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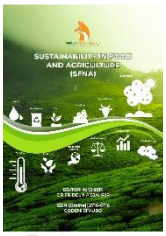

RESEARCH ARTICLE

A REVIEW ON WEED IN DIRECT-SEEDED RICE (DSR)

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ABSTRACT

Oryza sativa, cereal crop grown worldwide which feeds 60% of world. DSR, feasible and resource conserving technique of rice cultivation is gaining popularity, but due to weed infestation, crop experience a yield loss from 15%-100%. Various journals were assessed and books were consulted with the objective of compiling the various weeds of DSR and their management strategies in a comprehensive single document. Weed can be manage by different methods but integration of all methods is the best and eco-friendly compared to chemical one. Biotechnological method for development of herbicide resistance varieties, biological methods are new and are best alternative options. Different pre and post emergence herbicides could be applied to kill or suppress in short period with recommended doses and stage of crop. No single method is perfect for killing all the weeds, integrating different strategies having different modes of action can reduce the weed density and resistance to herbicides.

KEYWORDS

Direct-seeded rice, weed, integrated, biotechnological, herbicides

1. Introduction

Rice (*Oryza sativa)* is a major staple food crop for around 60% of the world population which belongs to family Poaceae (Bista, 2018). It helps to insecure food security and livelihood for millions of people globally (Singh et al., 2016). More than 90% world's rice is grown in Asia (Bista, 2018), which provides 30-75% of the total calories to more than 3 billion Asians (Khush, 2004). In Nepal, rice is the major food crop in term of production and economy which can be widely adapted in all ecological zones of Nepal, cultivated from terai to hilly region (Marasini *et al.*, 2016). Rice is primary source of income for more than two-third of household. It fulfills 50% of the calorie requirement of Nepalese people contributing 21% to the Agriculture Gross Domestic Product (AGDP) (MoAD,2015). The average yield of rice in Nepal is 3.17 tha^{-1} and attainable yield is 5.00 tha^{-1} which shows an yield gap of 1.83 (Marahatta *et al.*, 2017).

In Nepal, rice is cultivated mainly by transplanting 20-25 old days seedlings on puddled soil (land preparation with wet tillage). Puddling reduces weed population, enhance nutrient uptake by creating anaerobic condition, increase the water use efficiency by reducing the evaporation and percolation loss and aids seedling establishment *(*Marahatta *et al.*, 2017). But transplanting is becoming expensive and increasingly difficult due to shortage as well as high cost of labor, scarcity of water, high cost of cultivation etc. It also cause detrimental effects in soil properties, successive crops like wheat, paddy and in atmospheric environment through emission of methane gas (Marasini *et al.*, 2016). Water resource is depleting every year which hints that farmer have to seek an alternative option with less water consumption in the future. Also, transplanting needs 240 to 250 man-h/ha, which is 25% of the total labor requirement for rice crop cultivation (Ojha & Kwatra, 2014). Urbanization cause labor scarcity as well as hike in wage rate. Hence, there is an utmost need of an feasible and resource conserving technique of rice cultivation, where DSR is gaining popularity in rice cultivation.

1.1 DSR status

Direct seeded rice (DSR), probably the oldest method of rice crop establishing in the field from seed directly rather than transplanting the seedlings from nursery (V. Singh et al., 2016), (Kaur & Singh, 2017). It avoids basic operations in rice cultivation like puddling, transplanting and maintenance of standing water in rice field. It is gaining popularity as a feasible and best alternative method which overcome all the limitation of transplanting method. Absence of transplanting shock in DSR pull its maturity 7 to 10 days earlier than transplanted rice (Rana *et al.,* 2014). 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). Globally, about 23% of rice cultivation is done under DSR (Rao *et al.*, 2007). In Asia, the DSR is practiced in area about 29 million ha, approximately 21% of total area in the region (Pandey, S., 1999). DSR helps in reducing overall water demand by minimizing the loss from evaporation, leaching, percolation and water needed for land preparation (TP, 2001).

