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Weed management in direct seeded rice in Indian perspective: A review

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Abstract
Transplanting rice seedlings in puddled conditions is the major rice cultivation system in many parts of the world. The transplanting system provides a high and stable yield. It is labour-intensive and requires around 1500-2000 mm of irrigation water (1500-2000 mm). A decrease in irrigation water and labour availability forced the farmers to adopt a direct seeding system, especially in Asian countries where rice is a staple crop. Wet direct seeding of rice cultivation saves the amount on labour expenditure but it has very low water-saving potential. Dry direct seeding is another rice establishment method that has the potential to save both water and labour. Seedling raising, puddling, and transplanting of seedlings are omitted in the dry direct seeding system, weed infestation is one of the major constraints responsible for poor productivity in direct-seeded rice, especially in dry direct seeding (Singh *et al*., 2006). Strategies for weed management in direct-seeded rice depend on the critical period of weed control, weed flora, and the method adopted. The sole application of pre or post-emergence herbicides does not provide effective control over weeds as compared to a combination of pre and post-emergence herbicides in rice (Walia *et al.*, 2008). As a long-term goal to achieve sustainable management of weeds in Direct seeded rice (DSR) an integration of different weed management methods stale seedbed, mulch and integrated weed management (IWM) are essential.

Keywords: Direct seeded rice, weed flora, IWM, critical period of weed control

1. Introduction

Rice (*Oryza sativa* L.) is the staple food for around 60% of the world's population and belongs to the family of Poaceae (Bista, 2018) [16] hence called "Global grain" (Balai *et al*., 2013) [11]. Rice is grown on 161 million hectares of land with an annual production of about 509.87 million metric tons of milled rice (Statista 2021) [115] around 90% of the world's rice is grown in Asian countries it-self (Muthayya *et al.*, 2014) [80]. The population of the world is increasing and the food demand is also increasing. Thus, food production needs to be increased by 70% to meet up the global food demand by 2050 (Muthayya *et al.*, 2014) [80]. The horizontal expansion of rice area is limited in a future period of decrease of agricultural land. Thus, the additional rice production should come from the increase in productivity. The major challenge to achieving increased production include scarcity of water and labour, increased wage rates and production cost, soil, and environmental degradation. Transplanting rice seedlings in puddled conditions is the major method of rice establishment in the world, especially in Asia. The major benefit of the transplanting system of growing rice includes increased nutrient availability (e.g. iron, zinc, phosphorous) and weed suppression. Puddling is a tillage practice of mixing soil and water by which a hard pan is developed below the plow zone to reduce soil permeability under conventional planting. High loss of water occurs during the puddling process, surface evaporation, and percolation. Traditional puddle transplanted-flood irrigated low-land rice culture uses more than 80% of the developed freshwater resources used for irrigation purposes of which about half is used for rice production (Dawe *et al*., 1998) [37].

Puddling and transplanting consume 30 percent of the total water requirement of rice. It has been reported that 2 M ha of fully irrigated and 13 M ha of partially irrigated land in Asia during the wet season experience physical water scarcity (Ali *et al*., 2014). It is also reported that South Asia may experience a 30% decline in agricultural production by 2050 due to water shortage (Hossain and Siddique, 2015) [53].

Transplanting takes 240 to 250 man-h ha^{-1}, which is 25 percent of the total labour requirement of the rice crop (Ojha and Kwatra, 2014) [83]. The direct seeding method of rice can be followed in two ways the first method is dry direct seeding and the second one is wet direct seeding.

Wet direct seeding has been followed in many Southeast Asian countries in response to increased labour scarcity and wage rates. In contrast, in areas where scarcity of both labour and irrigation water is prominent, dry direct seeding is the best alternative to conventional practice for sustaining rice production (Pandey *et al*., 2002) [86], (Gathala *et al.*, 2014) [47]. Mitra *et al*., 2005 [81] reported that the yield per hectare of production is similar to that of the transplanting method and this gave more economic returns.

With the declining water resources and labor, the conventionally flooded system of rice is losing its sustainability and economic viability (Bhushan *et al*., 2007) [14]. The decreasing water table, increasing costs for the uplifting water from the below-ground levels and climatic changes have further aggravated the problem. Dry direct seeding (DDS) is a new system of rice cultivation where rice seed is sown into the dry cultivated land at optimum moisture for seed germination (Joshi *et al*., 2013) [61]. This method ensures the sowing of much more area in less time with the same available farm power and labour compared with the conventional system. There is a savings of water required for puddling and during the period from sowing to the late tillering stage. Farmers may accept the DDS system as an attractive alternative to the traditional transplanted conventional systems for dry season rice cultivation as it reduces irrigation and labour costs, and gives higher yield.

