Managing weeds in dry direct seeded rice: A profound challenge

□P Gyawaly[1*], SK Sah[2], RK Bhattarai[1], B Chaulagain[1] and P Pantha[3]
[1]National Agronomy Research Centre, Khumaltar, Lalitpur
[2]Agriculture and Forestry University, Rampur, Chitwan
[3]Agriculture Sector Development Programme, Birendranagar, Surkhet
*Corresponding author email: pankajgyawaly@gmail.com

Abstract
Dry Direct Seeded Rice (DDSR) is a promising technology to address environmental, water, labor and profitability issue that is constantly threatening the rice farming community around the world. Rice yield under DDSR is primarily limited due to weeds. There are instances of complete crop failure in DDSR owing to poorly managed weeds. More than 50 weeds species infest DDSR crop due to aerobic nature of soil confronting a major challenge in the wide spread adoption of dry direct seeding. Direct-seeded rice faces a potential threat from changes in the competing weed flora, with an increase in those species that are difficult to control. This review article presents the prospects of DDSR along with the available weed management strategies such as preventive, physical, chemical, cultural and biological methods and their judicious use. Over reliance on only one approach of managing weeds may be back firing as well. The use of chemical means are getting popular in an alarming rate for being cost effective, without calculating the environmental concerns which might lead to herbicidal resistance and negative consequences to environment and human health. Therefore, it is necessary to understand the environment while shifting from transplanted rice to dry direct seeding, identifying weeds flora and choosing or integrating the best weed management practices foreseeing the future consequences. The logical integration of available weed management options that is ecologically sound, economic and effective for season long weed control is the main essence that ensures the sustainability of rice production.

Keywords: Dry direct seeded rice, herbicides, integrated weed management

Introduction

Basically, there are two methods of rice establishment viz. tsransplanting and direct seeding. Transplanting of 20-30 days old nursery raised seedlings in the puddled soil is the most common method of establishment of rice in Asia as well as in Nepal (Kumar and Ladha, 2011, Shah and Bhurer, 2005), whereas direct seeding refers to direct planting of rice seeds in the main field without puddling (Farooq *et al.*, 2011) and it covers 26% of the total rice area in the world (Rao *et al.*, 2007) and 10% in Nepal (NARC, 2007). Transplanted rice (TPR) faces severe threat due to increasing shortages of water and labor, therefore the incentive to develop and adopt dry direct seeded rice (DDSR) has increased. Kumar and Ladha (2011) reported that DDSR saves up to 60% of labor, 35% water with reduction in methane emission and cost of cultivation by 92% and 32% respectively saving about $50 per hectare, also DSR crop matures 7-14 days earlier ensuring timely planting of succeeding crop. Although DDSR has evolved as a promising technology to minimize cost of production by drastically reducing labor and water requirement, several challenges confront the wide-scale adoption of DDSR by farmers. Weed infestation, stagnant yield, unavailability of purposely developed varieties, panicle sterility, nutrient availability, pests, diseases and water management are the challenges (Nguyen and Ferrero, 2006), among which high weed infestation is the major bottleneck in DSR especially in dry fields (Rao *et al.*, 2007). In absence of effective weed control measure the yield penalty in DDSR was found very high often leading to drastic reduction in yield or no yield at all (Kim and Ha, 2005; Rashid *et al.*, 2012, Busi *et al.*, 2017). Due to aerobic nature of soil in direct seeding establishment, the weed pressure is more and difficult to control compared to transplanting establishment. Managing weeds effectively is purely technical and very tedious in fact, in DDSR. Reliance on only one strategy may not achieve the satisfactory level of weed control. Therefore, the use of available weed management strategies in conjunction rather than in isolation with proper judgement is essential for sustainable weed management in DDSR.

Materials and Methods

This manuscript is purely a review article. The information presented here is the result of rigorous review on the past research/review works carried out by various Scientists on dry direct seeded rice at different times. After the extensive review of the available and accessible reading materials related to dry direct seeded rice, the relatable information are summarized under various headings.

Results and Discussion

Challenges of dry direct seeded rice

Direct-seeding of rice has the potential to provide several benefits to farmers and the environment over TPR. However, Kumar and Ladha (2011) stated that in majority of the cases (16 out of 25) the yields of DDSR were found lower than CT-TPR. According to Kumar and Ladha (2011), the possible risks associated with dry direct seeding are:

- Sudden rain immediately after seeding can adversely affect crop establishment.
- Reduces availability of soil nutrients such as N, Fe, and Zn especially in Dry-DSR
- Appearance of new weeds such as weedy or red rice.
- Increases dependence on herbicides.
- Increases incidence of new soil-borne pests and diseases such as nematodes.
- Enhances nitrous oxide emissions from soil.
- Relatively more soil C loss due to frequent wetting and drying.

Weed flora

The composition of weed communities in rice fields is continuously changing and is influenced by cultural, mechanical, chemical, and environmental factors (Bhandari and Moody, 1981). In DSR the weed communities are floristically diverse and more in abundance than TPR (Tomita *et al.,* 2003; Rao *et al.*, 2007). Vongsaroj (1997) reported that the broad leaves dominated weed communities in TPR subsequently shift towards grasses and sedges dominated with DSR. It was found that the weeds like as *Echinochloa crus-galli, Ischaemum rugosum* and *Leptochloa chinensis*, which were not common to rice fields became widespread and dominant in Malaysia after the introduction of DSR in the 1970s (Azmi *et al.,* 2005). Direct-seeded rice faces a potential threat from changes in the competing weed flora, with an increase in those species that are difficult to control (Johnson *et al.*, 2003). These include *I. rugosum, E. crus-galli, E. colona, L. chinensis,* and *Cyperus* spp. According to Singh (2013), major weeds infesting DSR field at 40 days after seeding (DAS) were: *Cynodon dactylon* (6.2%), *Dactyloctenum aegypticum* (2.2%), *Echinochloa colona* (20.3%), *Echinochloa crusgalli* (5.9%), *Leptochloa chinenis* (1.7%) among grasses; *Ammannia baccifera* (1.9%), *Caesulia axillaries* (4.5%), *Commelina benghalensis* (6.1%), *Physalis minima* (6.3%), *Eclipt aalba* (3.3%), *Euphorbia hirta* (5.1%), *Phyllanthus niruri* (12.6%), *Ludwigia* spp. (1.3%), *Trianthema monogyna* (3.8%) among broad-leaved weeds and *Cyperus difformis* (5.4%) among Sedges.

