Progressive Agriculture 27: 1-8, 2016 ISSN: 1017 - 8139

Progressive Agriculture
Journal homepage:http://www.banglajol.info/index.php/PA

Weed management on direct-seeded rice system - a review

MM Hossain*, M Begum, MM Rahman, MM Akanda[1]

Department of Agronomy, Bangladesh Agricultural University, Mymensingh 2202, Bangladesh; [1]Project officer, Department of Agricultural Extension, Noakhali, Bangladesh

Abstract

In direct seeded rice (DSR) cultivation systems, rice and weed seedlings emerge simultaneously and there is no standing water to suppress weed emergence and growth at crop emergence. For this reason, weeds are considered one of the major biological constraints in DSR and cause a substantial rice yield loss. Weeds are mainly controlled using herbicides or manually. However, manual weeding is becoming less effective because of labor crisis at critical times and increased labor costs. Herbicides are replacing manual weeding as they are easy to use but there are concerns about the sole use of herbicides, such as evolution of resistance in weeds, shifts in weed populations, cost of weed management to farmers and concerns about the environment. There is a need to integrate different weed management strategies to achieve effective and sustainable weed control in DSR systems. This paper describes different approaches, including preventive and cultural approaches, to manage weeds in DSR culture systems.

Key words: Weed, DSR, herbicides, IWM, CPWC

***Corresponding Author:** mmhshakil@yahoo.com

Introduction

Rice (*Oryza sativa* L.) is the leading cereal of the world (Juraimi *et al.,* 2013) and two third of the Asian peoples receive their daily calories from rice (Rahman and Masood, 2012). World's rice demand is projected to increase by 25% from 2001 to 2025 to keep pace with population growth (IRRI, 2003). In most Asian countries, rice is grown by manual transplanting of seedlings into puddled soil which creates a hard pan below the plough layer and reduces soil permeability and deteriorates soil structure and soil quality for the subsequent upland crops. Puddling and transplanting operations consume a significant quantity of water; in some cases, up to 30% of the total rice requirement (Chauhan, 2012). About 55% of the total rice area is irrigated and concerns are increasing about the availability of water and which triggers farmers in many Asian countries to be shifted from manual transplanting to DSR systems. Weeds are the number-one biological constraint and major threat to the production and adoption of DSR systems (Chauhan, 2012) and can cause rice yield losses of up to 50% and the risk of yield loss is greater than transplanted rice and as high as 50-91% (Rao *et al.,* 2007.

A single weed control approach may not be able to keep weeds below the economic threshold level, and may results in shift in the weed flora, resistance development and environmental hazards. Therefore, adoption of diverse technology is essential for weed management because weed communities are highly responsive to management practices (Buhler *et al.,* 1997). This review article aims to sum up earlier work on different sustainable weed management approaches in DSR.

Weed community in rice field

There are about 350 species have been reported as weeds of rice. The grasses are ranked as first followed by sedges and broadleaf weeds (Holm *et al.,* 1977). Different rice ecosystems and cultural practices determine dominant weed species or group, rice-weed competition and the weed control strategy (Datta and Balatzar, 1996). A list of major weeds found in rice fields in Asia has been presented in Table 1.

Table 1. Major weeds in rice fields in Asia (IRRI, 2003)

Weed category	Scientific name	Family name
Grass	*Digitaria setigera*	Poaceae
	D. ciliaris	Poaceae
	Echinochloa colona	Poaceae
	E. crus-galli	Poaceae
	E. glabrescens	Poaceae
	Eleusine indica	Poaceae
	Ischaemum rugosum	Poaceae
	Leptochloa chinensis	Poaceae
	Oryza sativa (weedy rice)	Poaceae
	Paspalum distichum	Poaceae
Sedge	*Cyperus iria*	Cyperaceae
	C. difformis	Cyperaceae
	C. rotundus	Cyperaceae
	Fimbristylis miliacea	Cyperaceae
Broad leaf	*Commelina benghalensis*	Commelinaceae
	Eclipta prostrata	Asteraceae
	Ipomoea aquatica	Convolvulaceae
	Ludwigia octovalvis	Onagraceae
	L. adscendens	Onagraceae
	Monochoria vaginalis	Pontederiaceae
	Sphenoclea zeylanica	Sphenocleaceae

Weed management strategies

Various weed management strategies are available and depending on the location and available resources, there is a need to include as many strategies as possible. Some of the strategies discussed below are applicable for only dry-seeded rice systems and others are applicable to both (dry and wet) seeding systems.