1.2 Types of DSR

There are three principles method of establishing DSR: 1. Dry-seeding (seed is broadcasted or drill into dry soil), 2. Wet seeding (sowing pre-germinated seeds on wet soil) and 3. Water seeding (seeds sown in standing water). Direct seeded rice is a resource conservation technology which lower the methane gas emission and also the productivity of DSR is 5-10% more than that of transplanted rice (Marasini et al., 2016). Dry-DSR reduces water (12-35%) and labor use up to 40% which decreases the cost

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of production (Mann *et al.*, 2007). However, there is yield reduction in in dry soil condition in compared to wet soil condition. Before Green revolution, rainfed rice were often broadcast into moist soil which yielded low and also prone to weed competition (V. Singh et al., 2016). Whereas, Wet-DSR save 11-18% irrigation water compared with transplanting method (Cabangon, R et al, 2002). But DSR often produce lower yield than transplanting method due to poor crop establishment, higher spikelet sterility (Bhushan et al., 2007). And high weed infestation is major hinderance for better yield in DSR; especially in dry soil condition (Rao AN et al, 2007). Under good water condition and proper weed management, yield potential in DSR is equivalent to transplanted rice (Awan et al., 1989).

However, DRS is economical than transplanting method. Nepal has made self-sufficiency target in rice production by 2020 AD, which can be achieved only by adoption of DSR technology in rice cultivation that also help in adoption of climate change scenario (Marasini et al., 2016). Weed is considered as a serious threat to direct seeded rice as it compete with crop for nutrients, light, moisture, and space and it is reported that weed reduce yield up to 48%, 53% and 74% in transplanted, direct seeded in wet condition and direct seeded in dry condition respectively (Ramzan, 2003). Hence, effective weed control method is needed to make direct seeded rice more economical and best alternative for transplanting method.

1.3 Major Weed in DSR

Several countries of Southeast Asia have shifted their rice cultivation method from Transplanted Puddled Rice (TPR) to DSR in recent year (Marasini et al., 2016). Weed is a major constraint in the cultivation of direct seeded rice crop especially in Dry-DSR. Rice crop is infested with different weed flora consisting of aquatic, semi-aquatic and terrestrial weeds. In rice only 350 weed species is reported(V. Singh et al., 2016). And around 50 weed species are found invading DSR crops field (Caton BP, 2003), (Rao et al., 2007). Some of the major weed present in DSR crop are mention in the Table no 1,2 and 3 where grasses posing serious problems in rice production followed by sedges and bread-leaf weeds worldwide(V. Singh et al., 2016). Dicotyledonous weeds in transplanted field whereas annual grasses such as *E.crusgalli and L.chinensis* and sedges such as *F.miliacea* are observed as dominant *in Veitnam* (Kaur & Singh, 2017). In DSR, weeds emerges along with crops increase the cost of production as well as increase competition in nutrients, water and space which reduces the economic yields up to 90% (Rao et al., 2007). Wide adaptability and faster growth of weeds lead to dominance of weed in crop habitat (Rao, 2011).

Table 1: Common grass weed species of DSR

Scientific Name	Common names	Family
Echinochloa colona	Wild rice	Poaceae
E. crus-galli	Barnyard grass	Poaceae
Elusine indica	Goosegrass	Poaceae
Leptochola chinensis	Sprangletop	Poaceae
Digiteria sanguinalis	Large crab grass	Poaceae
Bracheria ramose	Signal grass	Poaceae
Cyanodon dactylon	Bermuda grass	Poaceae
Dactylotenium aegyptium	Crown foot grass	Poaceae

Source: (Singh et al., 2016)

Table 2: Common Broad leaf weed of DSR.