Sharma (2013) during 2011 and 2012 in Chitwan, Nepal, recorded from DDSR field that among broad leaf weeds *Amiscophacelus axillaris, Ageratum conizoides* and *Melochia corchorifolia* were dominant at 20DAS whereas *Aeschynomene indica, Alternenthera sessilis, Commelina diffusa, Cleome viscosa, Euphorbia hirta, Monochoria vaginalis* and *Sphenoclea zeylanica* dominated during 40 and 60 DAS. The grasses like *Echinocloa colona, Cynodon dactylon* and Digitaria ciliaris were dominant at 20 DAS and infested the field till harvest. During later stage of crop growth *Digitaria setigera, Eleusine indica, Iscchaemum rugosum, Paspalum scrobiculatum* and *Setaria glauca* emerged dominantly. In the same way, *Cyperus difformis, C. iria* and *Fimbristylis miliacea* were consistently dominant sedges at 20 DAS and thereafter. *Cyperus compresus* was observed during 40 and 60 DAS while *Scirpus juncoides* infested the field from 60 DAS till harvest.

Weeds: The major biological constraint

Weeds are serious concern while shifting from CT-TPR to DSR and more specifically to DDSR (Rao *et al.,* 2007; Farooq *et al.,* 2011). In TPR, puddling creates anaerobic condition and hinder weed seed germination, transplanted seedlings has size advantage to suppress weeds however, in DDSR rice seeds are planted in dry fields and there is no water layer to suppress weeds initially (Kumar *et al.,* 2008; Rao *et al.,* 2007). As a result rice seedlings are prone to weed competition from the early stage of crop emergence. In aerobic soil weeds emerge more rapidly than the crop and proliferate by using the fertilizers and nutrient applied rendering the crop with very less productivity. In early growth stage weeds makes 20 -30% of growth whereas crop makes only 2-3% of its growth (Moody, 1990). Weeds compete with the crop for various factors such as moisture, nutrient, light and space resulting in yield loss in the range 30 to 90% (Singh *et al.,* 2007). In addition, weeds are difficult to identify from crop during early stage of growth in broadcasted DDSR where manual or mechanical weeding becomes ineffective. More than 50 weed species infest direct-seeded rice, causing major losses to rice production worldwide where the new weed species that were no longer seen in transplanted rice start to emerge with greater diversity (Rao *et al.,* 2007; Tomita *et al.,* 2003). Evolution of weedy rice (*Oryza sativa f. spontanea*) also known as red rice is another threat to adoption of DDSR, especially in Asian countries. Weedy rice is difficult to control because of its genetic, morphological, and phenological similarities with rice and matures early with high shattering ability (Ferrero, 2003). Weedy rice is highly competitive and causes severe rice yield losses ranging from 15% to 100% (Kumar and Ladha, 2011). Weed management become increasingly difficult with DDSR as various cases of herbicide resistance has been reported from countries like Philippines, Malaysia, Vietnam, Thailand and Korea. So far, no cases of herbicide resistant has been reported in South Asia but preventive measures should be considered instantly (Kumar and Ladha, 2011).

Critical period of weed competition (CPWC)

A major threat to yields of direct-seeded rice crops is weed competition and high costs of weed control (or unavailability of efficient weed control methods), which will be a major factor constraining the widespread adoption of direct seeding (Singh *et al.,* 2008). In DDSR weeds and crop emerge simultaneously and there is serious competition among them for space, water, nutrients and sunlight which may lead to yield reduction of crop. The optimum time, at which crop must be free of the adverse effect of weeds, is referred to as the critical period of weed competition. In other words it is the time frame during which the yield is reduced by weed crop competition or the minimum duration for crop to be weed free to prevent any compromise in the yield. Knowledge of CPWC helps scheduling weed management interventions such as weeding and herbicide applications (Matloob *et al.,* 2014) which reduce the cost and hazards associated with indiscriminate herbicide use. CPWC limits the weed management practices within the certain time frame to make weed management more easy, effective and economical. The start and end of CPWC is exclusively dependent on choice of cultural practices, crop and weed characteristics and agro climatic conditions (Knezevic *et al.,* 2002).

The effective period of weed-crop competition in DSR occurs in two phases; i.e. between 15-30 days, and 45-60 days after seeding. The competition beyond 15 days after seeding may cause significant reduction in the grain yield however, competition for the first 15 days only may not have much adverse effect on crop. Chauhan and Johnson (2011) reported that critical periods for weed control, to obtain 95% of a weed free yield, was estimated between 17 to 56 days after sowing of the DSR crops at 15-cm row spacing. The critical period of weed infestation determined from the field experiment was similar for the three New Rice for Africa (NERICA) varieties and the O. sativa parent (WAB 56-104), and was between 14 and 42 days DAS. Weed competition either before or after these critical periods had negligible effects on crop yield (Toure *et al.,* 2013). In dry direct drill-seeded rice, the “critical period” of weed competition has been reported to be 15–45 days after seeding (Rao and Nagamani, 2007; Singh *et al.,* 1999; Yaduraju and Mishra, 2004). Weed infestation up to 15 DAS or weed-free for 60 or 75 DAS produced grain yields similar to those of plots kept weed-free throughout the growing season (Singh, 2008). Under saturated conditions, the CPWC was found between 2 and 71 DAS, while in flooded conditions, it was found between 15 and 73 DAS (Juraimi *et al.,* 2009).

