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S Rathika
Department of Agronomy, Anbil Dharmalingam Agricultural College and Research Institute, Tamil Nadu Agricultural University, Tiruchirapalli, Tamil Nadu, India

T Ramesh
Department of Agronomy, Anbil Dharmalingam Agricultural College and Research Institute, Tamil Nadu Agricultural University, Tiruchirapalli, Tamil Nadu, India

P Shanmugapriya
Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India

Corresponding Author:
S Rathika
Department of Agronomy, Anbil Dharmalingam Agricultural College and Research Institute, Tamil Nadu Agricultural University, Tiruchirapalli, Tamil Nadu, India

Weed management in direct seeded rice: A review

S Rathika, T Ramesh and P Shanmugapriya

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Abstract
Direct seeding is done by sowing of pre-germinated rice seeds under puddled condition either manually or by drum seeding methods. Direct seeded rice (DSR) cultivation needs only 34 per cent of the total labour requirement and saves 29 per cent of the total cost of the transplanted rice. Weed infestation and competition are severe in direct wet seeded rice as compared to transplanted rice, because of the simultaneous growth of both crops and weeds. Uncontrolled weeds decreased the yield by 96 per cent in dry DSR and 61 per cent in wet DSR. The yield loss due to weeds varies from 40 to 100 per cent in direct seeded rice. Any delay in weeding will lead to increased weed biomass which has a negative correlation with yield. Though manual weeding is considered to be the best, undependable labour availability and escalating labour cost in many cases have given impetus to the development and use of new chemicals for weed control. In contrast to this, chemical weed control offers economic and efficient weed control if applied at proper dose and stage. The combination of chemical, manual and mechanical weed control is an efficient integrated weed management strategy for effective weed control in direct seeded rice.

Keywords: Direct seeded rice, crop-weed competition, crop establishment, weed control methods, economics

Introduction

In Tamil Nadu, rice is being cultivated under different ecosystems *viz.*, transplanted puddled lowland rice, direct seeded lowland rice (Wet seeded rice in puddled soil and Dry seeded rice in un-puddled soil), dry seeded upland rice and deep water rice. Most of the farmers in the intensive cropping areas are shifting from conventional transplanting to System of Rice Intensification (SRI) and direct seeded rice due to shortage of labour and scarcity of water (Rathika and Ramesh, 2018) [70]. Additionally, late onset of monsoon, unpredictable rainfall pattern and delayed release of canal (Cauvery) water favour to go in for dry or wet seeding under puddled condition. In direct seeded rice (DSR) under puddled condition, grasses cause maximum yield reduction followed by sedges and broad leaved weeds. Nowadays, chemical weed control in DSR has gained importance because of the intensity of weed problems coupled with the scarcity of labour for weeding and its accelerated cost. The use of herbicides either singly or in combination with manual or mechanical weeding in puddled direct seeded rice has been highlighted by several workers (Sangeetha *et al*., 2009) [75]. However, evaluation of herbicides in crops is a continuous process as newer herbicide molecules are being released for use. Several new herbicides molecule are launched for transplanted rice but their efficiency for direct seeded rice is not well known and need to be investigated. Use of alternative herbicides with wide spectrum control of the weeds in direct seeded puddled rice is the need of the present time (Nath *et al*., 2014) [52]. In this situation, use of herbicides is becoming more popular in DSR because saves on labour and less cost of cultivation (Vikram Singh *et al*., 2016; Rathika and Ramesh, 2019) [100, 71].

Weed flora in direct seeded rice field

Changes in crop establishment, from transplanting to direct seeding also resulted in marked changes in the composition of weed flora (Singh, 2008) [84, 93]. Adoption of direct seeding technology may result in weed flora shifts towards more difficult to control and competitive grasses and sedges (Kumar and Ladha, 2011). The weed flora of wet seeded rice crop is sowing and shallow depths of water up to 3 weeks after sowing.