Scientific name	Common name	Family
Alternanthera sessilis	Khaki weed	Amarathaceae
Ammania baccifera	Redstem	Lythraceae
Caesulia axillaris	Pink node flower	Asteraceae
Celosia argentia	Quail grass	Amarathaceae
Cleome viscosa	Cleome	Capparaceae
Comelina benghalensis	Wandering jaw	Commelinaceae
C. com munis	Dayflower	Commelinaceae
Cyanotis axillaris	Creeping cradle	Commelinaceae
Digera arvensis	Digerakondra	Amarathaceae

Source: (Singh et al., 2016)

Table 3: Common sedges weed of DSR

Scientific name	Common name	Family
Fimbristylis miliacea	Globefingerush	Cypraceae
Cyperus difformis	Small flower umbrella sedge	Cypraceae
C.iria	Flat sedge	Cypraceae
C.royundus	Purple nut sedge	Cypraceae

Source: (Singh et al., 2016)

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 also, the absence of the suppressive effect of standing water on weed emergence and growth (Kaur & Singh, 2017). In different DSR, weed can cause yield loss ranges from 15-20%, but in severe case it may exceed 50% (Hasanuzzaman et al., 2009) or even can cause complete failure (Jayadeva et al., 2011), which occur mostly after one hand weeding (or partial weed-free conditions) in weed-infested fields (Bhagirath Singh Chauhan, 2012). According to (V. Singh et al., 2016), 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.

With a shift from TPR to other rice establishment method, there can be drastic change in weed flora composition (Singh *et al.*, 2009). Diverse weed flora were observed in Dry-DSR than in TPR (Tomita *et al.*, 2003). 46 weed species were observed in transplanted rice in 1989 and 21 new weed species were added to the weed flora after 3 years of Wet-DSR (Kumar & Ladha, 2011) . Based on the study conducted in India by (Singh *et al.*, 2009), the number of species of grasses, broadleaves, and sedges in TPR was 6,4 and 4 respectively whereas, it increased to 15 grass species, 19 broadleaf species which show diverse weed flora in DSR than in TPR by the addition of weed species in DSR which were not adopted in TPR. This cause more difficult to control weed in DSR. Weedy rice (*Oryza sativa f.spontanea*), also known as red rice, has been a serious threat in the areas where TPR is replaced by DSR which has recorded an yield lose ranging from 15-100% (Kumar & Ladha, 2011). Weedy rice which evolve with DSR establishment method are difficult to control because of its genetic, morphological and phonological similarities with rice and also, herbicide which selectively control weedy rice at a satisfactory level has not achieved (Bista, 2018).

In DSR, the critical period of weed competition has been observed around 14-41 days after sowing (Chauhan, B.S. and Johnson, n.d.). Productivity of DSR increases if weeds are controlled effectively at initial growth stage of rice (0 to 40 DAS) (Maity, S.K. and Mukherjee, 2008). In Asia, manual weeding and herbicide application are common practiced to control weed. However, manual weeding is becoming less common because of unavailability of labor at critical period and sole use of herbicide result in evolution of resistance in weeds, shift in weed populations and environmental degradation and also, there is less availability of broad spectrum herbicides (Bhagirath Singh Chauhan, 2012). Therefore, there is need of integrating herbicide application and other weed management strategy on the critical period of crop-weed competition period for effective, long term, and sustainable weed control in DSR system.

2. Material and Method

This review paper was based on various journals, books, articles from online journals, websites, web page, books and many other sources of literature related with weed on direct seeded rice and its management stratigirs. All the information available was collected and compiled in a comprehensive single document in a scientific way and the findings from those literatures are summarized and concluded in this review and are presented in texts and tables.

3. Management

3.1 Chemical method

Chemically herbicides are widely used to kill or suppress the undesirable vegetation in chemical weed management. It is more popular among farmers than manual and mechanical methods due to low labor cost, low input cost and can be used in critical period easily. Chemical herbicides application depends upon selectivity of herbicides on dose, time of application and method of application. In DSR, many researchers opined herbicide application could be an alternatives to hand weeding (Anwar et al., 2012) (Chauhan and Johnson, 2011). Table- 4 shows the list of herbicides recommended for weed management in DSR.