Weed management in dry direct seeded rice

Weed management refers controlling weeds below the level that case any kind of harm or losses to crop or human and prevent any kind of prospect that cause managing weeds a problem in future. There are various methods of managing weeds in DDSR and judicious (economic, effective and sustainable) application of weed management methods require the knowledge about weed flora and the critical period to control them.

a) Preventive measures

Preventing weeds from entering an area may be easier than trying to control them once they have established. Prevention of weed introduction and spread is the most important strategy in managing weeds, establishment method, and ecosystem. Use of clean seeds, machineries, making irrigation channels, bunds, levees free from weeds will reduce the weeds infestation to considerable extent (Mahajan *et al.*, 2012).

b) Mechanical and manual weeding

Rice being monocot, it permits fair amount of disturbance of manual and mechanical weeding so it is more common and effective way (Singh *et al.*, 1999) of controlling weeds. However, labor requirement for manual weeding in DDSR is 150 to 200-labor-day/ha (Trung *et al.*, 1995; Roder, 2001). Manual weeding alone proves to be very expensive and depends on availability of labour (Ruthenberg, 1980) and climatic condition. Moreover, it is difficult to identify some mimic weeds during early stage of crops which interfere with yield ultimately. Mechanical weeding is removal of weeds by use of tools and implements like khurpi, hoe, cultivator, rotary and cono weeders etc. But it is limited to row seeded crops and dependent on soil moisture. Subudhi, (2004) reported that a dry land weeder (with a straight-line peg arrangement) has shown excellent performance in different soil types and with varying soil moisture levels and weed intensity, providing a labor savings of approximately 57% compared with hand weeding. Mechanical weeding could be more effective in situations in which continuous rains or dry spells may reduce the effectiveness of post emergence herbicides. It can also help to reduce overall herbicide use but the cost and labor involved is questionable.

c) Cultural methods

Weeds and crops compete with each other and weeds persist as a result of adaptation to agronomic or cultural management applied in field. Cultural practices significantly influence crop weed competition resulting into complex interactions. Grichar *et al.*, (2004) has opined that cultural approaches determine the competitiveness of crop against weed for underground and above ground resources which might influence the weed management. Tillage and land preparation method greatly affect the weed by reducing weeds seeds germination. Tillage practices determines the vertical distribution of weed seeds in soil profile and in turn affects crop establishment and weed emergence (Chauhan *et al.*, 2006). Weeds managed effectively for 2-3 years in zero tillage can reduce weed problems and make management easier. Precise land levelling improves seed germination, good stand establishment and crop ability to suppress weeds. Similarly, stale seedbed technique can also be incorporated in cultural practice. In this practice a light irrigation is provided in the land before final land preparation to allow the weeds to germinate followed by killing the weeds using shallow tillage or non-selective herbicide (Chauhan and Johnson, 2011). The success of stale seedbeds depends on several factors such as method of seedbed preparation, method of killing emerged weeds, weed species, duration of the stale seedbed and environmental conditions (Kumar and Ladha, 2011). Gopal *et al.*, (2010) reported 53% lower weed density in DDSR after a stale seedbed than without this practice. Bhurer *et al.*, (2013) found that stale seed bed followed by Pendimethalin 30 EC (stomp) @ 1 a.i. kg/ha followed by Bispyribac (nominee gold) @ 25 a.i. g/ha 10 % @ 200 ml/ha at 20 days gave economic and effective weed control with similar yields compared to hand weeding. Sowing of primed seeds enhance crop emergence and establishment is achieved easily. Hardening and priming seeds with growth promoters like growth regulators and vitamins have been successfully employed in rice to hasten and synchronize emergence, achieve uniform stands, and improve yield and quality (Basra *et al.,* 2006). Similarly, use of high seed rates as much as 200 kg/ha has been found in broadcasted DDSR with aim to suppress weeds (Moody, 1977). Also weed competitive rice varieties that make up vigorous early growth (leaf area and dry matter) accounted for 87% variation in grain yield between varieties in competition for weeds (Zhao *et al.,* 2006). Precise water management is essential as high soil moisture during or before crop emergence is detrimental for crop and soon after that maintaining some level of water depth is crucial for suppressing weeds (Moody, 1977). Most weeds have an optimum soil moisture level below or above which growth is suppressed; hence, time, duration, and depth of flooding can be managed to suppress weed growth.

Use of crop residue as mulch can suppress weeds through allelopathy and creating physical barrier for weed emergence. Singh *et al.,* (2007) found that wheat residue mulch of 4 t/ha reduced the emergence of grass weeds by 44–47% and of broadleaf weeds by 56–72% in dry drill-seeded rice. Timing and method of fertilizer application need due consideration to derive maximum benefits. Rice yield was found lower with surface broadcast of fertilizer than with subsurface fertilizer treatments as surface broadcasted fertilizer benefit weeds more (Chauhan and Abugho, 2013). Basal application of fertilizer should be delayed till weeds are removed and nitrogen should be applied only after use of pre emergence herbicide application. To increase fertilizer use efficiency top dressing of nitrogen should be done after weeding (De Datta, 1981). Sesbania co-culture is a practice in which rice and sesbania seeds are seeded simultaneously followed by knocking of sesbania at 25-30 DAS with the help of 2,4-D Ethyl ester (selective dicot herbicide). Sesbania being fast growing in nature, covers up the field in very few days thus offering smothering effect to suppress the weeds. Sesbania co-culture in addition with weed suppression fix atmospheric nitrogen, add biomass to soil and facilitate crop emergence in areas where soil crust formation is a problem (Gopal *et al.,* 2010).