Singh *et al*., 2013 [104] reported that Direct seeded rice (DSR), probably the oldest method of rice crop established in the field from seed directly rather than transplanting the seedlings from nursery. It is gaining popularity as a feasible and best alternative method that overcomes all the limitations of the transplanting method (Parameswari *et al*., 2014) [84]. With the absence of transplanting shock in DSR, the crop came to maturity 7 to 10 days earlier than transplanted rice (Rana *et al*., 2014) [92]. It was also recorded at par in yield in comparison to transplanted rice (Awan *et al*., 2006) [8] (Madhushekar *et al*., 2021) [73]. Though DSR has several advantages and could be an effective alternative to traditional transplanting, it is also having major constraints which are poor germination, uneven crop stand, high weed infestation etc.

Different countries like U.S.A, Srilanka, India, Malaysia, Phillippines, Brazil, China, Combodia, Bangladesh etc., have been successfully practicing DSR (Kumar V and Ladha JK 2011) [66]. Globally, about 23% of rice cultivation is done under DSR (Rao *et al*., 2007) [93]. In Asia, the DSR is practiced in area of about 29 million ha, approximately 21% of the total area helps in reducing overall water demand by minimizing the loss from evaporation, leaching, percolation, and water needed for land preparation.

2. Weed flora in DSR

Common weed flora in DSR includes grasses, sedges and broad leaf weeds (BLW). Weed flora present in DSR will vary depending on the season as well as climatic and edaphic conditions. The major weeds which causes high yield losses are *Echinochloa colona* (L.), *Echinochloa crus-galli* (L.) P. Beauv., *Leptochloa chinensis* (L.) Nees, *Oryza sativa* L. *f. spontanea* Roshev and *Ischaemum rugosum* Salisb. *Cyperus iria* L., *Cyperus diffor*mis L., *Schoenoplectus juncoides* (Roxb.) Palla and (L.) Vahl., *Eclipta prostrata* (L.), *Spheoclea zeylanica* Gaertner and *Ludwigia hyssop*ifolia (G. Don.) Excell. Raj *et al*., (2013b) [90] reported that in Kuttanad, during *kharif* season BLW predominate (39.3 percent) followed by sedges (38.9 percent) and grassy weeds (21.8 percent) whereas in *rabi* season weed flora percent was not the same as in the previous season weed flora percent of sedges (96.8 percent) are predominant followed by BLW (2.7 percent) and grasses (0.5 percent). Reddy *et al*., (2013) reported that drum seeded and direct seeding of rice was infested with composite weed flora comprising of grasses (59%), sedges (17%), and broad leaved weeds (24%).

Singh *et al*., 2008 [103] opined that changes in method of crop establishment from transplanting to direct seeding method resulted in marked changes in the composition of weed flora. Kumar and Ladha 2011 [66] reported that continuous practice of DSR may result in weed flora shifts towards and becomes difficult to control grasses and sedges. We must adopt different weed management techniques based on weed flora as well as critical period of weed competition, the available resources.

Several Southeast Asian countries have shifted from Transplanted Puddled Rice (TPR) to DSR method of rice cultivation. Rice crop is infested with different weed flora of different habitat like aquatic, semi-aquatic and terrestrial weeds to the tune of 350 weed species (Singh *et al*., 2016) [111]. Rao *et al*., 2007 [93] reported around 50 weed species are found invading DSR crops field these results are in line with Caton BP *et al*., 2003 [24]. In DSR, weeds emerge along with crops right from sowing which causes competition for resources like water, space, and nutrients and there-by increase in cost of cultivation, and thereby reduces the economic yields up to 90% (Rao *et al*., 2007) [93].

The weed is more problematic in DSR than in TPR because rice and weed emerge in about same time and competition occur at same seedling size and the absence of the standing water on weed emergence and growth (Kaur & Singh, 2017) [25]. According to (Singh *et al*., 2016) [111], 20-100% yield loss due to weed like *Echinochola* spp., *Leptochloa* spp., *Cyanotis* spp., *Digitaria* spp., and *Alternanthera* sp in DSR is observed in different places.

Change of rice establishment method, from TSR to DSR there can be change in weed flora composition (Singh *et al*., 2009) [112]. Diverse weed flora was observed in Dry-DSR than in TPR (Tomita *et al*., 2003) [118]. In Transplanted rice there was 46 weed species were observed in 1989 and 21 new weed species were added to the weed flora after 3 years of Wet-DSR (Kumar & Ladha, 2011) [66]. (Singh *et al*., 2009) [112], in TPR method, the number of species of grasses, broadleaves, and sedges recorded was 6,4 and 4 respectively. The number of weed species is increased to 15 grass species, 19 broadleaf species in DSR method of rice cultivation which show diverse weed flora in DSR than in TPR. This cause more difficult to control weed in DSR. Weedy rice (*Oryza sativa f. spontanea*), also known as red rice, has become a serious problem in the areas where TPR is replaced by DSR recorded an yield lose from 15-100% (Kumar & Ladha, 2011) [66]. Weedy rice in DSR method is difficult to control because of its morphological and genetical similarities with rice crop (Bista, 2018) [16].