As weeds emerge almost at the same time as that of the crop in direct wet seeded rice and weed competition with rice crop is greater, hence weed management by herbicide is more crucial (Singh and Singh, 2010) [86]. The major weeds associated with the direct seeded rice (DSR) were *Cyperus rotundus, C. iria, C. difformis, Eclipta prostrata* and *Portulaca oleracea* (Riaz *et al.,* 2007) [73]. Maity and Mukherjee (2011) [46] observed that the weed flora in DSR consisted of grasses like *Cynodon dactylon* and *Echinochloa colona,* sedges like *Cyperus rotundus, Cyperus iria* and *Fimbristylis miliaceae* and broad leaved weeds like *Ludwigia parviflora, Ageratum conyzoides, Spilanthes paniculata, Eclipta alba* and *Enhydra fluctans*. Raghavendra *et al.* (2015) [64] found that *Echinochloa colona, Echinochloa crus-galli, Fimbristylis miliaceae, Eclipta alba, Ammania baccifera, Ludwigia parviflora*, *Marsilea quadrifoliata* and *Monochoria vaginalis* were the major weed species in direct wet seeded rice. Ajay Singh *et al.* (2017) [2] observed that the weed flora in DSR was mainly dominated by *Cyperus difformis, Cyperus rotundus, Leptochloa chinensis, Echinochloa glabrescens, Eclipta alba* and *Ammania spp*. In direct wet seeded rice, the major grass weeds were *Echinochloa crusgalli* (L.), *Echinochloa colona* (L.), *Leptochloa chinensis* (L.) and *Panicum repens* (L.) and the common sedges included *Cyperus difformis* (L.), *Cyperus iria* (L.) and *Fimbristylis miliacea* (L.). Among the broad leaved weeds, *Eclipta alba* (L.), *Ammania baccifera* (L.) and *Ludwigia parviflora* Roxb. were the dominant species (Rathika and Ramesh, 2019) [71]. Suryakanta *et al.* (2019) [96] found that major weeds in the dry direct seeded rice under irrigated ecosystem were *Echinochloa cruss-galli, Echinochloa colona* and *Leptochloa chinensis* among grasses; *Cyperus iria* and *Cyperus difformis* among sedges; *Ammania baccifera* and *Alternanthera sessilis* among broadleaf weeds.

Crop-weed competition

Productivity of rice in India is declining due to an array of biotic and abiotic factors. Weeds are the prime yield-limiting biotic constraint that competes with rice for moisture, nutrients and light. The problem of weed interference is more in direct seeded than transplanted rice (Rathika and Ramesh, 2018) [70]. Weeds in direct seeded rice adversely affect the yield, quality and cost of production as a result of competition for various growth factors. The yield loss may vary from 10 per cent to complete failure of the crop depending upon the situation. The yield decrease in direct seeded rice increases with the increase in weed competition duration during the initial period. But, at later stages or after a certain stage, the rate of decrease may not change because maximum damage has already occurred (Johnson, 1996). Yield loss depends on several factors such as associated weed flora, degree of infestation, rice ecosystem, growing season, cultivar raised, cultural and management practices followed. Because of wide adaptability and faster growth, weeds dominate the crops habitat and reduce the yield potential (Rao, 2011). Bhatt and Kukal (2011) reported that uncontrolled weeds in direct wet seeded rice can reduce yields to the tune of 53 per cent and losses were reported even up to 90 per cent.

Raj *et al*. (2013) reported that, season long weed competition in wet seeded rice caused 69.71 and 67.40 per cent reduction in grain yield during *kharif* and *rabi* season, respectively. Reduction in yield to the tune of 34 per cent in transplanted rice, 45 per cent in direct seeded low land rice and 67 per cent in upland rice due to weeds were reported in India (Muthukrishnan *et al.,* 2010). In Tamil Nadu, the yield loss of rice is around 111.81 thousand tonnes per year due to weeds alone (Chinnusamy *et al.*, 2012) [26]. Vikram Kumar (2015) [99] showed that the loss in grain yield of rice due to unchecked weed growth throughout the crop growth period was estimated to be 30 to 75 per cent in DSR. Direct seeded rice was more vulnerable for loss of grain yield due to the presence of weeds compared to transplanted rice and it adversely affects not only the grain yield and crop quality (Arunbabu and Jena, 2018) [5]. In India, yearly loss of rice grain production is around 15 million tonnes due to heavy weed infestation (Singh *et al*., 2018) [82]. Chaudhary *et al.* (2018) [22] found that shorter panicle length was recorded on weedy check plot of dry DSR which might be due to draining of nutrients by weeds and lowest thousand grain weight because of the unfavorable environment created by weeds throughout the crop cycle. Karthika *et al.* (2019) [36] reported that in the unweeded check, the yield reduction was noticed upto 67 per cent.

Table 1: Loss of grain yield in different methods of rice establishment in India (Ladu and Singh, 2006; Singh *et al.,* 2011) [42, 92].