d) Chemical methods

With the availability of different herbicides, it has been possible to manage weeds in DSR in an effective and more economical ways. Herbicides are different in their mode of action and hence control specific groups of weed flora. They are used effectively as pre-plant/burn down, pre emergence, and post emergence weed control in DSR. Pendimethalin, oxadiargyl, and pyrazosulfuron are widely used as pre emergence herbicide and common post emergence herbicides are bispyribac sodium, penoxsulam, pyrazosulfuron, bentazone, bensulfuron, carfentrazone, clomazone, cyhalofop, molinate, propanil, and fenoxaprop. Glyphosate and paraquat are recommended pre plant herbicides (Kumar and Ladha, 2011).

There are various considerations for use of herbicides. It is crucial to select the right herbicide depending upon the weed flora present in a given field. In addition, the correct rate, timing, and application techniques should be used. Continuous use of single herbicide may lead to shift in weed flora and herbicide resistant biotype may develop. Therefore, a careful choice of herbicides must be made to control different flushes of weeds that arise in DDSR and use them in sequence and rotational manner to control weeds effectively. Tank mixtures of herbicides can be used when two or more herbicides are compatible to broaden the spectrum of weed control in such a way that each herbicide controls the weeds missed by the other one. Kelly and Coats (1999) has mentioned that the use of two or more herbicides sequentially or in combination to broaden the spectrum of chemical weed control, reduce production costs, and/or prevent the development of weeds resistant to certain herbicides.

Effect of Pendimethalin on weeds and yield of DDSR

It acts as mitotic poison and inhibits root growth by disrupting cell division and cell elongation killing germinating seeds rather than seedlings. It is used as a selective herbicide in both pre and early post emergence to control most of grasses and certain broadleaf weeds (Valverde *et al.,* 2001). Weeds seeds are small and with less energy compared to rice which are susceptible to network of herbicide upon germination. Pendimethalin is effective when there is sufficient soil moisture in the field and @ 2-3 DAS when rice seeds have imbibed water in order to avoid injury. Mishra and Singh (2008) reported that pre-emergence application of pendimethalin 1.0 kg/ha followed by one hand weeding or harrowing at 30 DAS significantly reduced the population of *Echinocloa colona* compared with weedy check in DDSR. The sequential applications of pre-emergence herbicides such as pendimethalin at 1,000 g/ha followed by 2,4-D at 500 g/ha was found to be effective in controlling mixed weed flora and resulted in higher grain yields and gross returns of DDSR (Singh *et al.,* 2006).

Effect of Bispyribac sodium on weeds and yield of DDSR

It acts as branched chain amino acid i.e. aceto lactate synthesis (ALS) inhibitor and is effective as foliar spray in post emergence application. It is a selective herbicide which works based on absorption, translocation and differential metabolism. In rice it is absorbed and rapidly metabolized into non herbicidal products. It is a selective herbicide effective to control grasses, sedges and broad leaf weeds in rice (Schmidt *et al.,* 1999) but poor on grasses other than *Echinochloa* species, including *Leptocloa chinensis, Dactyloctenium aegyptium, Eleusine indica, Ergrostis* species and has no residual control. Ranjit and Suwanketnikom (2005) observed that post emergence application of bispyribac sodium (bispyribac Na) @ 50 g/ha gave number of tillers per m^2 ranged from 205 in weedy check plots to 335 in straw mulch + bispyribac sodium along with higher yield which was at par with the yield recorded in hand weeding twice. Bispyribac sodium provided excellent control of grass (*Echinochloa* spp.) and sedge weeds (*Cyperus* spp.) which was particularly effective when applied at higher rates (25-30 g/ha) and early application timings (15-20 DAS) (Gill *et al.,* 2006). It was also observed that sole application of bispyribac sodium caused more than 80% reduction in total weed density and about 78% reduction in weed dry weight (Khaliq *et al.,* 2011). Sharma (2013) from her experiment concluded that sole as well as sequential application of bispyribac sodium with pendimethalin as pre emergence was effective in controlling weeds in DDSR producing higher grain yields and economic return.

Effect of 2,4-D on weeds, growth and yield of DDSR

It is a selective herbicide used as post emergence and is effective for the control of broad leaf weeds and some annual sedges in rice. 2, 4-D at 500 g/ha at 30-35 DAS provided effective control of non-grasses and sedges in wet and dry seeded rice (Bindra *et al.,* 2002). It is a synthetic auxin that regulate abnormal metabolism in dicots resulting in uncontrolled growth and later inhibition of these processes leading to death of plant and has no residual control. Sequential applications of residual pre emergence herbicides followed by 2, 4-D performs better than do residual herbicides alone (Nyarko and De Datta, 1991). The use of 2,4-D at 500 g/ha at 30–35 DAS provides effective control of non-grasses and sedges in wet and dry-seeded rice (Bindra *et al.,* 2002; Moorthy and Saha 2002; Saha *et al.,* 2003). Singh *et al.,* (2006) recorded higher net returns from 2, 4-D ethyl ester when applied @ 500 g a.i./ha than weed free treatment and also reported the control of broadleaf weeds in DSR. Bhurer et al, (2013) stated that application of pendimethalin 1 a.i. kg/ha followed by 2,4-D 1 a.i kg /ha at 25 DAS followed by hand weeding 45 DAS is the best way obtaining higher yield and controlling weeds effectively in dry direct seeded rice.

e) Integrated weed management (IWM)

DDSR is thought to be an alternative to TPR and the area under DDSR is expected to increase in future owing to water and labor crisis. However, weeds continue to be serious threat that can undermine DDSR performance. The use of any single approach would not provide season-long and sustainable weed control because of the variation in dormancy and growth habits of weeds (Chauhan, 2012). Swanton and Weise (1991) stated that none of the control measures in single can provide acceptable levels of weed control, and therefore, if various components are integrated in a logical sequence, considerable advances in weed management can be accomplished. Chauhan (2012) has devised various components of integrated weed management in DDSR.