Table 3: Recommended herbicides for weed management in DSR.

Herbicides (trade name)	Dose (g/ha)	Application stage	Weed control
Pre-emergence herbicides			
Pendemethalin 30 EC	1000-1500	0-3 DAS	Annual and some BLWs control
Pretilachlor 30.7% EW	450-600	0-3 DAS	Grassy weed under puddle conditions
Oxadiagryl 16 EC	90	0-3 DAS	Grasses and sedge. BLWs control not satisfactory
Oxyflurofen 23.5 EC	150-240	0-6 DAS	Control annual grasses, BLWs and sedges.
Anilofos 30 EC	400	3-5 DAS	Annual grasses and some BLWs
Oxidiazon 25 EC	500-750	Pre emergence or early post emergence	Control broad spectrum of weeds. Soil shouldn't be disturbed after its application.
Post-emergence Herbicides			
Cyhalofop-butyl 10 EC	75-80	15-20 DAS	Annual grasses particularly barnyard grass and *Leptochola*
Bispyribac- sodium 10 SC	20	15-20 DAS	Annual grasses some BLWs and sedges.
Penoxsulam 24 SC	22.5	15-20 DAS	Annual grasses some BLWs and sedges.
Chlorimuron-ethyl + Metsulfuronmethyl 20 WP	4	15-20 DAS	Broad spectrum weeds including annual BLWs and grasses.
2,4-D 38 EC, 34 EF, 80 WP	750-1000	20-25 Das	Apply where Sedges and BLWs weeds are dominant. Drain before application of herbicide reflood again for few days. Good against water hyacinth and *Monochoria.*
Ethoxysulfuron 15%WDG	12.5-15	15-20 DAS	Broad leaves and sedges.

Source: (Singh et al., 2016).

All the chemical herbicides are toxic: so, they must be handled with safety measures. It is also desirable to rotate the application of combination of herbicides for effective results and to resist the development of resistance to herbicides in weeds.

3.2 Mechanical Method

Mechanical weeding involves the weeding by hands which is called as manual weeding or by mechanical tools like cono-weeder (Devkota & Yadav, 2014). Manual weeding involves the pulling out the weeds from the soil after 25-40 days after sowing (DAS) when weeds are sufficiently large enough to be pulled out leading to losses in soil during initial stage of crop growth (Bista, 2018).So, controlling weeds solely by hand weeding is practically and economically impossible because of labor scarcity and rising of labor wages. To reduce the herbicide application and to prevent the production and accumulation of weed seed, one or two hand weeding is recommended (Devkota & Yadav, 2014). It was reported that twice hand weeding in compared to weedicides and untreated control resulted in lower weed density (Rekha, K. B., 2002). Mechanical weeding using hand-pushed weeders like cono weeder is tedious as well as time consuming (Bhagirath Singh Chauhan, 2012) however, reduce the labor to some extent than in manual weeding. But, mechanical weeder is only feasible to use where rice is sown in proper rows (Raj & Syriac, 2017). Also, with the use of weeder, weeds which emerge within rows are difficult to remove (Bhagirath Singh Chauhan, 2012).

Mechanical method of weeding also includes chopping and wick wipe application. Chopping is applicable for controlling weed which are taller than cultivated rice (eg, weedy rice) which include chopping of weedy rice panicle before seed sets in weed with the help of machete or a special knife attached to a stick (Singh *et al.*, 2013). Wick wipe application include use of weed wipers made up of a frame with a rope, sponge, or carpet which can absorb the herbicide solution and it is wipe on the weeds without affecting the crop because of the difference in the height of crop and weed. This application is used in for weedy rice where it reduces the viable seed setting and is more applicable for short saturated rice cultivars (Raj & Syriac, 2017).

