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Weed management practices in direct seeded rice (*Oryza sativa* L.): A review

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Abstract
Rice (*Oryza sativa* L.) is an important staple crop in India, where it is mainly grown by manual trans planting of seedlings into puddled soil. Recently, however, there is a trend toward direct seeded rice use of labor and water scarcity. In DSR, weeds are the main biological constraint. The success of direct seeding is almost totally depend on effective weed control, so weed control is the key factor in direct seeded rice. Due to changes in crop physiology and increased weed invasion, the degree of flooding in rice may lead to reduced yields. If weeds are managed, then direct sowing culture can evenly be successful as compared to transplanting method. Herbicides are used to manage weeds in DSR systems, but the use of herbicides alone does not provide effective and sustainable weed control. Therefore, there is a need to integrate herbicide use with cultural weed management approaches; hence, it is necessary to evaluate different pre and post emergence herbicides to provide wider option to the farmers for weed control in direct seeded rice.

Keywords: direct seeded rice; herbicide; rice; weed management; economics

Introduction

Rice (*Oryza sativa* L.) a member of Poaceae family is relished as staple food by majority (more than 60%) of world's population. Rice plays a pivotal role in Indian agriculture, as it is the principal food crop for more than 70 per cent of the world population. Among the cereal crops, it serves as the principal source of nourishment for over half of the global population (Davla *et al*., 2013) [13]. India is the second largest producer of rice only after China. In India, the area under cultivation of rice is about 44.1 million hectares with the production of 105.3 million tonnes and average productivity 2.39tonnes ha^{-1} (Paula Bianca Ferrer, 2011). It is cultivated under different situations that is from below sea level in Kerala to about 2000m altitude in Himalayan region, from 8^0 N latitude in Kanyakumari to35 ^{0}N latitude in Kashmir, annual rainfall from 1250 cm (Assam) to 25cm (Rajasthan) from sandy loam soils to heavy black cotton soil and from normal to saline alkali soils.

Although India has achieved self-sufficiency in rice requirement, the major share of this increase was come through increased area, but land is the scare resource to meet the demand of 126.14 million tonnes by year 2030, we have to increase our productivity (Paroda and Kumar, 2000) [39]. There is a large gap between achieved and achievable yield with the exception of Tamil Nadu (15%) and Punjab (22%), the yield gap is in the range of 35-37 per cent for most of the states. Uttar Pradesh is is grown over an area of 5.54 million hectares with production and productivity of 12.51 million tonnes and 2.06 tonnes ha^{-1}, respectively (Anonymous, 2014) [2]. The yield gap for Uttar Pradesh is 56.5 per cent. Major factors that cause yield gap are more than 50% area under rice being rainfed, faulty.

Dry-seeded rice (DSR) has been developed as an alternative method of rice establishment that reduces labor requirement and other inputs while increasing or maintaining economic productivity and alleviating soil degradation problems (Ladha *et al*., 2009; Farooq *et al*., 2011) [30, 16]. However, some studies reported a reduction in yield when shifting from puddled transplanted rice (PTR) to DSR using alternate wetting and drying (AWD) water management (Bhushan *et al*., 2007; Choudhury *et al*., 2007) [8]. The yield reduction was related to the management practices applied and the climatic conditions in the planting site (Belder *et al*., 2004; Gathala *et al*., 2006 and Singh *et al*., 2011) [7, 17, 61].

The sustainability of DSR, however, is endangered by heavy weed infestation (Chauhan, 2012 and Mahajan *et al*., 2013) [9, 32]. Weeds are the major constraint towards the success of DSR (Rao *et al*., 2007) [49]. Estimated losses from weeds in rice are around 10% of total production grain yield; however, such losses can be much higher (Rao *et al*., 2007) [49]. In wet-seeded and dry-seeded rice, weed growth reduced grain yield by up to 53 and 74%, respectively (Ramzan,

2003) [48], and up to 68–100% for direct seeded rice (Mamun, 1990) [34]. The DSR fields are more species-rich with greater diversity in weed flora than TPR (Tomita *et al*., 2003) [67]. In DSR systems, land preparation operations influence weed seed distribution in the soil profile and the comparative abundance of weed species (Chauhan and Opena, 2012) [9].

Weed control is particularly challenging in DSR systems because of the diversity and severity of weed infestation, the absence of standing water layer to suppress weeds at the time of rice emergence, and no seedling size advantage of rice over the weed seedlings as both emerge simultaneously. Therefore, a systematic, efficient and effective weed management depends on timing and method of land preparation (Maity and Mukherjee 2008), effectiveness of herbicides (Sinha *et al*., 2005) [62], relative to the dominant weed species and soil conditions at the time of application (Street and Mueller, 1993) [63], effect of weather on weeds (Maity and Mukherjee, 2008) and effect of combining herbicides and manual weed control (Rao *et al*., 2007) [49]. Moreover, weed surveillance may also prove beneficial in selecting suitable herbicides and weed management strategies in a region (Singh *et al*., 2009 and Anwar *et al*., 2012a) [3].