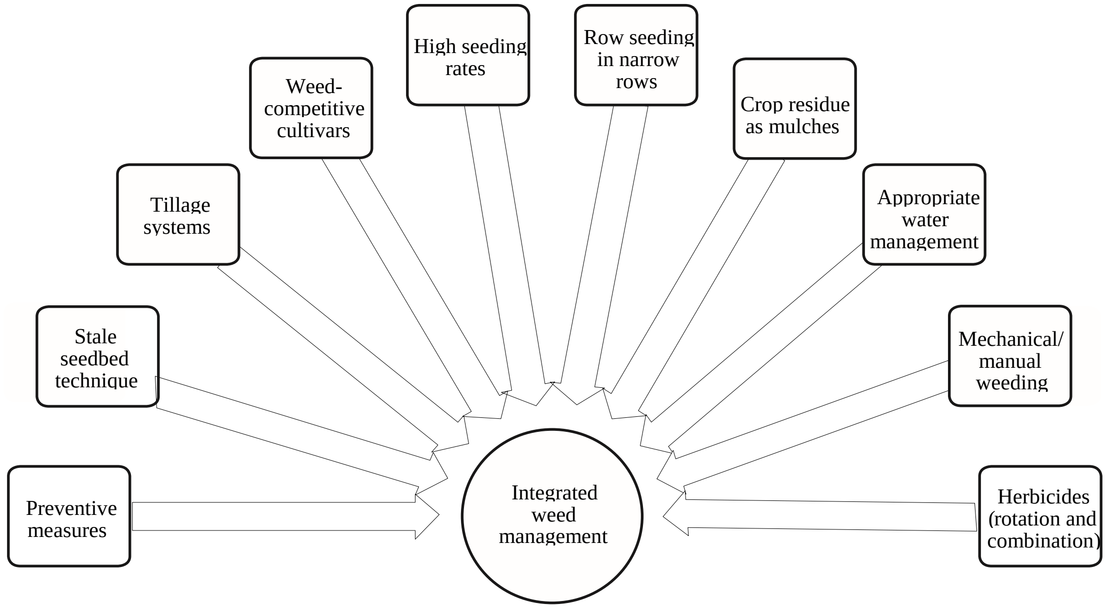

Fig.1 Different weed management strategies for direct-seeded rice systems (Chauhan, 2012)

Use of herbicide will inevitably increase in future due to increasing labor scarcity and wage rates (Kumar and Ladha, 2011). Herbicides are a possible solution to manage weeds in DSR, but the sole use of herbicides cannot provide effective and season long weed control and depending entirely on herbicides is no longer ecologically sound, economically feasible, and effective against the diverse weed flora in DSR (Matloob *et al.*, 2014). Similarly, excessive herbicides lead to environmental pollution (Spliid and Koeppen, 1998) and impoverishment of the natural flora and fauna and shift in weed species dominance (Azmi and Baki, 2002). Reliance on a single herbicide could result in quantitative changes in the structure of the weed population in as few as five years. In order to achieve sustainable, economic and effective weed management, various weed management strategies such as preventive, physical, cultural and chemical must be integrated in a logical sequence. IWM is particularly desired for the DDS rice due to hardy weeds, shifts in weed flora and the appearance of repeated flushes of weed flora. Integration of diverse technologies is essential for weed management because weed communities are highly responsive to management practices and environmental conditions (Buhler *et al.*, 1997).

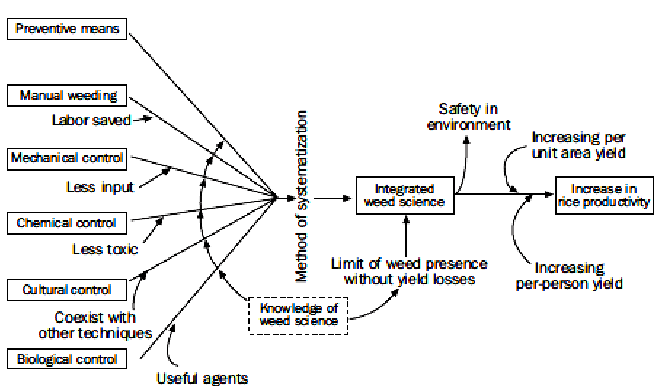

Fig. 2: A conceptual model of integrated weed management (IWM) (Singh *et al.*, 2005)

Buchanan (1976) defined IWM as “the application of many kinds of technology in a mutually supportive manner”. Integrated weed management better utilizes resources and offers a wider range of management options (Buhler *et al.*, 2000). Out of various options available for weed management selection, integration, and implementation of effective weed control means with due consideration of economics, environmental, and sociological consequences is the concept of integrated weed management. Juraimi *et al.,* (2013) suggest integrated approaches for sustainable weed control in direct seeded rice, such as the use of clean certified seeds, higher seeding densities, cultivation of competitive variety, seed invigoration, stale seed bed preparation, crop rotation, water and fertilizer management along with rotation of herbicides with different mode of actions followed by manual weeding and rouging after mid stage of rice growth. For sustainability of direct seeded rice culture, long term changes in weed flora, herbicide efficacy, resistance, residual toxicity and environmental implications of continuous use of herbicides should be properly addressed.