3.3 Cultural Method

Cultural method significantly influence the crop's competitiveness with weeds for above and below ground resources and hence, this is one of the important approach for weed management (Dass *et al.*, 2017). Different cultural method for weed management in DSR rice are;

3.3.1 Tillage system

DSR can be sown under zero-tillage or reduced-tillage conditions, or after thorough land preparation which influence weed seedling emergence where zero till system retain most of the weed seeds near the soil surface, whereas high soil disturbance systems thoroughly mix weed seeds within cultivation layer (Chauhan, 2012). Tillage system influences the vertical distribution of weed seeds in the soil profile which affect the weed emergence because of factor such as predation, seed dormancy, seed longevity, seed size etc (Chauhan, B. S. and Johnson, 2010). A study in Philippines reported that greater emergence of tropic ageratum, southern crabgrass, junglerice, eclipta, goose-grass in zero-till soil than in conventional till system which may be due to their small size and light requirement for germination (Chauhan, B.S. and Johnson, 2009). Lack of disturbance of the root systems of established weeds leads to association of perennial weed species with minimum or zero-till system which needs the increasing rate of nonselective herbicide before crop sowing (Chauhan.B.S., 2012). Despite greater emergence of weed under zero-till, this system also reduces weed seed bank if weeds are controlled effectively because soil will not be disturbed which prevent the weed seeds movement to the soil surface and weed seed bank present on the soil surface can be reduced by stale seedbed practice, predation etc, (Chauhan.B.S., 2012). Whereas, deep tillage system helps in burying the weed seeds below the maximum depth of their emergence if a large amount of weed seeds accumulates on the soil surface under continuous zero-till system (Chauhan, B. S. and Johnson, 2010). Hence, there is conflicting result with weed response to tillage system which needs a better understanding on weed response to tillage system for effective management of weed in DSR.

3.3.2 Stale seed bed technique

This is desirable weed management technique which not only reduces weed emergence but also manage large weed seed bank which occur due to weed infestation in the past (Rao *et al.*, 2007). Weeds are allowed to germinate and grow by irrigating field one or two times 2-4 weeks prior to sowing and then grown weeds are killed by either a nonselective herbicide (glyphosate or paraquat) or by tillage (Devkota & Yadav, 2014) which assumed to suppress weeds upto 53% (Bista, 2018). The rice seed should be sown with minimum disturbance for avoiding the germination of seeds buried at deeper depth and also to pevent its exposure to light and other stimuli which may encourage emergence of weedy rice (Singh *et al.*, 2013). In Dry-DSR, Stale seed bed technique using glyphosate application @ 1 kg ha^{-1} was found more effective in reducing weed and also found producing higher grain yield and B:C ratio in compare to stale seed bed technique using shallow tillage (M. . Singh, 2013). The stale seed bed technique is very effective in reducing the weedy rice in DSR (Raj & Syriac, 2017). Stale seed bed technique produces higher number of grain per panicle, straw yields, lower sterility and highest harvest index than normal seed bed (S.Marahatta et al., 2017). Weed species which have low seed dormancy and are inable to emerge from a depth greater than 1 cm such as *Cyperus iria, Cyperus difformis, Fimbristylis miliacea* (L.) Vahl, *Leptochloa* *chinensis* and *Eclipta prostrate* are more susceptible to the stale seed bed technique (Chauhan, B. S. and Johnson, 2010).

3.3.3 Land Levelling

Land levelling helps to provide weed free seed bed while sowing. Wooden / metal board are usually used for land levelling. And also laser land levelling can be adopted which uses large tractor and soil movers that equipped with global positioning system (GPS) and laser guided instrumentation which aids in moving soil either by cutting or filling to create the desired slope or level (Raj & Syriac, 2017). It help to achieve uniform and better crop establishment (Jat *et al.*, 2009), manage water and increased herbicide use efficiency (B.S Chauhan, 2012). Laser land levelling reduces the weed population up to 40% and the labor requirement for weeding by 75% (Rickman, 2002).