3. Critical period of crop-weed competition

Crop-weed competition is more severe in DSR than in transplanted rice. Because weeds and rice seedlings emerge simultaneously, the competitive advantage of the crop is reduced and the alternate events of wetting and drying enhance the growth of weeds. When competing, plants have similar vegetative habits and demand resources, and then the competition becomes severe. The severity of competition depends not only on competing species but also on its density, duration, and the fertility status of the soil. DSR it is crucial to minimize the crop-weed competition especially during the early stages of the crop (Singh, 2008) [103].

To get high productivity in DSR method, reducing weed competition and effective utilization of resources is very important during the critical weed-free period. Chauhan and Johnson, 2011 [31] reported that the critical period of weed competition has been reported to be 14 to 41 days after sowing the results are in-confirmative (Maity and Mukherjee, 2008) [77]. Whereas, Azmi *et al*., (2007) [9] reported that critical period for weed control in DSR was from 12 to 60 DAS. Weed free situation for first 60 or 70 DAS produced yield comparable with weed free situation until harvesting in DSR (Singh 2008) [103].

In Asia, manual weeding and herbicide application are commonly practiced to control weed. However, manual weeding is becoming less common because of the unavailability of labour at critical periods and sole use of herbicide result in the evolution of resistance in weeds, shift in weed populations, environmental degradation also, there is less availability of broad-spectrum herbicides. Therefore, there is a need of integrating herbicide applications and other weed management strategies on the critical period of crop-weed competition period for effective, long-term, and sustainable weed control in DSR system.

4. Yield due because of weeds in DSR

The emergence of competitive weeds, absence of water to suppress the weeds at the time of seedling emergence, and prevalence of hard to control weeds, are the major reasons for high infestation of weeds in DSR. Weeds will affect the crop yield, quality, and cost of production due to competition for various resources (Singh, 2008) [103]. Because of wide adaptability and faster growth, weeds dominate the crop's habitat and reduce the yield potential (Rao, 2011) [94]. However yield loss depends on several factors like weed flora present, percentage of weed infestation, season, variety, and cultural practices followed. On average, yield loss, due to weed competition ranges from 15 to 20 percent, but in severe cases, it may exceed 50 percent (Hasanuzzaman *et al*., 2009) [52] or even complete crop failure (Jayadeva *et al*., 2011) [59]. Raj *et al*., (2013b) [90] reported that season-long weed competition in wet-seeded rice caused 69.71 and 67.40 percent reduction in grain yield during *kharif* and *rabi* seasons, respectively.

5. Methods of weed control

5.1 Cultural methods of weed control

Cultural approaches play significant role to determine the competitiveness of a crop with weeds for above ground and below ground resources and hence might influence weed management (Dass *et al*., 2016) [36]. The following are different cultural methods of weed control

a. Land levelling

Good land preparation helps in reducing weed densities by providing a weed free seed bed at the time of sowing. To obtain a uniform crop stand the field should be levelled prior to sowing. Levelling is usually done by using leveler which can be operated either by bullock drawn or machine drawn.

Jat *et al*., 2009 [58] reported that use GPS machine for land levelling helped in better crop establishment, precise water control and increased herbicide use efficiency which is in conformity with Chauhan, 2012 [25]. Running of Laser leveler can reduces the weed population up-to 40 percent and labour requirement for weeding for about 75 percent i.e.,16 man-days ha^{-1} (Rickman 2002) [98]. Whereas Banerjee, 2015 reported that laser land leveling reduces the labour requirement for weeding operations by 86.7 per cent.

b. Stale seed bed technique (SSB)

SSB is one of the cultural management strategies can be used before the crop sowing to reduce weed seed bank in the field SSB is a very effective weed management practice against weedy rice (Delouche *et al*., 2007) [39] Jose *et al*., (2013) [60] and reduces up to 53% of weedy rice over the control (Singh *et al*., 2007) [109]. A significant reduction of 25-30% in the viable seed bank of *E. colona* and *Dactyloctenium aegyptium* L. (Willd) (Renu *et al*., 2007) [97] and 13-33% reductions in the overall seed bank after rice harvest have been recorded (Singh *et al*., 2018) [113]. Low dormancy in seeds enables quick germination after irrigation and exposure to sunlight (Chauhan B S and Johnson DE 2008) [27]. SSB technique is effective against weeds like *Eclipta prostrata*, *C. difformis*, *F. miliacea*, and *Euphorbia hirta* L., but species like *Amaranthus spinosus* L., *Eleusine indica* (L.), and *I. rugosum* need stimulation for germination (Benech-Arnold *et al*., 2000) [13]. Hard seed-coated weeds like *Commelina benghalensis* L., *Cyperus diffusa*, *Corchorus olitorius* L., *Mimosa invisa* L. and *Mimosa pudica* L. remains difficult with SSB (Chauhan B S and Johnson DE 2009) [28].