Weed prevention approach

Prevention is the most basic of all weed control methods which restricts introduction and spread of weeds (Buhler, 2002). Preventive measures include using weed-free seeds, maintaining clean fields, borders, and irrigation canals, and cleaning farm equipment's (Datta and Baltazar, 1996). Rice seeds contaminated with weed seeds may introduce problematic weed species to a new field and enrich the soil weed seed bank. In addition to clean crop seed, the machinery used for tillage, sowing, harvesting, or threshing operations should also be cleaned before moving it from one field to another. Bunds and irrigation canals free from weeds may also help to reduce the spread of weed seeds through irrigation water.

Cultural approach

Cultural approaches play significant role to determine the competitiveness of a crop with weeds for above ground and below ground resources and hence influence weed management (Grichar *et al.,* 2004). Some cultural practices are described below:

(a) Judicious selection of cultivars: Cultivar (s) to be used in DSR could be a good alternative to control weeds. Selection of cultivar (s) might be based on following of two attributes-

(i) Weed-competitive cultivars: Rice cultivar (s) with strong weed competitiveness is deemed to be a low-cost safe tool for weed management (Gibson and Fischer, 2004). In general, cultivars with high tillering ability, high early growth rate, high leaf area index and specific leaf area, long leaves and droopy plant type are more weed suppressive. Tall and traditional cultivars with droopy leaves are superior competitors to short-statured modern cultivars with erect leaves. Competitive rice cultivar *viz*., hybrids usually have better vigor than inbreeds and effectively suppressed the infestation of *Echinochloa spp*. (Gibson *et al.,* 2001).

(ii) Allelopathic cultivars: Allelopathic rice cultivars can contribute to weed suppression. In Philippines, 111 rice cultivars have been evaluated for weed suppression capability against barnyard grass (Olofsdotter, 2001) and claimed that allelopathy can give 34% of the reduction in total weed dry weight after 8 weeks of seeding. Several accessions of rice germplasm in the field were found to decrease the growth of *Heteranthera limosa*, which caused 21% reduction in the yields of DSR (Dilday *et al.* 1994). Leaves extracts from rice seedlings at the six-leaf stage inhibited the growth of *Heteranthera limosa* and *Lactuca sativa* (Ebana *et al*., 2001) Hence, it could be said, there is tremendous scope to incorporate these allelopathic rice cultivars in DSR systems to manage weeds.

(b) Stale seedbed technique: In stale seedbed technique, weeds are allowed to germinate and the emerged weed seedlings are killed by using a nonselective herbicide (glyphosate or paraquat) or shallow tillage. In this way, there will be only a few weeds in the crop as most of the weed seedlings emerged in the top 2-cm soil layer. However, protracted emergence of some weed species may occur due to different kinds of dormancy present in different weeds. Most weed species conducive to be controlled by this practice are those that have low initial dormancy and are present in the top soil layers, such *as Leptochloa chinensis, Eclipta prostrata, Digitaria ciliaris, and Ludwigia hyssopifolia.* The use of the stale seedbed practice could also help to reduce the problems of hard-to-control weeds, such as *Cyperus rotundus*, weedy rice, and volunteer rice seedlings (Chauhan, 2012).

