium aegyptium*, *Setaria glauca* and *Cynodon dactylon* among grasses; *Cyperus rotundus* and *Cyperus iria*, among sedges; and *Phyllanthus niruri*, *Lindernia viscose* and *Amaranthus viridis* among the broad-leaf weeds. The grasses, sedges and broad-leaved weeds constituted 30.0, 44.3 and 25.7% of total weed flora, respectively [14].

Therefore, it is important that a systematic weed monitoring program be put in place along with the introduction of DSR. This would make it possible to develop adequate IWM strategies, including identification of new herbicides that are effective against a wide spectrum of weeds.

Evolution of Weedy Rice: In some countries (e.g. Malaysia, Vietnam and Sri Lanka), the adoption of direct-seeded rice systems has made weedy rice infestation one of the most serious problems. In India, weedy rice may also become a problematic weed with the spread of DSR systems. Weedy rice is highly competitive and causes severe rice yield losses ranging from 15 per cent to 100 per cent. Weedy rice also reduces milling quality if it gets mixed with rice seeds during harvesting[15]. Selective herbicides to manage weedy rice in cultivated rice are not available and therefore managing weedy rice would be a challenging problem for farmers in India. In the absence of selective herbicides, various cultural approaches may be exploited to reduce the problem of weedy rice. For example, in Malaysia, proper land preparation coupled with the stale seedbed technique using non selective herbicides (paraquat/glyphosate) before planting rice has been recommended to reduce the density of weedy rice[16]. Herbicide-resistant rice technologies offer opportunities for selective control of weedy rice but the risk of gene flow from herbicide-resistant rice to weedy rice poses a constraint for the long-term utility of this technology[17]. Various strategies might be followed (the use of clean seeds and machinery, use of stale seedbed practice, thorough land preparation, rotation of different rice establishment methods, use of high seeding rate and row-seeded crop, use of purple-coloured cultivars, use of flooding, and adoption of crop rotation) to manage weedy rice in Asia[18].

Losses due to Weeds: Weed competition is one of the major causes of low yield of upland rice reducing yield (Table-2) up to 100%. Among the various reasons for low productivity, in absence of proper weed control, rice yields are reduced by 35-100 per cent in DSR[5]. In recent studies, yield losses caused by uncontrolled weeds in dry seeded rice were 85–96% under conventional tillage[19] and up to 98% in zero tillage conditions[20]. Weeds pose major problem in rice production due to the prevalence of congenial atmosphere during *Kharif* season and uncontrolled weeds compete with dry seeded rice and reduce yield up to 30.2%[13]. Weeds are a serious problem because dry tillage practices and aerobic soil conditions are conducive for germination and growth of weeds, which can cause grain yield losses from 50 to 90%[21]. Uncontrolled weed-crop competition lowered the grain yield by by 96% in dry direct-seeded rice, 61% in wet direct-seeded rice [22]. It is estimated that direct seeded rice yield is reduced by 60% and even 100% due to huge weed infestation[4].

Table: 2. Estimated yield losses caused by weeds indifferent methods of rice establishment in India*.

Method of rice Establishment	Weeds	% reduction in yield due to weeds
Transplanted rice	Season long Competition	12 to 69.5%
Upland direct seeded rice	Season long Competition	93.6%
Dry-seeded rice zero tillage	Season long Competition	98%
Dry-seeded rice	pre-, post-flooding periods and complete crop growth period	17.4 to 25.8; 10.03 to 48.3 and 34.4 to 72.6%
Upland rice	Uncontrolled weeds	97.2%

**Summarised based on several published papers.*

Uncontrolled weeds reduce the yield by 96% in dry direct-seeded rice, 61% in wet direct-seeded rice and 40% in transplanted rice[23]. Direct sown rice in puddled soil faces severe infestation of weeds, which reduce the yield to an extent of 78 %[24]. However, the unchecked weed competition causes yield losses to the tune of 50-65 % under wet direct sown summer conditions. The unchecked weeds under weedy plots reduced the grain yield by 64.41 and 64.40% compared with the grain yield of weed-free treatment and by 62.36 and 62.36% compared with that of anilofos @ 0.4 kg/ha supplemented with 1 hand-weeding at 30 DAS[25]. The loss in grain yield due to unchecked weed competition was estimated to be 33.5 and 51.9 % during 1997 and 1998, respectively[26]. Weed in direct seeded rice cause 73 % loss in yield and the farmers may end-up using most of the labour saved by wet seeding to control weeds.