3.3.4 Residue Mulch and Cover Crop

Crop residue on the soil surface conserve soil and moisture and also influence the weed emergence. However, the influence of residue on weed emergence and growth depends on many factor such as quantity and position of weed seeds relative to residue, the allelopathic potential of the residue and biology of weed species (Bhagirath Singh Chauhan, 2012). Residue mulch act as a physical barrier for the emerging weeds and also secrete allelochemical which have an inhibitory effect on the early growth and development of weeds (Bista, 2018). It was found that wheat residue mulch @ 4 ton/ha when used reduces the emergence of grass weeds by 44-47% whereas broadleaf weeds by 56-72% in dry-drill-seeded rice (Singh *et al.*, 2007). Also, high amount of residue prevent the light penetration causing delay in the weed emergence which makes weed less competitive in respect to rice (Bhagirath Singh Chauhan, 2012).

3.3.5 Weed Competitive Cultivar

The cultivar's morphological characters and their competitive ability has an important role in crop-weed competition (Bhagirath Singh Chauhan, 2012). For both low and high input cropping system, weed competitive cultivar is an low cost strategy of an overall IWM and also seems to be most efficient way of delivery to farmer (Andrew *et al.*, 2015). Weed competitive cultivar has two component i.e, weed tolerance ability and weed suppressive ability where weed tolerance is the ability of crops to maintain high yield despite weed competition and crop with weed suppressive ability suppress the weeds growth through competition (Raj & Syriac, 2017). Cultivars character such as plant height, early and rapid growth, higher tiller number, droopy leaves, high biomass accumulation at early stage, high leaf area index and high specific leaf area during vegetative growth, rapid canopy cover and early vigor aids in weed management (Raj & Syriac, 2017). But tall variety may not be desirable trait in future rice system as they use more nitrogen to meet increasing demand which leads to lodging (Bhagirath Singh Chauhan, 2012). Variety Gautam was found to be highly competitive in suppressing the *Echinochloa* spp than Prabhat and Krishna Hamsa variety (Kumar, P *et al.,*, 2013).

3.3.6 Sesbania co-culture (Brown Manuring)

Sesbania as a green manure growing either as pre-rice or inter or mixed crop with rice is called sesbania co-culture which is also known as brown manuring (Raj & Syriac, 2017). In this weed management method, seed of sesbania is sown at 25 kg ha^{-1} together with rice which is killed with 2,4-D ester @ 0.5 kg ha^{-1} after 25-30 days (Bista, 2018) when sesbania is 30-40 cm tall (Raj & Syriac, 2017). For maximum weed suppression, the best time of sowing sesbania is on the rice sowing day which can reduce about half weed population without any adverse effect on rice yield (Singh *et al.*, 2007). Sesbania co-culture was more effective against broad leaf weed (BLW) and sedges whereas less effective on grasses. So, the effectiveness of this technique can be increased by the pendimethalin application as a pre-emergence herbicide which can overcome the problem of grass weed (Kumar V and Ladha JK, n.d.). For maximum weed suppression and grain yield, the best time for incorporating sesbania is at 30 DAS for semi-dry rice whereas best method is using 2,4-D @ 1 kg ha^{-1} for knocking down sesbania (Anitha, S. and Mathew, n.d.). Beside, Sesbania also involve in atmospheric nitrogen fixation which helps increases nitrogen in soil and also solve the crust formation problem (Bista, 2018).