(c) Tillage: Tillage can affect weed community through the changes in weed seed distribution in the soil. Primary tillage can reduce annual weed populations, especially when planting is delayed to allow weed seeds to emerge before final tillage (Buhler and Gunsolus, 1996). Shallow tillage before crop emergence and post plant tillage after crop establishment help to remove annual weeds and inhibit the growth of perennial weeds (Buhler, 2002). On the other hand, zero tillage favors weed infestation (Hach, 1999).

(d) Seeding density: Higher seeding rate favors rice more than weeds and increases yield under weedy conditions (Phuong *et al.,* 2005). *Echinochloa cruss-galli* and *Leptochloa chinensis* densities were reduced at higher rice seeding rates of 200 kg/ha and 100 kg/ha, respectively (Hiraoka *et al.,* 1998). Higher seeding rate of rice has been advocated not only for weed control but also for avoiding higher risk of poor seedling establishment and direct seeding with 300 rice seeds/m^2 successfully suppressed weeds under aerobic soil conditions (Anwar *et al.,* 2011).

Row seeding with narrow spacing: A direct-seeded rice sown in rows allow farmers to practice inter row cultivation. In row-seeded crops, weedy rice emerging between the rows can be distinguished and pulled out. In addition, weeds grown in wider rows may have greater biomass than weeds grown in narrow rows. Therefore, a direct-seeded crop should be grown using narrow row spacing to obtain faster canopy closure and less penetration of light and ultimately less weed growth (Chauhan, 2012). Row seeding in east-west direction resulted in lower yield loss under weedy condition (Phuong *et al*., 2005). Effect of rice row spacing and weed emergence time (days after crop emergence) on biomass of *Echinochloa colona and E. crus-galli* presented in Figure 1.

(e) Crop residue*:* Crop residues are known to have a chemical (allelopathic) as well as a physical effect on the growth of subsequent crops and weeds (Purvis *et al.* 1985, Mason-Sedun *et al.* 1986). Residue affects weed growth by reducing light and modifying soil temperature. Seedlings of many weed species can be suppressed by using crop residue as mulches (Chauhan, 2012). Effects of rice residue amount on seedling emergence of different weed species presented in Figure 2.

(f) Seed quality: Using quality seeds from certified source which are free from any contaminants might be an important approach to manage weeds in DSR systems. Fields free of weedy rice planting with rice seeds contaminated by only 2 seeds/kg may result in a soil infestation of 10 kg weedy rice seeds/ha after only three seasons (Noldin, 2000).

Seed priming

A robust seedling stand obtained from primed seeds enhanced rice competitiveness against weeds (Ghiyasi *et al.* 2008; Anwar *et al.,* 2012b).

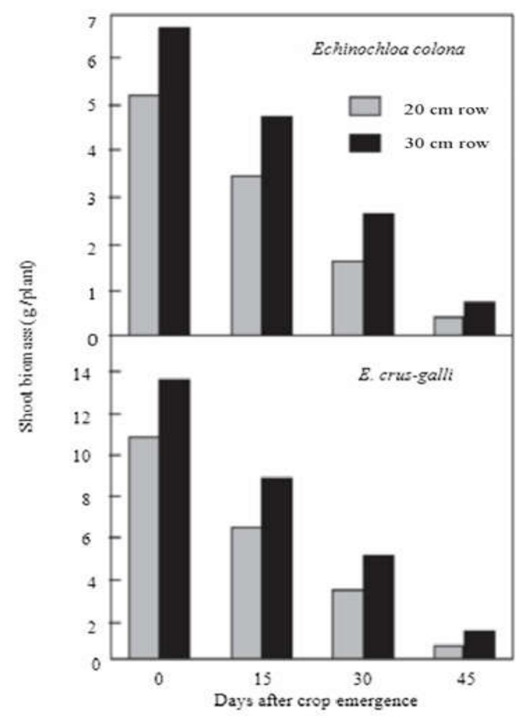

Figure 1. Effect of rice row spacing and weed emergence time (days after crop emergence) on biomass of *Echinochloa colona* and *E. crus-galli* (Chauhan, 2012)