In DSR, SSB followed by shallow plowing after two weeks resulted in an 80% and 40% reduction in the density and weed biomass, respectively (Singh *et al*., 2010) [107]. The weed seed bank depletion due to SSB provides a less competitive environment for rice during the initial stage (Isik *et al*., 2011) [56]. Brainard *et al*., (2013) [22] have also reported a decline in the density of grassy weed and *C. rotundus* by 42-67% and 22-51%, respectively, with SSB. The seed bank depletion of *E. colona* and *D. aegyptium* with SSB provides a competitive advantage to rice (Bhullar *et al*., 2018) [15]. The SSB practice with bispyribac-sodium as a sequential post-emergence herbicide remains desirable under double DDSR; (Mahajan *et al*., 2011) [74].

In SBB, initially a light irrigation will be given or after a rainfall the field is allowed to emerge weed seedlings, after that emergence of weed seedlings are killed using a herbicide like glyphosate or shallow tillage or flooding. This technique not only reduces weed emergence but also reduces the number of weed seeds in the soil seed bank (Rao *et al*., 2007) [93]. The success of SSB depends on several factors like method of seedbed preparation, method of killing emerged weeds, weed species, duration of the stale seedbed (Ferrero, 2003) [126], and environmental conditions (e.g., temperature) during the stale seedbed period. Chauhan and Johnson 2008 [27] reported that weed species, especially *Cyperus iria, Cyperus difformis, Fimbristylis miliacea* (L.) Vahl *Leptochloa chinensis,* and *Eclipta prostrata*, are relatively more susceptible to the SSB technique because of their low seed dormancy and their inability to emerge from a depth greater than 1 cm these findings are in-line with Chauhan and Johnson, 2010 [29]. Singh (2013) [104] reported that in SSB technique, application of glyphosate@1 kg ha^{-1} under DDSR condition is more effective in reducing the weed density and recorded higher grain yield than SSB using shallow tillage.

c. Weed competitive cultivar

Weed-competitive cultivars is an attractive low-cost strategy of an overall IWM program for both low- and high-input cropping systems and the most efficient way of delivery to farmers (Andrew *et al*., 2015) [3]. This strategy has two components: first is weed tolerance and the second is weed-suppressive ability. The ability of crop plants to maintain high yields despite of weed competition is known as weed tolerance, whereas weed suppressive ability is the ability to suppress the growth of weeds by the crop through competition. Caton *et al*., 2003 [24] found that rice characteristics that compete with weed include plant height together with early and rapid growth rate, higher tiller number (Fischer *et al*., 1997) [46], droopy leaves (Dingkuhn *et al*., 1999) [40], and high biomass accumulation in the early growth stage, high LAI (Dingkuhn *et al*., 1999) [40], rapid canopy cover (Lotz *et al*., 1995) [72] and early vigour (Zhao *et al*., 2006) [122] etc., Kumar *et al*., (2013) [67] reported that out of three cultivars, Gautam was highly competitive in suppressing the *Echinochloa* spp. compared to the Prabhat and Krishna Hamsa varieties.

d. Crop rotation

Crop rotation is often considered to be a vital tool of cultural weed management. Weed demography and subsequent population dynamics were altered with crop rotation (Liebman and Gallandt, 1997) [70]. This technique helps in breaking the weed seed cycle and facilitates the identification of weedy rice. Growing crops like soybean, mungbean, Cotton, maize, etc., as break crop in rotation with rice crop helps in breaking the weed seed cycle (Scavino *et al*., 2013) [99]. Crop rotation allows using other herbicides and other cultural operations that cannot be used in rice (Singh *et al*., 2013) [104]. Gill and Holmes 1997 [48] reported that the rotation of rice with forage crop offers diverse mechanisms to suppress weeds through competition, grazing, and mowing. Intensification of a rice-wheat system by including short-duration vegetables (pea or potato) followed by late wheat can also improve weed control without herbicide applications (Chhokar *et al*., 2008) [34].

e. Water and nutrient management

In DSR method, with or without dry tillage and sowing followed by irrigation is common. As a cultural method pre-sowing irrigation is often advised under DSR to control weeds. Water management strongly influences Weed seed germination, emergence, population, growth, maturity duration and seed production. After establishment, micro-irrigation, especially drip irrigation may help in reducing the weed menace in DDSR. In drip-irrigated DDSR, higher grain yield and water savings (up to 42%) have been reported (Sharda *et al*., 2016) [101].