Critical Period of Crop-weed Competition: The critical period for weed control is a period in the crop growth cycle during which weeds must be controlled to prevent yield losses[27]. The critical period is dynamic. It varies with weed species, climate, soil and production practices. As per the literature available on studies on critical period of crop weed competition (Table-3) showed that first thirty to seventy days are critical, depending of the type of rice cultivar and the method of rice establishment.

Table: 3. Critical period of crop weed competition (CPCWC) for rice under different methods of rice establishment in India*.

Method o rice establishment	CPCWC*
Transplanted rice (TPR)	first 20 to 45 DAT
Wet-seeded rice (WSR)	15 to 60 DAS
Upland rice-direct-seeded rice	first 30 DAS
Dry-seeded rice	Up to 90 DAS

**Summarised based on several published papers.*

As far as DSR is concerned initial four weeks are critical[28], initial 15-30 days after sowing are critical period for crop-weed competition[29]. Some studies have reported in DSR crop might be kept weed free up to 90 DAS. Thus, keeping the DSR free of weeds particularly during the initial stage of crop growth have recorded highest grain yield.

Weed Control through Different Herbicides in DSR: In DSR systems, herbicide use is must and their use is likely to increase further with the rising labour scarcity. Herbicides should not be considered as a replacement for other weed control methods, however, but should be integrated with them. Various pre- and post-emergence herbicides are used in DSR systems to control weeds (Table-4). Pendimethalin has been found to be superior to oxadiargyl, particularly against *D. aegyptium*, *L. chinensis*, and *Eragrostis spp.* Pendimethalin 0.75 kg ha^{-1} suppressed weeds effectively in upland rice[30]. Pendimethalin 0.75 kg ha^{-1} applied at 8 days after sowing effectively controlled *Echinochloa colonum* and recorded rice grain yield at par with three hand weedings. Each increment of pendimethalin from 0.4 kg to 2.0 kg ha^{-1} reduced both density and dry matter of all the weeds[13]. Pre-emergence application of pendimethalin 0.75 kg ha^{-1} recorded higher grain and was at par with two hand weedings[31]. In general, sequential applications of a pre-emergence herbicide (e.g., pendimethalin or oxadiargyl) followed by post-emergence herbicide (e.g., bispyribac-sodium) can provide effective weed control in DSR. Post-emergence application of bispyribac sodium 0.025 kg ha^{-1} at 20 days after sowing in combination with pre-emergence pendimethalin 0.75 kg ha^{-1} gave effective weed control. In direct seeded puddle rice lowest weed dry matter was recorded with the pre-emergence application of pendimethalin 0.75 kg ha^{-1} or thiobencarb 1.25 kg ha^{-1} followed by post-emergence application of bispyribac 25 & 30 g ha^{-1}. Bispyribac sodium gave efficient weed control (WCE 90.5%) as compared to ethoxysulfuron + iodosulfuron and ethoxysulfuron[32] while as, lowest efficency of bispyribac sodium was reported with 0.3 kg ha^{-1} applied at 10–12 days against *L. chinensis*.

Table: 4. Herbicides reported to be effective in dry-seeded rice in India*

Herbicide	Rate (kg ha^{-1})	Time of Application - Days after seeding (DAS)
Anilofos	0.4	7 DAS
Anilofos + 2,4-D	0.4+0.6	7 fb 25DAS
Anilophos fb Cyhalofop butyl	0.4 fb 0.09	3 DAS fb 35 DAS
Butachlor + safener	1.5	4 DAS
Butachlor fb 2,4-D	1.25 fb 0.5	PRE fb POST
Cyhalofop butyl	0.120	15 DAS
Dithiopyr	0.180	3 DAS
Fenoxaprop-p- ethyl	0.07	POE
Fluchloralin	1.5	PRE
Oxadiazon	0.5	PRE
Oxadiazon fb oxadiazon	0.4 b 0.4	PRE fb 45 DAS
Oxyflourfen	0.25	3 DAS
Pendimethalin	1.5	3 DAS
Pendimethalin fb 2,4-D	1 fb 0.6	PRE fb POST
Pretilachlor	1	2 DAS
Pretilachlor+ safener	0.3	4 DAS
Pyrazosulfuron	0.015 to 0.030	6 DAS
Pyrazosulfuron ethyl + molinate	15 to 30 + 1.5	6 DAS b 15 DAS
Quinclorac	0.375	PRE
Thiobencarb fb 2,4-D	1 fb 0.5	PRE fb 20 DAS
Thiobencarb fb Cyhalofop butyl	1 fb 0.09	4 fb 35 DAS