S. No	Methods of rice establishment	Reduction in yield due to weeds (%)
1	Upland rice	97
2	Upland dry seeded rice	94
3	Dry seeded rice	17-73
4	Wet seeded rice	85

Critical period of competition

In the crop growth period, there exists a critical period during which the crop is very sensitive to weed competition. The presence of weed beyond a certain period of time will cause significant yield reduction. According to Ladu and Singh (2006) [42] direct seeded rice kept weed free for the first 30 DAS produced grain yield similar to that of weed free period upto harvest. The effective control of weeds at initial stages of rice growth (0 to 40 DAS) could help in improving the productivity of DSR (Maity and Mukherjee, 2008) [45]. Singh (2008) [84, 93] opined that a weed free situation for first 60 or 70 DAS produced yield comparable with weed free situation until harvesting. The critical period of weed competition is longer for direct seeded rice (15 to 45 DAS) as indicated by Singh *et al.* (2008) [84, 93]. The period within 20 to 50 DAS appeared to be an important factor in crop-weed competition in dry DSR (Khaliq Abdul and Matloob Amar, 2011).

Table 2: Critical period of crop weed completion in rice is influenced by different rice establishment methods (Arunbabu and Jena, 2018) [5].

S. No	Rice establishment method	Critical period of crop-weed competition
1	Transplanted rice	20-40 DAT
2	Wet seeded rice	15-60 DAS
3	Dry seeded rice	15-60 DAS
4	Rainfed direct seeded rice	0-90 DAS
5	Upland direct seeded rice	30 DAS

*DAT: Days after transplanting; DAS: Days after sowing

Effect of crop establishment methods on weed management

System of rice cultivation in various rice growing regions varies largely due to soil and climatic condition as well as irrigation system of the region. Transplanting is the most dominant and traditional method of crop establishment in irrigated lowland rice. Ramamoorthy and Subbaiah (1999) [67] observed that wet seeded rice culture by drum seeder could be a viable alternative to transplanted rice in irrigated areas of India. Direct seeded rice is a resource-conserving technology relative to transplanted rice, but it is subjected to heavy weed infestation (Awan *et al.* 2015, Mahajan and Chauhan, 2015) [7, 43].

Transplanted rice *vs* Direct seeded rice

Farmers had achieved a breakthrough in raising the productivity of rice through transplanting (Singh and Bhattacharyya, 1989) [85]. Transplanting is the most dominant method of crop establishment in irrigated lowland rice (Biswas *et al.,* 1991) [17]. According to Chandra (1992) [21], line transplanting increased plant height and grain yield due to more uniform distribution of sun light within the canopy compared to direct seeding method. Govindarasu *et al.* (1998) [30] stated that for wet seeding, the field is puddled and properly levelled and sprouted seeds are sown uniformly by broadcasting or in lines by using seed drill. Direct seeding offers certain advantages *i.e.* saves labour, faster and easier planting helps in timely sowing, less drudgery, early crop maturity by 7-10 days, less water requirement, tolerance to water deficit, often higher yield, low production cost and more profit, better soil physical conditions for following crops and less methane emission (Balasubramanian and Hill, 2002) [9]. The risks of crop yield loss due to competition from weeds in direct seeded rice was greater than in transplanted rice because the weeds and rice emerge together and farmers are not usually able to use standing water to suppress weeds at the early growth stage of rice (Chauhan and Johnson, 2010) [23]. Direct seeding involves dry and wet seeding in which seeds are sown directly in the main field rather than transplanting. In dry direct seeding, it is sown by either broadcasting or dibbling and in wet seeding, pre germinated seeds are sown under puddled conditions (Kaur and Singh, 2017) [37]. However, the direct seeded rice is considered as the best alternative for transplanting, heavy weed infestation is one of the major constraints for its adaptation (Karthika *et al.,* 2019) [36].

Direct sowing over the puddled field by drum seeder can be successfully adopted in irrigated lands. Success of DSR depends largely on weed control especially with chemical methods of weed management. Various herbicides have been used for controlling weeds in DSR but efficiency of chemical methods based on single herbicide treatment may be unsatisfactory because of their narrow spectrum of weed control. Application of different pre emergence herbicides including thiobencarb, pendimethalin, butachlor, oxadiazon and nitrofen has found to control weed satisfactorily in DSR. Among the different post emergence herbicides, ethoxy sulfuron, bispyribac sodium, cyahalofop-butyl, petrilachlor, chlorimuron, metsulfuron and penoxsulum were found effective against complex weed flora in DSR (Singh *et al.,* 2007; Mahajan *et al.,* 2009) [87, 91]. Therefore, application of several herbicides in sequence could be more useful (Chauhan and Albugo, 2013) [24]. The trend for an increase in herbicide use has been reinforced by the spread of DSR (Suryakanta *et al.,* 2019) [96].