3.3.7 Crop rotation

Crop rotation breaks the weed seed cycle as well as facilitates the weedy rice identification which influence the weed demography and subsequent population leading to better control of weeds (Raj & Syriac, 2017). Rotating rice crop with other crops, such as soyabean, mungbean, cotton, maize, etc., effectively control weedy rice which also allow the use of herbicide and cultural practices that cannot be used in rice (Singh *et al.*, 2013). It was found that the intensification of rice-wheat system including short duration vegetables followed by late wheat can improve in controlling weed without herbicides application (Chhokar *et al.*, 2008).

3.3.8 Seed rate

High seed rate and narrow spacing not only compensate the poor seed quality and poor crop emergence but also suppress the weed growth and reduce the rain yield loss due to the closure crop canopy which reduces the weed competition and also allow less light penetration through its leaves (Bhagirath S Chauhan, 2012) . A study in Malaysia reported that in DSR field infested with weedy rice, there is an increase in rice grain yield with an increase in the seeding rate from 20 to 80 kg ha^{-1} (Azmi *et al.*, 2000).

3.3.9 Line sowing

Farmer in many Asian region follow broadcasting method at high seeding rate for sowing the rice seed which improves the crop's competitiveness by their rapid canopy cover but lead to difficulties in distinguishing weed species among crops, especially when weed species resemble the rice crop at seedling stage causing problem in performing mechanical or manual weeding (Bhagirath Singh Chauhan, 2012). Line sowing of cultivated rice facilitates the identification of weedy rice seedling that emerges between rows and helps in removing weed by inter-cultivation operation which will be easier in row seeded crops (Singh *et al.*, 2013),that affect similarly in other weeds. It was reported that row spacing in DSR has a less effect on the grain yield of crop in weed absence condition but in the field where there is weeds competition, wider the spacing result in lower the grain yield (Akobundu, 1985). Similarly in another study, it was reported that weeds growing in 30 cm row spacing within rice had 34 % greater biomass than weeds which grown in 25 cm rows (B. S.Chauhan and D. E. Johnson, 2011).

3.3.10 Water management

Water management can be considered as important factor in influencing the density, growth, and species composition of weeds (Bhagirath S Chauhan, 2012). Flooding comprise an important component of weed management for the crops, as rice is tolerant of flooding but many weed species are not which indicate their differential response to flooding (Chauhan.B. S. and Johnson.D.E, 2010). Hence, time duration and depth of flooding influence the growth of weed species and their's abundance in the rice field (Liebman *et al.*, 2003). Early and continuous flooding to a shallow depth of 2 cm helps to suppress the problematic weeds *viz., Leptochloa chinensis* whereas continuous submergence to a depth of 2-4 cm suppress the emergence and growth of weed species such as *Cyperus iria, Fimbristylis miliacea, Leptochloa chinensis and Ludwigia hyssopifolia* (Raj & Syriac, 2017). Study in Philippines reported that a flooding depth of 2 cm reduced growth of four weedy rice biotypes by more than 85% (Chauhan.B.S, 2012). In a recent study it was reported that flooding intermittently to a depth of 2 cm for 2 of 7 days for 28 days compared with 0 cm reduces the emergence of *Chinese sprangletop* by 26%, whereas emergence declined by 72% if soil flooded continuously for 28 days (Chauhan.B. S. and Johnson.D.E, 2008). But it is applicable only in area with sufficient water availability.

3.3.11 Soil solarization

In soil solarization method, the soil temperature is raised to lethal level for many weed seeds and soil borne pathogen by using transparent polyethylene sheet (LDPE film) which is placed on the soil surface to trap soil radiation that suppress the weed by killing them before emergence (Raj & Syriac, 2017). It was found that the density of grassy weeds and BLW and weed dry weight reduce effectively if soil are covered with 100 μ thickness (400 gauge) LPDE sheets prior to planting for 30 days and is found effective in hot areas (Khan *et al.*, 2003). Under transparent mulch, soil temperature at 5 cm rose by 10-15°C and at 10 cm depth by 10-20°C (Raj & Syriac, 2017).