*PRE=Pre emergence application; POST = Post emergence; *Summarised based on several published papers.*

Pre-emergence oxyflourfen 0.2 kg ha^{-1} resulted in highest weed control efficiency (96.5 percent), though rice grain yield was highest at 0.1 kg ha^{-1}. Dithiopyr 0.18 kg ha^{-1} applied 3 days after sowing proved effective for reducing density as well as dry matter of weeds and was at par with pendimethalin 1.0 kg ha^{-1}[33]. Application of butachlor (1.5 kg/ha), produced the highest grain yield followed by pretilachlor 0.5 kg/ha, broadcasting of Sesbania knock down with 2,4-D 0.5 kg/ha which were at par during two year of experimentation[34]. In direct seeded puddled rice, pretilachlor 0.62 kg ha^{-1} was more effective in reducing weed dry matter as compared to butachlor alone, butachlor + one hand weeding and two hand weedings[35]. Pretilachlor 1.0 kg ha^{-1} had less weed density and weed dry matter than other (pendimethalin, cyhalofopbutyl, quinclorac and clefoxydim) herbicides[36].

Sequential Application of Herbicides: Sequential applications of a pre-emergence herbicide (e.g., pendimethalin or oxadiargyl) followed by post-emergence herbicide can provide effective weed control in DSR, if coupled with some other weed management strategies. Pre-emergence oxyflouren 0.125 kg ha^{-1}, pendimethalin 1.25 kg ha^{-1} and thiobencarb 1.25 kg ha^{-1} each followed by one hand weeding were equally effective on weeds. Pre-emergence application of pendimethalin at 1.0 kg ha^{-1} followed by 2, 4-D (EE) 0.50 kg ha^{-1} resulted in maximum reduction in weed density and weed dry matter accumulation and hence recorded the maximum weed control efficiency[37].

Pretilachlor 0.75 kg ha^{-1} + safener with butachlor 1.0 kg ha^{-1} followed by mechanical weeding reduced the dry matter and recorded grain yield similar to hand weeded plots. Pre-emergence pretilachlor-plus at 0.30 kg ha^{-1} on 2 day followed by hand weeding at 45 days after sowing registered lower total weed density and higher weed-control efficiency[38]. Integration of 1 hand weeding at 30 days with pre-emergence pendimethalin 1.0 kg or pretilachlor 0.75 kg ha^{-1} or sequential application of pre-emergence herbicides followed by post-emergence application of 2,4-D (0.5 kg ha^{-1}) or fenoxaprop (0.07 kg ha^{-1}), were at par with each other and with two hand weeding[39]. In future, the combination of two or more herbicides [e.g., bispyribac + pyrazosulfuron, bispyribac + azimsulfuron, bispyribac + ethoxysulfuron, bispyribac + fenoxaprop (with safener), penoxsulam + cyhalofop, pendimethalin followed by bispyribac + pyrazosulfuron, pendimethalin followed by bispyribac + azimsulfuron, pendimethalin followed by bispyribac + ethoxysulfuron, pendimethalin followed by bispyribac + fenoxaprop (with safener)] may become a part of an effective and integrated approach to achieve more satisfactory control of complex weed flora in DSR.

Conclusion: Weeds are the major constraint in DSR production systems. In this article, we discussed various aspects related to weeds in DSR systems. There is a need to step up coordinated extension efforts to educate farmers on judicious use of herbicides in India, in integration with other weed management methods. In India, future research in DSR systems should focus on the integration of appropriate management practices and appropriate herbicide application dose, timing and combinations. There is also a need to study weed biology and ecology in DSR systems in different rice ecosystems. Understanding ecology of weeds associated with rice including knowledge of intererence thresholds, biology and growth habits of weeds of rice is essential to shift the crop weed balance in favor of crop rather than weeds.

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