Crop establishment methods on weed dynamics

A major problem encountered in direct seeding of rice is weed control. In direct seeded rice, weed emergence occurs almost at the same time as that of rice plants and thereafter competition is severe at early stages of the rice (Balyan, 1982; Reddy *et al*., 1994) [10, 72]. Prasad *et al.* (2001) [61] stated that the lowest weed density and weed dry weight were recorded under transplanting method followed by puddled sowing of sprouted seeds and dry drilling. Singh *et al*. (2005) [90] reported that the weed density was higher in DSR (dry direct seeding unpuddled) and least in WSR (wet seeding in puddled soil) and TPR (transplanted) establishment methods. Uphoff (2006) [98] emphasized that when paddy fields are not kept flooded, weed problems will become more severe and require more weeding. Hassan *et al*. (2010) [31] found that transplanted rice reduced the weed population as well as dry matter with higher weed control efficiency resulting in higher grain yield than WSR. Parameshwari *et al.* (2015) [56] observed that the crop establishment methods influenced the weed management practices and improved the weed control efficiency. The highest weed control efficiency of 90.4 and 88.1 per cent were recorded under transplanted and direct seeded rice, respectively. Suryakanta *et al.* (2019) [96] reported that the highest weed control efficiency was recorded in weed free condition and lowest in weedy check condition dry direct seeded rice under irrigated ecosystem.

Crop establishment methods on growth attributes

In direct seeded rice, leaf area growth starts two weeks earlier and leaf area index (LAI) is higher than that in transplanted rice (Schnier *et al.,* 1990) [77]. Bharathi (1996) [13] noted that number of tillers per unit area and LAI were more in row sown rice than those in broadcast and transplanted rice. Increased plant height was recorded with direct sown rice than transplanted rice (Prabhakar and Reddy, 1997) [60]. Pal *et al.* (1999) [54] studied the different methods of rice establishment and revealed that line planting produced higher LAI, dry matter accumulation and consequently higher crop growth rate. Ni *et al.* (2000) from IRRI observed that in direct seeded puddled rice, the crop growth rate, LAI and dry matter production at tillering were associated with their competitiveness against weeds, whereas, relative crop growth rate, net assimilation rate and tillering capacity of the crop did not show such association. Singh *et al.* (2004) [89] found that plant height was more under non-puddled direct seeded rice at 30 and 60 DAS. However, tillers m^{-2} and dry matter accumulation were higher under puddled rice using rotavator. According to Kumar *et al.* (2008) direct seeding of sprouted seeds under puddled condition recorded higher growth attributes than other systems of cultivation.

Parameshwari *et al.* (2015) [56] observed that the crop establishment methods significantly influenced the plant height at harvest. The taller plants were observed under transplanted rice and it was comparable with SRI. However, it was significantly higher than that of direct seeded rice under puddled condition. Karthika *et al.* (2019) [36] reported that weed free upto panicle initiation stage had recorded the tallest panicle and higher yield among the different weed management practices in direct seeded rice under puddled and unpuddled rice conditions.

Crop establishment methods on yield attributes and yield

Wet seeded rice producing similar or higher yield than transplanted rice was well documented by several workers in Philippines (Khan *et al.,* 1990 and Moody, 1993), [39, 49] in India (Ramasamy *et al.,* 1994, Rachel and Martin, 1995) [68, 63] and in Pakistan (Majid *et al.,* 1996) [47]. Prasad *et al.* (2001) [61] stated that between two direct seeding methods (dry drill seeding at 15 cm distance, broadcasting sprouted seeds under puddled condition); puddled sowing of sprouted seeds resulted in significantly higher yield attributes than dry drilling. Grain and straw yields were also higher under puddled sowing condition than dry drilling. Budhar and Tamil Selvan (2002) [19] revealed that wet seeding by broadcasting (57.2 q/ha) and wet seeding by drum seeder (56.6 q/ha) has recorded higher yield than transplanting (55.8 q/ha) but drum seeding method did not give significantly higher yield over transplanting.