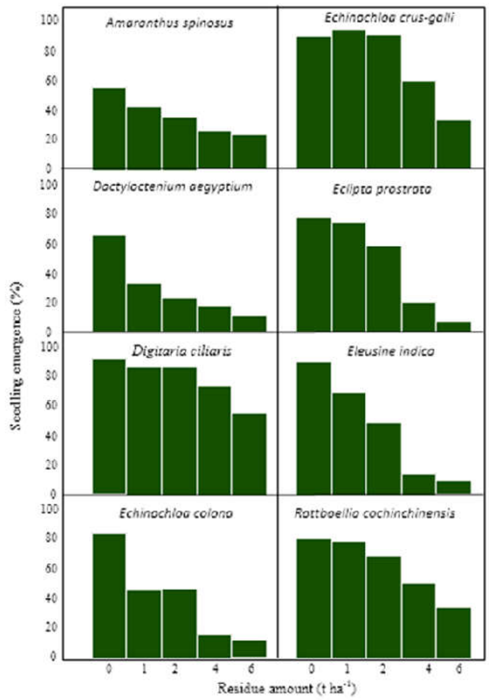

Figure 2. Effect of rice residue amount on seedling emergence of different weed species (Chauhan, 2012)

(g) Crop rotation: Crop rotation affects weed demography and subsequent population dynamics and hence, considered to be a vital tool of weed management (Liebman and Gallandt, 1997). Rotation combinations of 25 crops reduced weed density compared to monoculture (Liebman and Ohno, 1998).

(h) Intercropping: Intercropping can reduce both weed density and biomass to a great extent due to decreased light transmission through the canopy (Baumann *et al.,* 2000). Intercropping with *Sesbania* for 30 days were found effective in controlling weeds in DSR (Singh *et al.,* 2007).

(i) Cover crops: Incorporation of cover crop into the soil may add allelo-chemicals to the soil to prevent germination and establishment of weeds (Buhler, 2002). About 25% reduction in weed seed bank density and 22% reduction in weed biomass 7 years after introduction of rye cover crop in corn were observed by Moonen and Barberi (2004).

(j) Fertilizer management: Weeds became less competitive when N was applied at early growth stages of crop compared with later application and weeds are found to be more responsive to added N than that of crop (Blackshaw *et al.,* 2000). Fertilizer management can definitely alter the competitive balance between crops and weeds, but methods to incorporate it into integrated weed management are yet to be developed (Buhler, 2002). Weeds may remain dormant in cow dung and hence, concerns should be given to use cow dung in DSR systems.

Chemical approach

Weedicides offer the most effective, economical and practical way of weed management (Hussain *et al.*, 2008). For the last few decades, herbicides considered tremendous contributor to agriculture (Juraimi *et al.,* 2013). In large scale rice farming, herbicide based weed management has become the smartest and most viable option (Anwar *et al.,* 2012a). Herbicides may be considered to be a viable alternative to hand weeding (Chauhan and Johnson, 2011; Anwar *et al*., 2012a). A list of commonly used herbicides in direct seeded rice field with their active ingredients, application time and target weed groups has been presented in Table 2.

Physical approach

Physical control of weeds is done manually or mechanically. Harrowing has been found effective in DSR, especially when the crop plants are larger than weeds (Rasmussen and Ascard, 1995). Hand weeding is very easy and environment-friendly but tedious and highly labor intensive and thus is not an economical for the farmers (Juraimi *et al.,* 2013). Mechanical weeding using hand pushed weeders is feasible only where rice is planted in rows; however, weeds emerging within rows are difficult to remove with these weeders (Chauhan, 2012).

Biological approach

Myco-herbicides using different fungi e.g. *Exserohilum monocerus* and *Cocholiobolus lunatas* found to control barnyard grass. *Setosphaeria sp.* and *C. rostrata* were also found to control *Leptochloa chinensis* effectively (Thi *et al.,* 1999). However, scope of using myco-herbicides is limited to control weeds in DSAR because fungal pathogen requires flooded conditions.