Selection of weed control measures based on the weed flora in dry seeded rice would enable farmers to control weeds with lower cost. Matloob *et al.*, (2014) has reported that the combined use of narrow row spacing (e.g., 15 cm) and a high seeding rate (e.g., 80-100 kg/ha) along with the application of an effective pre emergence herbicide (e.g., oxadiazon) can help to suppress weeds more effectively than using a single weed management approach. A combined use of high seeding rate and the application of oxyfluorfen at 0.25 kg/ha increased the competitiveness of rice against weeds (Angiras and Sharma, 1998). Similarly, Maity and Mukharjee (2008) revealed that among the herbicides and cultural methods combined, butachlor and sesbania brown manuring followed by 2,4-D at 40 DAS recorded the lowest dry weight of weeds at all the growth stages, leading to highest weed control efficiency of 80.8% and 86% in 2006 and 84.7 and 88.1 % in 2007 at 30 and 60 DAS respectively. Bhurer *et al* (2013) found that the use of Pendimethalin followed by 2,4-D followed by one hand weeding produced higher and statistically similar yields with weed free treatment with highest net return and benefit cost ratio among other treatments in both years 2010 and 2011. Weed dry weight was significantly reduced due to the treatment as a result highest yield and yield attributing traits were observed. They suggest that amid increasing wage rate and labor scarcity integrated weed management through Pendimethalin 30 EC (stomp) @ 1 a.i. kg/ha as pre emergence herbicide application followed by 2,4-D sodium salt 80 WP @ 0.5 a.i. kg/ha followed by one hand weeding or stale seed bed followed by Pendimethalin 30 EC @ 1 a.i. kg/ha followed by Bispyribac (nominee gold) @ 25 a.i. g/ha 10 % SC @ 200 ml/ha at 20 days of seeding resulted best alternative for manual hand weeding practices giving higher net return per unit investment.

Conclusion

Being said that DDSR is a promising technology that stands out in the shortcomings of TPR in the context of water and labor scarcity, but the success of DDSR crop looms uncertain amidst the serious challenge to manage weeds effectively. However, availability of various herbicides has made weed management easier and economical. Under this scenario, we cannot undermine the consequences of haphazard use of herbicides to rice production system and ultimately to environmental and human health. Careful rotation and choice of herbicides to prevent herbicidal resistance is must and at the same time proper timing of herbicide application taking critical period of weed control, level of weed infestation, weed flora and weather conditions into consideration. Sole reliance on herbicides is not sustainable approach for DDSR system as herbicides may be regarded as best alternative until other ecofriendly solutions are developed. Rationalizing use of herbicide integrating with preventive, cultural, mechanical and biological strategies to manage weeds is the dire need for sustainability of DDSR.

References

Angiras NN and V Sharma. 1998. Integrated weed management studies in direct seeded upland rice (*Oryza sativa*). *Indian J. Weed Sci.* 30: 32–35.

Azmi M and BB Baki. 2002. Impact of continuous direct seeding rice culture on weed species diversity in the Malaysian rice ecosystem. In Proceedings of the Regional Symposium on Environment and Natural Resource, Vol. 1, pp. 61-67.

Azmi M; DV Chin; P Vongsaroj and DE Johnson. 2005. Emerging issues in weed management of direct-seeded rice in Malaysia, Vietnam, and Thailand. In: Rice is Life: Scientific Perspectives for the 21st Century, Proceedings of the World Rice Research Conference, 4–7 November 2004, Tsukuba, Japan, pp. 196–198.

Bhandari DC and K Moody. 1981. Ecology of weed communities growing in association with a rainfed rice (*Oryza sativa* L.) cropping system. In: Paper Presented at the 12th Annual Conference of the Pest Control Council of the Philippines, 13–15 May 1981. University of Philippines Los Banos, Los Banos, Laguna, Philippines.

Bhurer KP; DN Yadav; JK Ladha; RB Thapa and K Pandey. 2013. Effect of integrated weed management practices on performance of dry direct seeded rice (*Oryza sativa* L.). *Agron JN. Vol.* 3(53-63)

Bindra AD; BD Kalia and J Shekhar. 2002. Bio-efficacy of promising herbicidal molecules in direct-seeded sprouted puddled rice. *Indian J. Weed Sci.* 34(1&2): 39-41.

Buchanan GA. 1976. Management of the weed pests of cotton (*Gossypium hirsutum*). In Proceedings of the U.S.-U.S.S.R. Symposium: The integrated control of the arthropod, disease and weed pests of cotton, grain sorghum and deciduous fruit, Lubbock, TX. pp.168-184

Buhler DD; RG Hartzler and F Forcella. 1997. Implications of weed seed bank dynamics to weed management. *Weed Science,* 329-336.

Buhler DD; M Liebman and JJ Obrycki. 2000. Theoretical and practical challenges to an IPM approach to weed management. *Indian J. Weed Sci.* 48:274-280

Busi R; KN Nghia; BS Chauhan; V Francesco; T Maurizio and BP Stephen. 2017. Can herbicide safeners allow selective control of weedy rice infesting rice crops? *Pest Management Science.* 73: 71–77

Chauhan BS and DE Johnson. 2011. Row spacing and weed control timing affect yield of aerobic rice. *Field Crops Res.* 121: 226-231.

Chauhan BS. 2012. Weed management in direct-seeded rice systems: International Rice Research Institute: Los Baños (Philippines). 20 p.

Chauhan BS and SB Abugho. 2013. Fertilizer Placement Affects Weed Growth and Grain Yield in Dry-Seeded Rice (*Oryza sativa* L.) Systems. *American Journal of Plant Sciences.* 4: 1260-1264.