The maximum grain yield was observed in direct seeded and transplanted plots treated with two hand weeding and higher fertilizer dose of 120: 60: 60 kg N, P_2O_5 and K_2O/ha (Singh *et al.*, 2006) [94]. Yadav *et al.* (2006) [101] stated that almost equal grain yield of rice under transplanted (55 q/ha) and drum seeding (53 q/ha) methods. Bisht *et al*. (2007) [16] reported that all the tested agro techniques of crop establishment (SRI, drum seeding, dry seeding and broadcasting of sprouted seeds) were found to produce grain yield statistically on par to that of conventional method of transplanting. Aslam *et al*. (2008) [6] revealed that highest number of productive tillers per unit area (232) was noted in direct seeding followed by double zero tillage (219), bed planting (207) and conventional planting (200), respectively. Prasad *et al*. (2010) [62] found that grain yields in transplanted (4367 kg/ha) and drum seeded rice (3933 kg/ha) were on par with each other but significantly superior over direct seeded rice (2992 kg/ha) as a result of reduced weed competition measured in terms of low weed density and dry weight. Rice yield was maximum in mechanized transplanting but it was statistically on par with direct seeded rice. The highest rice yield was obtained in farmer conventional transplanting. It was further revealed that although transplanting methods produced higher filled grains panicle^{-1}, 1000 grain weight but it was statistically similar to DSR methods (Ali *et al*., 2014) [3]. Parameshwari *et al.* (2015) [56] observed that no significant differences among different crop establishment methods were noticed in number of grains panicle^{-1}, panicle length and test weight. Iqbal *et al.* (2017) [32] found that maximum 1000 grain weight was recorded in direct seeded rice followed by transplanted rice.

Crop establishment methods on economics

Transplanting gave the highest gross and net returns and showed superiority to direct seeding. However, benefit cost ratio (BCR) was almost alike under direct seeding and transplanting (Thakur, 1993) [97]. A study at Tamil Nadu reported the maximum net returns and energy use efficiency in direct seeding with drum seeder over random or line transplanting of seedlings (Bhuvaneshwari, 1998) [15]. Whereas Prasad *et al.* (2001) [61] obtained the highest gross return, net returns and BCR under transplanting compared to other methods of cultivation. Similarly, economic advantages of transplanting over drum seeding have also been reported by Sanjay *et al.* (2006) [76]. In contrary, Budhar and Tamil Selvan (2002) [19] claimed that direct seeding practices *viz*., wet seeding by manual broadcasting and drum seeding recorded higher net income (Rs.21551 and 21214/ha) and BCR (2.51 and 2.48, respectively) against traditional transplanting (Rs.18666/ha and 2.10). Economic factors and technology development in rice production are the major drivers that have led to the adoption of direct seeding methods for rice establishment in place of transplanting in Asia (Pandey and Valasco, 2002) [55].

Gaire *et al.* (2013) [28] reported that in direct seeded rice three hand weeding gave the highest gross return, net return and BCR. Shelar (2014) found that maximum net returns (Rs.16878.66 /ha) and B:C ratio (1.37) was recorded in the treatment of pre emergence application of oxadiargyl at 120 g/ha + post emergence application of bispyribac sodium at 25 g/ha direct seeded rice. Iqbal *et al.*(2017) [32] reported that the highest BCR was recorded in direct seeded rice followed by transplanted rice and concluded that direct seeded rice is a site specific technology for sowing of rice which save labor and energy. Karthika *et al.* (2019) [36] reported that higher net return and B:C ratio was observed with the application of Bensulfuron methyl (0.6%) + Pretilachlor (6% GR) (10 kg/ha) *fb* 2,4-D (1.25 kg/ha) + one hand weeding at 45 DAS in direct seeded rice ecosystems.

Weed control strategies

Hand weeding

In India, manual weeding is the most prevalent practices in different cultures of rice but this practice is effective only when weeds attain certain stature to provide better grip for uprooting (Bhan, 1980) [11]. Hand weeding (20 and 40 DAS) twice performed the best in enhancing all the growth and yield parameters (Singh and Namdeo, 2004) [89]. Hand weeding twice resulted in significantly higher panicle number and grain yield (Suganthi *et al*., 2005) [95]. The highest weed control efficiency of 66 per cent was recorded with two hand weeding at 30 and 45 DAS as reported by Payman and Singh (2008) [84, 93].