Blackshaw *et al*., 2004 [18] reported that, weeds uptake nutrients faster during early growth stages and competes with crop hence recommended to banding of fertilser and coinciding with crop demand would lower weed densities and biomass.

The fertilizer doses and application methods can modify weed–crop competition by affecting weed demography, development, and competitive ability (Bajwa *et al*., 2015) [19]. Emergence or suppression of certain weeds and their biology may influenced by the time, rate and method of fertilizer application (Cathcart RJ and Swanton C J 2003) [23].

A higher starter dose for initial slow-growing crops may promote weeds and reduce yields (Major *et al*., 2005) [76]. Surface application of fertilizer favor the weed seeds lying on the upper soil layers (Guza *et al*., 2008) [51]. Surface banding of nitrogen and phosphorus as a cultural weed management method often reduces weed emergence and growth in DSR over surface broadcasting (Chauhan B S and Abugho S B 2013) [26].

f. Residue mulch

Keeping crop residue as a mulch influences weed infestation by affecting weed seed survival, germination, emergence, and development. Weed management under DSR through crop residue mulch offers various direct and indirect advantages in crop microclimate in maintaining soil temperature, conserving soil moisture, suppressing weeds and adding organic matter in due time. Mulch practices significantly reduce the emergence of different weed types, namely grassy, broadleaf, and sedges up to 73-76%, 65-67% and 22-70%, respectively.

Around 4-6 t ha^{-1} of crop residue application in the field supresses the different type of weeds especially grasses and sedges like *Echinochloa crus-galli*, *Echinochloa colona*, *D. aegyptium*, *I. rugosum*, *Eleusine indica* and *Murdannia nudiflora* L. Brenen however it doesn't affect the emergence and growth of weed species such as *Trianthema portulacastrum* L., *Amaranthus viridis* L., and *Ipomoea tribola* L (Lee *et al*., 2011) [69]. The success of crop residue as a weed management depends on the type and volume and weed seed morphology and its relative position.

Van chin 2001 reported that residues of Brassica spp., exhibit Allelopathy which alters the emergence and growth of weeds. The seed size disparity between small-seeded weed species and the larger size of rice seeds offers prospects for weed suppression in DSR with residue use. *Sesbania* co-culture with rice as brown manure and use of selective herbicides (2,4-D ethyl ester or bispyribac sodium) at 25-30 DAS reduces weed emergence. Seed priming integrated with precise seeding technology improves the speed and synchrony of seed germination by reducing germination time and improving the overall crop performance in DSR (Mahajan *et al*., 2011) [74].

Seed priming results in an increase in seed vigour by 50%, a higher seedling dry weight of 35-60% and resistance to various abiotic stresses (Juarimi *et al*., 2012) [62], Hydro-priming (Goswami *et al*., 2013) [50], solid matrix priming (Zheng *et al*., 2016) [124], spermidine, osmo-hardening with KCl, polyethylene and polyamine pre-treatment (Farooq *et al*., 2009) [43] and nutri-priming with phosphorus and boron (Rehman *et al*., 2012) [96] have been found to be very beneficial.

Priming treatments also produced the most vigorous seedlings with 50 percent more vigour index compared to unprimed seeds. Seedling dry weight was increased by 60 and 35 percent due to hardening and hydro priming, respectively. Anwar *et al*., 2012 [5] reported that synchronized emergence of primed seeds can ensure vigorous crop stand with rapid canopy development which given an advantage to the crop over weeds. Relative yield loss was reduced by around 10 percent due to priming (Juarimi *et al*., 2012) [62]. This was mainly due to the fact, that priming reduces the risk of poor stand establishment and crop losses due to weeds.

g. Plant population dynamics through crop geometry and seed rate

Enhancing the seed rate in DDSR from 20 to 80 kg ha^{-1} is often useful to offer competition for weeds in various parts of Asia (Chauhan *et al*., 2011) [31] and (Zhao D L 2006) [123]. The rice yield increases as seed rates increase up to 150 kg ha^{-1} under DSR in Malaysia (Azmi M and Karim S.M.R 2008) [10], Latin America (Fischer A J and Antigua G 1997) [45] and the United States (Estorninos L E and Gaely D R., 2002) [42] Rice crops sown with higher seed rates also demand less herbicide. Liebman *et al*., 2001 [71] reported that to achieve better competitive ability by the crop plants, increasing plant population given less weed competition by the weed seeds. This strategy adoption offered narrow row spacing and higher leaf area index, increased light interception per unit of leaf area for crops and decreased light penetration for developing weeds. The results are in-confirmitivity with Chauhan *et al*., 2011 [31].