Chauhan BS, G Gill and C Preston. 2006. Tillage system effects on weed ecology, herbicide activity and persistence: A review. Aust. J. Exp. Agric. 46: 1557–1570.

De Datta SK. 1981. Principles and Practices of Rice Production. John Wiley and Sons, New York, 618pp.

Farooq M; KHM Siddique; H Rehman; T Aziz; DJ Lee and A Wahid. 2011. Rice direct seeding: Experiences, challenges and opportunities. *Soil Tillage Res.* 111: 87–98.

Ferrero A. 2003. Weedy rice, biological features and control. In: R. Labrada, and I. Addendum (eds.) Weed Management for Developing Countries. Plant Production and Protection Paper. FAO, Rome, Italy. pp. 89–109.

Gill MS; P Kumar and A Kumar. 2006. Growth and yield of direct-seeded rice (Oryza sativa) as influenced by seeding technique and seed rate under irrigated conditions. *Indian J. Agron.* 51: 283–287.

Gopal R; RK Jat; RK Malik; V Kumar; MM Alam; ML Jat; MA Mazid; YS Sahrawat; A Mc. Donald and R Gupta. 2010. Direct dry seeded rice production technology and weed management in rice based systems. Technical bulletin, International Maize and Wheat Improvement Center. New Delhi. India. 28p.

Grichar WJ; BA Bessler and KD Brewer. 2004. Effect of row spacing and herbicide dose on weed control and grain sorghum yield. *Crop Protec.* 23:263-267

Johnson DE; M Mortimer; A Orr and C Riches. 2003. Weeds, rice, and poor people in South Asia. Chatham (UK): Natural Resources Institute. 10 p.

Juraimi AS; MYM Najib; M Begum; AR Anuar; M Azmi and A Puteh. 2009. Critical period of weed competition in direct seeded rice under saturated and flooded conditions. *Pertanika J. Trop. Agric.* Sci. 32: 305–316.

Juraimi AS; MK Uddin; MP Anwar; MTM Mohamed; M Razi and M Azmi. 2013. Sustainable weed management in direct seeded rice culture: A review. *Aust J. Crop Sci.* 7(7), 989-1002.

Kelly ST and GE Coats. 1999. Influence of fertilizer particle size on efficacy of dithiopyr, prodiamine, oryzalin, and oxadiazon for southern crabgrasss (*Digitaria ciliaris*) control. *Weed Technol.* 13:385–389.

Khaliq A; A Matloob; HM Shafique; ZA Cheema and A Wahid. 2011. Evaluating sequential application of pre and post emergence herbicides in dry seeded fine rice. *Pak. J. Weed Sci. Res.* 17:111–123.

Kim SC and WG Ha. 2005. Direct-seeding and weed management in Korea. **In:** Toriyama, K., Heong, K. L., Hardy, B. (Eds.), Rice Is Life: Scientific Perspectives for the 21st Century. International Rice Research Institute, and Tsukuba (Japan): Japan International Research Center for Agricultural Sciences, Los Banos (Philippines), pp. 18~ 1– 184. Proceedings of the World Rice Research Conference held in Tokyo and Tsukuba, Japan, 4–7 November 2004.

Knezevic SZ; SP Evans; EE Blankenship; RC Acker and JL Lindquist. 2002. Critical period for weed control: the concept and data analysis. *Weed Sci.* 50, 773–786.

Kumar V and JK Ladha. 2011. Direct seeding of rice: recent development and future research needs. *Advances in Agronomy.* 111, 297-413.

Kumar V; R Bellinder; R Gupta; RK Malik and DC Brainard. 2008. Role of herbicide-resistant rice in promoting resource conservation technologies in rice–wheat cropping systems of India: A review. *Crop Prot.* 27, 290–301.

Mahajan G; BS Chauhan and J Timsina J. 2012. Opportunities for Weed Control in Dry Seeded Rice in North-Western Indo-Gangetic Plains, Herbicides - Environmental Impact Studies and Management Approaches, Dr. Ruben Alvarez-Fernandez (Ed.), ISBN: 978-953-307-892-2, InTech, Available from: http://www.intechopen.com/books/herbicides-environmental-impact-studies-and-managementapproaches/opportunities-for-weed-control-in-dry-seeded-rice-in-north-western-indo-gangetic-plains.

Maity SK and PK Mukherjee. 2008. Integrated weed management in dry direct seeded rainy season rice (*Oryza sativa*). *Ind. J. Agron*. 53: 116–120.

Matloob A; A Khaliq and BS Chauhan. 2014. Weeds of Direct-Seeded Rice in Asia; Problems and Opportunities. *Advances in Agronomy,* 130, 58p.

Mishra JS and VP Singh. 2008. Integrated weed management in dry seeded irrigated rice (*Oryza sativa*). *Indian Journal of Agronomy.* 53 (4): 209-305.

Moody K. 1977. Weed control in multiple cropping. “Cropping Systems Research and Development for the Asian Rice Farmer”, pp. 281–293. International Rice Research Institute, Los Ban˜ os, Laguna, Philippines.

Moody K. 1990. Post-planting weed control in direct-seeded rice. Paper presented at a Rice Symposium, September 25-27. Malaysian Agricultural Research and Development Institute, Penang, Malaysia.

Moorthy BTS and S Saha. 2002. Evaluation of pre- and post-emergence herbicides for their effects on weeds and upland direct seeded rice. *Indian J. Weed Sci*. 34 (3&4): 197-200.

NARC. 2007. Research highlights: 2002/03-2006/07. Communication, Publication and Documentation Division, Nepal Agriculture Research Council (NARC), Khumaltar, Lalitpur, 17 p.

Nguyen NV and A Ferrero. 2006. Meeting the challenges of global rice production. *Paddy Water Environ*. 4: 1–9.