The lowest weed count and weed dry weight was recorded under twice hand weeding in DSR (Roy *et al.*, 2010) [74]. Nadeem Akbar *et al*. (2011) [51] reported that hand weeding was more effective in decreasing weed density and dry weight and increasing weed control efficiency and rice yield than the mechanical hoeing and chemical weed control method in direct seeded rice. Hand weeding at 20 and 45 DAS recorded significantly taller plant height and higher dry matter production in DSR (Sheeja *et al*., 2013). [80] Nath *et al.* (2014) [52] found that among different weed control treatments, two hand weeding at 20 and 40 DAS had highest weed control efficiency (75.7%) in DSR. Kankal (2015) reported that maximum height, numbers of tillers/0.25 m^2 and dry matter accumulation in rice crop was recorded by hand weeding thrice (20, 40 and 60 DAS) in drilled rice. Chaudhary *et al.* (2018) [22] found that two hand weeding produced the highest thousand grain weight in dry DSR. Devi and Singh (2018) [82] reported that two hand weedings at 20 and 40 DAS recorded maximum yield, NPK content in grain and straw in direct seeded rice.

Mechanical weeding

Increasing demand for labour and escalating cost of agrochemicals together with phytotoxicity effects necessitated the farmers to think of mechanical measures of controlling weeds. Mechanical weeding had the advantage of economical, non-polluting without residual problems and it is relatively safe to the operator (Mishra and Sahoo, 1971) [48]. Senthilkumar *et al.* (2003) [78] reported that rotary weeder weeding had the advantage of 10.9 per cent of increased crop yield/ha rather than using hand weeding. Rajendran *et al.* (2005) showed that 22 to 24 per cent yield increase due to the use of mechanical weeder. The highest weed suppression and increase in rice yield by 25 per cent over unweeded check under mechanical hoeing and it was statistically on par with hand weeding treatment (Nadeem Akbar *et al.*, 2011) [51]. Hand weeding is very easy and environment-friendly but tedious and highly labour intensive and thus is not an economical for the farmers (Juraimi *et al.*, 2013) [35]. Mechanical weeding resulted 72 per cent reduction in the total weed density compared with the control. Mechanical weed management followed by chemical application led to higher efficacy in weed control over the control (Arunbabu and Jena, 2018) [5].

Chemical weed control

In rice, the conventional method of weed control *i.e.* hand weeding is very laborious, expensive and inefficient. Use of chemical to control weeds has been found effective and economical. Chemical weeding is easier, time saving and economical as compared to hand weeding alone (Brar and Mishra, 1989) [18]. Chemical weed control can be considered as a better alternative (Singh *et al*., 1998) [88]. Herbicidal weed control methods offer an advantage to save labour and money, as a result, regarded as cost effective method of weed control (Ahmed *et al*., 2000) [1]. Herbicides provide superior weed control and are more labour efficient than manual or mechanical methods of weed management (Chauhan *et al*., 2014) [25]. Jacob *et al*. (2014) [33] reported that the major advantage in going for herbicidal control of weeds in DSR is the reduction in the cost of cultivation.

Pre-emergence application of herbicides is not possible always because of unfavorable climate and sowing pressure (Porwal, 1999) [59]. Continuous use of pre-emergence herbicides in high dose causes shift in weed flora from grasses to non-grassy weeds (Singh *et al*., 2009) [91] and development of herbicide resistance in weed due to long persistence in the soil. This necessitates use of post emergence herbicides for weed control in DSR, which provides broad spectrum, weed control and tackle the problem of herbicide resistance. Paswan *et al*. (2012) [57] opined that herbicides with different mode of action when mixed together, bind to different target sites in weeds and prevent the probability of target site resistance in susceptible species. Herbicides may be considered to be a viable alternative to hand weeding (Chauhan and Johnson, 2010; Anwar *et al*., 2012) [23, 4]. Singh *et al.* (2017) [83] found that sequential application of pendimethalin *fb* penoxulam produced the lowest weed density and total weed biomass over weedy check, and consistently produced higher growth, yield attributes and yield of DSR. Devi and Singh (2018) [82] reported that the application of bispyribac at 25 g a.i./ha + azimsulfuron at 17.5 g a.i/ha + NIS (0.25%) at 15-20 DAS recorded maximum yield (grain and straw) in direct seeded rice. Rathika and Ramesh (2019) [71] reported that application of PE pretilachlor + safener at 0.45 kg/ha + EPOE metsulfuron methyl + chlorimuron ethyl at 4 g/ha on 25 DAS recorded higher grain yield (4.91 t/ha), maximum net returns and BCR (Rs.42371/ ha and 2.23) in direct wet seeded rice.