3.4 Biological method

To reduce the dependency of herbicide in controlling weed, micro herbicide are being used (Raj & Syriac, 2017). In 1982, a powder formulation of *Colletotrichum gloeosporiodes* (Penz.) Sacc. f. sp. *aeschynomene* was registered to control northern jointvetch (*Aeschynomene virginica* (L.) B.S.P.) in rice (Smith, 1992). *Setosphaeria sp* cf *rostrata* was found effective for controlling *Leptochloa chinensis* (Thi *et al.*, 1999). Other different herbicides bio agent like fish, tadpoles, shrimps and duck can be used in controlling weeds in irrigated lowland rice but cannot be used in aerobic rice (Raj & Syriac, 2017).

3.5 Biotechnological approach; Herbicide-resistant rice

Herbicide resistant rice is type of rice resistant to particular herbicide so that the herbicide when used in rice would damage the weed but not rice. The herbicide resistant rice was developed mainly for effective and selective control of weedy rice where three major herbicide resistant rice system developed i.e., imidazolinone resistance rice (IMI-rice), glyphosate resistant rice and gluphosinate-resistat rice, among which glyphosate and gluphosinate-resistant rice are transgenic one and imidazolinone resistant rice is non transgenic (Raj & Syriac, 2017). The imidazolinone-resistant rice, glyphosate-resistant rice and glufosinate resistant rice are resistance to imidazolinone, glyphosate and gluphosinate group of herbicides respectively but only IMI-rice has been commercialized whereas, in Asia it is only released in Malaysia (Singh *et al.*, 2013).

Glyphoste and glufosinate are non-selective, broad-spectrum and post emergence herbicide with no soil or residual activity (Singh *et al.*, 2013). Glyphosate resistance crop lines are obtained by inserting gene derived from *Agrobacterium* sp. strain CP4 which encodes a glyphosate-tolerant enzyme called as CP4 EPSP synthase whose expression results in glyphosate-tolerant crop that enable effective weed control by allowing post emergent herbicide application and similarly, the gluphosinate resistant crop line contain a gene known as bar or pat gene which is isolated from *Streptomyces hygroscopicus* and *s. viridochromogenes* that encodes phosphinothricin acetyl transferase (PAT) which detoxifies phosphinothricin (Raj & Syriac, 2017). The imidazolinone group of herbicides is also broad spectrum herbicides which are effective at low doses and are applied as pre- and post-emergence having soil or residual activity and a favourable environment profile (Singh *et al.*, 2013). CLEARFIELD® rice was developed by mutation that is tolerance to imidazolinone herbicides (Raj & Syriac, 2017).

But there is risk of gene flow from herbicide-resistant rice to weedy rice which can be a serious threat for long term utility of this technology (Chauhan.B.S, 2013).

3.6 Integrated Weed Management Approach

Weed has become major threat in DSR planting method. For eco-friendly environment and sustainable management of weed, integrated weed management (IWM) method is most suitable for effective management of weed which include integration of all available methods of weed management like; mechanical method, cultural method, biological method, chemical method, biotechnological methods etc. A single method of weed control cannot provide effective and sustainable weed control due to the weed's variation in growth habit; therefore, there is need to integrate different approaches based on location and availability, for example, giving light irrigation in zero till system to stimulate weed emergence and then kill them with nonselective herbicide which is later used as a residue mulch, mechanical weeding to destroy escaped weeds and herbicide resistant weeds etc (Bhagirath S Chauhan, 2012). Effective IWM integrates many 'little harmer technology' instead of a single 'large harmer' method to manage or control the weed of wide range (Kumar & Ladha, 2011).

4. Conclusion

Weed in DSR is one of a major global threat to food security. The cost of labor and the weed management methods plays an important role in reducing the crop loses. For effective, eco-friendly and sustainable weed management in DSR we must follow IWM practices. But, chemicals methods could an alternative to be used to kill and suppress the weed for quick result in case of severe infestation.

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