h. Sesbania co-culture (Brown Manuring)

Growing sesbania as green manure either as pre-rice or intercrop or mixed crop (25 kg ha^{-1}) with rice is called brown manuring (sesbania co-culture). When sesbania attains a height of 30-40 cm tall around 25-30 days after emergence 2, 4-D ester @ 0.5 kg ha^{-1} is to be applied for weed killing. Singh *et al*., 2007 [109] reported that co-culture technology reduced the weed population by nearly half without any adverse effect on rice. Other benefits of sesbania co-culture are atmospheric nitrogen fixation and facilitation of crop emergence in areas where soil crust formation is a problem (Gopal *et al*., 2010) [49]. According to Singh *et al*., 2007 [109] to get maximum weed suppression in rice the sesbania to be sown on the same day. This technique was more effective against BLW and sedges, and less effective on grasses. Hence, the application of pendimethalin as pre-emergence proves good to overcome the problem of grass weeds (Kumar and Ladha, 2011) [66]. Anitha and Mathew (2010) [4] reported that, in case of semi-dry rice sesbania coculture to be incorporated at 30 DAS for maximum weed suppression and higher grain yields and the best method for knocking down sesbania was 2, 4-D spraying @ 1 kg ha^{-1}.

i. Submergence and weed control

Submergence is considered the best herbicide in direct-seeded rice. The number of weed species, growth of weeds and suppressing of germination are depends with submergence time, duration, and depth of flooding which are very critical. Problematic weeds like *Leptochloa chinensis*, the growth and emergences were suppressed when the crop flooded with a shallow depth of 2 cm. (Chauhan and Johnson, 2008) [27]. Continuous submergence to a depth of (2-4 cm) flooding helps to suppress the emergence and growth of *Cyperus iria*, *Fimbristylis miliacea*, *Leptochloa chinensis* and *Ludwigia hyssopifolia*. Sen *et al*., 2002 [100] reported that to minimize the rice weed competition, broadcasting pre-germinated rice seeds at 4-6 cm depth after inundating the field and maintaining the water level continuously helps good results. Good water management together with chemical weed control offers an unusual opportunity for conserving moisture and lowering the cost of rice production (Singh *et al*., 2009) [112].

j. Soil solarization

Soil solarization is a method of heating the soil's surface by using transparent polyethylene sheets (LDPE film) placed on the soil surface to trap solar radiation. Increased soil temperatures' became lethal for soil-borne pathogens such as root-knot nematodes, Fusarium etc., and weed seed present in the soil will die before they emerge. The other benefits of soil solarization are improved soil structure and enhances availability of nitrogen and other essential plant nutrients. Khan *et al*., (2003) [65] reported that covering the soil prior to planting with 100 µ thickness (400 gauge) LPDE sheets for 30 days was effective in reducing the density of grassy weeds and BLW and weed dry weight. Soil temperature at 5 cm depth under transparent mulch rose by 10-15 °C and at 10 cm depth rose by 10-12 °C.

5.2 Mechanical method of weed control

a. Chopping

Chopping is applicable for controlling weeds in rice plants, which are taller than cultivated rice. In many parts of the world, the weedy rice panicles or plants with similar morphology are cut with the help of a machete or a special knife attached to a stick (Singh *et al*., 2013) [104].

5.3 Chemical method of weed control

Chemical method of weed management is the smartest option of weed control in direct seeded rice. Usage of herbicides reduces the total energy requirement for rice cultivation (Singh and Singh, 2010) [107]. According to Begum *et al*., (2011) [12] chemical method of weed control becomes the popular and best alternative to hand weeding because of the tedious nature, high labour involvement in hand weeding (190-man days ha^{-1}), time consumption, and impractical under adverse weather conditions. Moreover, hand weeding becomes less effective on some occasions because of the escape or regeneration of perennial weeds having many flushes. Herbicide use becomes even more important, as rice and weed seedlings emerge simultaneously and some weed seedlings (e.g., *Echinochloa* spp.) are like rice seedlings in morphology (Chauhan, 2012) [25]. Among the different methods of weed management herbicides provide superior weed control and are more labour efficient than manual or mechanical methods (Chauhan *et al*., 2014) [30].