Nyarko K and SK De Datta. 1991. A Handbook for Weed Control in Rice. International Rice Research Institute, Los Banos, Philippines. 113p.

Ranjit JD and R Suwanketnikom. 2005. Response of Weeds and Yield of Dry Direct Seeded Rice to Tillage and Weed Management. In: Proc. 17th Asian Pacific Weed Science Society Conference. Bangkok, Thailand.

Rao AN and A Nagamani. 2007. Available technologies and future research challenges for managing weeds in dry-seeded rice in India. In “Proceedings of the 21st Asian Pacific Weed Science Society Conference from 2 to 6 October 2007, Colombo, Sri Lanka”, pp. 391–491.

Rao AN; DE Johnson; B Sivaprasad; JK Ladha and AM Mortimer. 2007. Weed management in direct seeded rice. *Adv. Agron*. 93: 153–255.

Rashid MH; MM Alam; AN Rao and JK Ladha. 2012. Comparative efficacy of pretilachlor and hand weeding in managing weeds and improving the productivity and net income of wet-seeded rice in Bangladesh. *Field Crops Res.* 128, 274–281.

Roder W. 2001. Slash-and-burn rice systems in the hills of northern Lao PDR. In: Description, challenges, and opportunities. International Rice Research Institute, Los Banos, Philippines. 201p.

Ruthenberg H. 1980. Farming systems in the tropics (3rd Ed.). Oxford, England: Clarendon Press.

Saha S; BTS Moorthy and J Beura. 2003. Performance of herbicides in puddled direct-seeded rice during summer. *Indian J. Weed Sci*. 35 (3&4): 208-210.

Schmidt LA; RE Talbert; FL Baldwin; EFS Rutledge and SS Wheeler. 1999. Performance of V-10029 (bispyribac) in rice weeds control programs. *South Weed Sci. Soc.* 52: 49.

Shah ML and KP Bhurer. 2005. Response of wet seeded rice varieties to sowing dates. *Nepal Agriculture Research Journal*, 6:35-38.

Sharma M. 2013. Weed dynamics and yield of dry direct seeded rice under different weed management practices at Rampur, Chitwan. M. Sc. thesis. Department of Agronomy, Trivubhan University.

Singh G; RK Singh; VP Singh; BB Singh and R Nayak. 1999. Effect of crop weed competition on yield and nutrient uptake by direct seeded rice (*Oryza sativa*) in rainfed lowland situation. *Indian J. Agron.* 44: 722–727.

Singh G; Y Singh; VP Singh; DE Johnson and M Mortimer. 2005. System level effects in weed management in rice-wheat cropping in India. BCPC International Congress on Crop Science and Technology, Glasgow, UK.

Singh MK. 2013. Competitiveness of rice cultivars under stale seedbed in dry direct seeded rice. Indian *Journal of Weed Science*, 45(3): 171–174.

Singh S; L Bhushan; JK Ladha; RK Gupta; AN Rao and B Sivaprasad. 2006. Weed management in dry seeded rice (Oryza sativa) cultivated in the furrow irrigated raised bed planting system. *Crop Prot.* 25: 487-495.

Singh S; JK Ladha; RK Gupta; L Bhushan; AN Rao; B Sivaprasad and PP Singh. 2007. Evaluation of mulching, intercropping with Sesbania and herbicide use for weed management in dry-seeded rice (*Oryza sativa* L.). *Crop Protection.* 26 (4): 518-524.

Singh S; JK Ladha; RK Gupta; L Bhushan and AN Rao. 2008. Weed management in aerobic rice systems under varying establishment methods. *Crop Prot.* 27, 660-671.

Spliid NH and B Koeppen. 1998. An extended survey of pesticides in ground water [groundwater]. DJF Rapport. Markbrug (Denmark).

Subudhi ECR. 2004. Evaluation of weeding devices for upland rice in the eastern ghat of Orissa, India. Int. Rice Res. Notes. 29: 79-81.

Swanton CJ and SF Weise. 1991. Integrated weed management: the rationale and approach. *Weed Technol.* 5: 657-663.

Tomita S; S Miyagawa; Y Kono; C Noichana; T Inamura; Y Nagata; A Sributta and E Nawata. 2003. Rice yield losses by competition with weeds in rainfed paddy fields in north–east Thailand. *Weed Biol. Manag.* 3: 162–171.

Toure A; JM Sogbedji and YMD Gumedzoe. 2013. The critical period of weed interference in upland rice in northern Guinea savanna: Field measurement and model prediction. *African Journal of Agricultural Research.* 8(17): 1748-1759.

Trung HM; NT Tan and HA Cung. 1995. Present status and prospect of weed control in rice in Vietnam. **In:** Proceedings of the 15th Asian-Pacific Weed Science Society Conference, Tsukuba, Japan. pp. 601-606.

Valverde BE; I Chaves; F Garita; E Ramfirez; J Vargas; C Carmiol; R Riches and JC Caseley. 2001. Modified herbicide regimes for propanil resistant jungle grass control in rainfed rice. *Weed Science,* 49:395-405.

Vongsaroj P. 1997. Weed Management in Paddy Fields. Botany and Weed Science Division, Department of Agriculture, Bangkok Amarin Printing Company, Bangkok, Thailand, p. 175.

Yaduraju NT and JS Mishra. 2004. Weed management in rice with special orientation to export. "SAARC RICE EXPO 2004", pp. 111–115. Maharashtra Chamber of Commerce and Industry and Rice Exporters Association of Pakistan, Mumbai, India.

Zhao DL; GN Atlin; L Bastiaans and JHJ Spiertz. 2006. Cultivar-weed competitiveness in aerobic rice, correlated traits, and the potential for indirect selection in weed free environments. *Crop Science* 46: 372-80.