Table 2. Commonly used herbicides in rice system (Azmi, 2012)

Herbicides	Time of application (DAS)	Dose	Salient features
Benthiocarb	5-7	6 L product/ha	Early post emergence herbicide, broad spectrum of weed control under saturated conditions
Bispyribac sodium	10-14	20-40 g ai/ha	Contact herbicide for early post emergence application, broad spectrum of weed control except *Leptocholoa chinensis*
Bensulfuron-methyl	6-10	300-500 g ai/ha	Effective against almost all annual and perennial broadleaved weeds and some sedges during pre-emergence and early post emergence under wet/standing water conditions
Cyhalofop-butyl	10-14	100 g ai /ha	Effective against *E. crusgalli* and *L. chinensis* until four leaf stage. Tank mixed with Sulfonyl urea gives wide spectrum of weed control
Fentrazamide	4-7	60-70 g product/10L	Early post emergence herbicide, effective against mostly grasses and some sedges, broadleaved weeds
Molinate + Bensulfuron	6-10	3.0 + 0.03 kg ai/ha	Wide spectrum of weed control under standing water conditions
Molinate + 2,4 -D	14-21	3.0 + 0.5 kg ai/ha	Early post emergence herbicide for *Echinicholoa* spp., wide spectrum of weed control
Pretilachlor	1-4	0.5 kg ai/ha	Pre-emergence herbicide, broad spectrum of weed control
Propanil	5-7	6 L product/ha	Early post emergence herbicide, broad spectrum of weed control under saturated conditions
Propanil + 2,4-D	6-10	2-4 kg a + 1 kg ai/ha	Early post emergence herbicide for grassy weeds, effective under dry and saturated conditions
Penoxsulam + Cyhalofop-butyl	6-10	12.5 g +62.5 g ai/ha	Effective against *E. crusgalli, L. chinensis, C. iria, F. miliacea* and *C. difformis* under saturated condition
Quinclorac + Bensulfuron	6-10	0.25+ 0.03 kg ai/ha	Quinclorac is effective against *Echinocholoa spp*. Bensulfuron combination gives wider spectrum of weed control

N.B.: (DAS= Days after sowing, ai= active ingredient, ha= hacter)

Integrated weed management

Integration of various components in a logical sequence, might accomplish considerable advances in weed management (Swanton and Weise, 1991). Various agronomic tools have been evaluated for their potentiality in managing weeds (Liebman *et al.,* 2001). But, all the agronomic tools may not work perfectly with every crop or weed species. Integration of higher seed rate and spring-applied fertilizer in conjunction with limited herbicide use managed weeds efficiently and maintained high yields (Blackshaw *et al.,* 2005).

Critical period for weed control

Understanding the concept critical period of weed control (CPWC) is one of the most important tools in integrated weed management (Swanton and Weise, 1991). CPWC is the period of time when weed control is necessary to avoid significant yield loss (Nazarko *et al*., 2005). It is the time interval between two components of weed interference namely, the critical weed interference periods (CWIP) and critical weed-free periods (CWFP). CWIP is the maximum length of time during which weeds can coexist with the crop without causing unacceptable yield loss and the CWFP is the minimum length of time required for the crop to be maintained weed-free before yield loss caused by late-emerging weeds (Isik *et al*., 2006).

Critical period (CP) falls between 14 and 28 DAS to control *Fimbristylis miliacea* and 16 to 53 DAS to control weedy rice (Begum *et al.,* 2008). Anwar *et al.* (2012c) determined CP as 7-49 days in off season and 7-53 days in main season to achieve 95% of weed-free yield, and 23-40 days in off season and 21-43 days in main season to achieve 90% of weed-free yield.

Conclusion

The land area under DSR systems is expected to increase in the future because of labor and water crisis. Weeds are the major constraints to DSR system and its management is a fundamental practice, failure of which may results in severe losses in terms of yield and economic return. Integrated approaches, 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 are suggested for sustainable weed control in DSR.

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