In present days weed control in rice with chemical methods should not be considered as a replacement for other methods, however, should be integrated with them. Hill *et al*., 2001 [54] reported that the success of weed control in rice crop through herbicides is closely linked to water management to provide suitable conditions for achieving specificity and minimizing the risk of phytotoxicity. Selection of right herbicide, correct time of application, proper dose and method of application are important criteria for higher weed control efficiency and crop yield. Jacob *et al*., (2014) [57] reported that the cost of cultivation significantly reduces under DSR method through application of herbicides. De Datta (1981) [38] opined despite some adverse environmental effects, herbicides are the most effective, practical and economical means of weed management in DSR. Currently, there are, no viable alternatives are available to replace herbicides for weed management in rice.

a. New generation post emergence herbicides

Herbicides are very effective for controlling weeds in DSR, but pre-emergence application of herbicides is not possible always because of unfavorable climate and sowing pressure (Porwal, 1999) [88]. The challenges with the preemergence herbicide are Limited application time window (0 to 5 DAS), toxicity to rice crop and critical water regime. Use of pre-emergence herbicides continuously in high dose causes shift in weed flora from grasses to non-grassy weeds (Singh *et al*., 2009) [112] and development of herbicide resistance in weed due to long persistence in the soil. Under these circumstances, it is advisable to use post emergence herbicides, which provides broad spectrum weed control and tackle the problem of herbicide resistance. The new generation post emergence herbicides are mainly ALS inhibitors, ACCase inhibitors and protox inhibitors. Post emergence herbicides are applied after the emergence of crop and weeds. These herbicides can be applied in crops during the time window from 4-25 DAS of rice. It should be used wisely at the correct stage of the weed and at appropriate dose.

b. Herbicide resistance and weed shift

Though herbicides are effective and economical in controlling of weeds in DSR, continuous use of same herbicide with similar mode of action will lead to the development of herbicide resistance and shift in weed flora. Herbicide with long residual activity, a single target site of action, a specific mode of action, and a highly effective kill rate for a wide range of weed species contribute to resistance development in weeds for a particular herbicide.

Mahajan and Chauhan 2008 [75] reported that the herbicidal resistance was developed by continuous use of pre-emergent herbicides like butachlor, anilophos and pretilachlor for the control of early flush of grassy weeds in transplanted rice. Throughout the worldwide, around 30 weed species associated with rice have evolved resistance to propanil, 2, 4-D and some of the more recently introduced sulfonylureas (Valverde *et al*., 2000) [119]. Due to the continuous use of butachlor, pretilachlor and anilofos weed shift from grasses to non-grasses and sedges in transplanted rice fields was noticed Rajkhowa *et al*., (2006) [91].

Use of herbicide mixtures and applying them in rotation to overcome the shift in weed flora and to prevent or delay the development of herbicide resistance in weeds (Duary *et al*., 2015) [41]. Rotational use of herbicides with different mode of action is known as Herbicide rotation.

c. Herbicide mixtures

Due to narrow spectrum of activity, use of single herbicides seldom furnishes satisfactory and season long weed control. To control broad spectrum weeds in single application herbicides mixtures will give better results (Damalas, 2005) [35]. A grass-effective herbicide in combination with herbicide that control both BLW and sedges will provide a wider spectrum of weed control (Mukherjee, 2006) [79]. Paswan *et al*., 2012 [85] opined that those 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. The herbicide mixture usage strategy controls the broad-spectrum weeds, and reduces the cost of application and load in the environment. (Aurora and De Datta 1992) [6]

The application of two different herbicides in mixed combination even at lower doses proved more effective against a broad spectrum of weeds. (Avudaithai and Veerabadran 2000) [7]. Singh *et al*., (2004) [127] reported that a ready-mix formulation metsulfuron-methylthyl + chlorimuron ethyl was very effective against diverse weed flora. Rahman *et al*. (2012) [5] reported that tank mix application of cyhalofop-P-butyl and bensulfuron methyl resulted in broad-spectrum control of grass, sedges, and BLW. Combination products containing penoxsulam and cyhalofop butyl increased rice productivity in direct-seeded rice (Lap *et al*., 2013) [68]. Field studies conducted at Thrissur, Kerala indicated post-emergence application of penoxsulam + cyhalofop butyl @ 135 and 150 g ha^{-1} resulted in very good control of all types of weeds in wet-seeded rice (Abraham and Menon, 2015) [1]. Raj *et al*., (2013a) [89] reported that the application of bispyribac sodium + metamifop 14 per cent SE @ 70 g ha^{-1} + PIW-111 wetter, 10-15 DAS resulted in enhanced rice yield in wet DSR. It was also pointed out that the pre-mix, bispyribac sodium + metamifop was better than their individual application in reducing the weed density and weed dry matter. The combination of two or more herbicides may become a part of an effective approach to achieving more satisfactory control of weed flora in DSR (Chauhan and Yadav 2013) [26].