A list of commonly used herbicides in direct seeded rice field with their active ingredients, application time and target weed groups has been presented in Table 3.

Table 3: Commonly used herbicides in direct seeded rice system (Azmi, 2012) [8].

Herbicides	Time of application (DAS)	Dose	Salient features
Benthiocarb	5-7	6 L product/ha	Early post emergence herbicide, broad spectrum of weed control under saturated conditions
Bispyribac sodium	10-14	20-40 g a.i/ha	Contact herbicide for early post emergence application, broad spectrum of weed control except *Leptocholoa chinensis*
Bensulfuron methyl	6-10	300-500 g a.i/ha	Effective against almost all annual and perennial broadleaved weeds and some sedges during pre-emergence and early post emergence under wet/standing water conditions
Cyhalofop butyl	10-14	100 g a.i/ha	Effective against *E. crusgalli* and *L. chinensis* until four leaf stage. Tank mixed with Sulfonyl urea gives wide spectrum of weed control
Fentrazamide	4-7	60-70 g product/10L	Early post emergence herbicide, effective against mostly grasses and some sedges, broadleaved weeds
Molinate+ bensulfuron	6-10	3.0 + 0.03 kg a.i/ha	Wide spectrum of weed control under standing water Conditions
Molinate + 2,4-D	14-21	3.0 + 0.5 kg a.i/ha	Early post emergence herbicide for *Echinicholoa* spp., wide spectrum of weed control
Pretilachlor	1-4	0.5 kg a.i/ha	Pre-emergence herbicide, broad spectrum of weed control
Propanil	5-7	6 L product/ha	Early post emergence herbicide, broad spectrum of weed control under saturated conditions
Propanil + 2,4-D	6-10	2-4 kg a.i/ha + 1kg a.i/ha	Early post emergence herbicide for grassy weeds, effective under dry and saturated conditions
Penoxsulam + cyhalofop butyl	6-10	12.5 g + 62.5 g a.i/ha	Effective against *E. crusgalli, L. chinensis, C. iria, F. miliacea* and *C. difformis* under saturated condition

(DAS = Days after sowing; a.i = active ingredient; ha = hectare)

Integrated weed management

No single weed control method can combat multitude of weed problems in a given area and so it is necessary to use a combination of physical, chemical (time of application) and cultural (method of seeding and intercropping) management techniques to achieve higher benefits in wet seeded rice cultivation. Gogoi (1995) reported that cultural and chemical combination had the greatest weed control efficiency. The integration of cultural and mechanical control with safe herbicides can be recommended for pollution free weed management (Bhan and Sushil Kumar, 1996) [12]. Integration of diverse technologies is essential for weed management because weed communities are highly responsive to management practices and environmental conditions (Buhler *et al*., 2000). Chemical method of weed control should not be considered as a replacement for other weed control methods, however, should be integrated with them. Karthika *et al.* (2019) [36] reported that the application of Bensulfuron methyl + Pretilachlor (10 kg/ha) *fb* 2,4-D (1.25 kg/ha) + one hand weeding @ 45 DAS was found to be the ideal combination for managing the weeds by increasing weed control efficiency under direct seeded condition with higher grain yield.

Table 4: Influence of IWM on the rice grain and biological yield of the direct sown puddled rice (Sharma and Singh, 2008) [84, 93].

S. No	Weed control measures	Grain yield (t/ha)	Biological yield (t/ha)
1	Weedy	0.7	7.7
2	Two hand weedings	5.0	12.0
3	Herbicide + one hand weeding	5.3	12.6
4	Criss cross sowing + one hand weeding	3.8	11.5
5	Criss cross sowing + one hand weeding + herbicide	5.5	13.3
LSD at 5%		0.1	2.8

Conclusion

It is inferred that no single weed control method is adequate in checking weed population in rice cultivation. Judicious mix of more than one method is warranted to keep the weed under control for higher productivity in rice. Hence, integrated weed management packages comprising of suitable herbicides supplemented with hand/mechanical weeding should be given focus for effective control of weeds in direct seeded rice towards targeted yield.

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