5.4 Biological method of weed control

Biological weed control using different herbivorous bio agents like fish, tadpoles, shrimps and ducks are used to control weeds in irrigated lowland rice in a few countries but these cannot be used in aerobic rice, where there is no standing water. Good control of sedges like *Fimbristylis miliacea* and *Cyperus iria* was achievied in rice- fish farming system (Pane and Fagi, 1992) [87]. Weed control by micro herbicides is now being studied to reduce herbicide dependency. In 1982 a powder formulation of *Colletotrichum gloeosporioides* (Penz.) Sacc. f. sp. *aeschynomene*, was registered as COLLEGO, for the control of northern jointvetch (*Aeschynomene virginica* (L.) B.S.P.) in rice (Smith, 1992) [114]. *Setosphaeria* sp. cf *rostrata* was identified as potential fungi for the control of *Leptochloa chinensis* (Thi *et al*., 1999) [117]. *Exserohilum monocerus* and *Cocholiobolus lunatus* are the other promising fungi identified as bio control agents for barnyard grass (Khadir *et al*., 2008) [64] and *Alternaria alternata* for the control of barn yard grass (Jyothi *et al*., 2013) [63]. Boyette *et al*., 1979 [20] reported that the endemic fungus *Colletotrichum gloeosporioides f. sp. jussiaeae* (C.g.j.) controlled >80 per cent of water primrose weed in rice after four weeks.

5.5 Integrated Weed Management (IWM)

Integration of different methods of weed control are essential because weed communities are highly responsive to management practices and environmental conditions (Buhler *et al*., 2000) [21]. Practicing of integrated weed management (IWM) approaches i.e., combinations of as many techniques (cultural, mechanical, biotechnological, chemical etc.) as possible will control weeds effectively rather than a single weed control technique.

Complete depend upon on chemical herbicides as a weed management strategy poses several economic and environmental risks (Sheeja Raj K and Syriac K 2017) [102]. The IWM approach with herbicides becomes imperative in the changing weed flora and crop-weed interference under DSR. The weed management practices should deplete weed seed banks, thus, following a IWM strategy with more emphasis on preventive and cultural methods to reduce dependence on herbicides in DSR system.

Blackshaw R E and Brandt R N 2008 [17] reported that higher seed rate and fertilizer for stimulating initial growth; later limits the herbicide as an effective weed management approach. Stale seedbed followed by use of crop residues as mulch and followed by applications of early and late postemergence herbicides can substantially reduce weed densities. Application of pretilachlor as pre-emergence herbicide either with single-hand weeding at 30 DAS or with brown manure through *Sesbania aculeata* given desirable weed management during the critical growth period of DSR in Eastern Indo-Gangetic Plains of India (Naz *et al*., 2020) [82]. The stale seedbed as a cultural weed management method when integrated with penoxsulam as early post-emergence and one hand weeding at 35-45 DAS achieved 76.8% and 94.3% weed control efficiency at 30 and 60 DAS, respectively. The weed control efficiency further increased to 93% and 97% with stale seedbed and penoxsulam at 10-15 DAS followed by metsulfuron-methyl plus chlorimuron ethyl at 35-40 DAS (Syriac *et al*., 2019) [116].

Growing cowpea or daincha as an intercrop and pre-emergence application of pendimethalin @ 1 kg ha^{-1} followed by hand weeding at 20 DAS as an integrated strategy has been found appropriate for reducing the weed competition in upland direct seeded rice (ICAR, 2007) [55]. Keeping 4 t ha^{-1} of wheat straw as a mulch Crop for DDSR also remains effective against both grassy and broad-leaved weeds. A weed suppression of up to 54% and an increase in yield by 22% has been reported (Singh *et al*., 2014) [128]. Likewise, maize mulch 5 t ha^{-1} provides weed suppression of up to 56% and increases in yield by 32% in DSR (Mohtisham *et al*., 2013) [78]. Higher nitrogen rates and pendimethalin plus bispyribac-sodium at 20 DAS followed by one hand-weeding results in higher net returns and water productivity under DSR.

6. Conclusion

Even though transplanting method of rice cultivation is a normal practice. Due to the population increase, shortage of water for agriculture purpose and increase in labour wages, the better alternative is direct seeded rice (DSR) there are of two types of DSR, first one is Wet direct seeded rice and second one is dry direct seeded rice. Direct seeded rice having benefits like no nursery requirement, no transplanting operations, field comes to maturity around 7-10 days but the main constraint is weed management. From change of TPR to DSR Control of weeds becoming problem and to achieve effective long-term and sustainable weed control. The main objective of the weed management approaches should be to deplete the weed seed bank from the soil and enable rice crop to be more competitive by either delaying the emergence or suppressing the weed emergence and growth. The other objective is after the emergence, of weeds in field condition use of different weed control methods to reduce the weed population below the economic thresholds without deteriorating the environmental quality. The use of any single strategy cannot provide effective, season-long, and sustainable weed control as weeds are hardy in nature, they vary in their growth habits, dormancy levels, life cycle, and dispersal mechanisms. Therefore, the weed management programmes should aim at the integration of all available methods thus the rice crop to be more competitive.

7. References

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