Many researchers working on weed management in direct seeded rice opined that herbicide may be considered to be a viable alternative/supplement to hand weeding (Kumar *et al*., 2008; Mahajan *et al*., 2009; Chauhan and Johnson, 2011 and Anwar *et al*., 2012a) [29, 61, 3]. Sharma (1999) [55] suggested that pre-emergence application of thiobencarb at 2.0 kg ha^{-1}, hand weeding 20 DAS, or post establishment intercrop cultivation at 37–42 DAS effectively controlled weeds and increased yield by 32.7–34.7%, 36.7% and 28.7– 83.9%, respectively.

Weed flora

Weed flora in DSR consists of various kinds of grasses, broad leaf weeds and sedges (Mahajan *et al.,* 2009). When farmers shift to DSR from TPR, the weed flora changes drastically (Rao *et al*., 2007) [49]. DSR fields are more species-rich with greater diversity in weed flora than TPR fields (Tomita *et al*., 2003; Singh *et al*., 2008; Kamoshita *et al*., 2010) [67] due to simultaneous germination of weeds with rice in absence of standing water to suppress weed growth (Chauhan and Johnson, 2010). In India, a large number of perennial species (*Paspalum distichum* L., *Cynodon dactylon* L. Pers., *Cyperus rotundus* L.) as well as annual grasses (*Echinochloa crus-galli* L.) and annual sedges (*Cyperus difformis* L. and *Fimbristylis miliacea* L.) were found in conventional-till DSR systems (Timsina *et al*., 2010) [66]. The broad leaved constituted 34.1 per cent, grasses 42.2 per cent and sedges 23.6 per cent of the total weed population under weedy conditions (Singh *et al*., 2007 & Ravisankar *et al*., 2008) [51]. *Echinochloa colona* and *E. crus galli* are the most serious weeds affecting DSR. The densities of these weeds in DSR depend upon moisture condition in the field.

The weed infestation is more in upland rice fol1owcd by puddled seeded rice. Estimated losses from weeds in rice are around 10% of total production grain yield; however, such losses can be much higher (Rao *et al*., 2007) [49]. DSR due to weed interference may be up to 100% (Singh *et al.,* 2014). In wet-seeded and dry-seeded rice, weed growth reduced grain yield by up to 53 and 74%, respectively (Ramzan, 2003) [48], and up to 68-100% for direct seeded Aus rice (Mamun, 1990; Gianessi *et al*., 2002) [34, 18].

Critical period of weed competition

The finding of most researchers showed that critical competition to affect the yield of rice occurs from 15-45 DAS. The competition period up to 45 DAS had the greater impact on yield of wet seeded rice (Madhu and Nanjappa, 1995; Govindrasu *et al.,* 1998) [31]. Chinnusamy *et al*. (2000) [11] reported that maintaining a weed free period up to 45 DAS was essential to augment the yield of medium duration rice. In rainfed lowland rice, 30-60 days after sowing period was considered as critical period for crop weed competition to avoid grain yield losses (Moorthy and Saha, 2005). Gopinath *et al*. (2012) [12] completed on an average, a weed population of 627 m^{-2} was recorded in the weedy check plots. The grain yield decreased by 78.5-94.8% due to season-long weed-crop competition as compared with hand weeding (20 and 40 DAS).

Weed management practices

Mechanical and manual

Harrowing has been found effective in direct seeded rice, especially when the crop plants are larger than weeds to escape damage (Rasmussen and Accard, 1995) [50]. In Vietnam, 85% farmers practice hand weeding in direct seeded rice (Mai *et al.*, 1998). Hand weeding is tedious and highly labor intensive, and; thus is not an economically viable option for the farmers. It has been estimated that 150 to 200-labor-dayha^{-1} are required to keep rice crop free of weeds (Roder, 2001) Moreover, morphological similarity between grassy weeds and rice seedlings makes hand weeding difficult at early stages of growth. The other problems with manual weeding include quite often weeding is delayed or even scuffed due to unavailability and/or high wages of labor (Johnson, 1996), and damage to the rice seedlings (Moody and Cordova, 1985; Moody, 1993).

Chemical method

Effective weed management practices are an important prerequisite in DSR culture, with herbicide application seemingly indispensable (Azmi *et al*., 2005) [4]. The trend for an increase in herbicide use has been reinforced by the spread of DSR. Herbicides are considered indispensable for cost efficient weed control in wet-seeded rice (De Datta *et al*., 1989). Chemical control, on the contrary, is the most effective, economic and practical way of weed management (Marwat *et al*., 2006; Hussain *et al*., 2008; Anwar *et al*., 2012a) [3].

Several pre and post emergence herbicides have been reported to provide a good degree of weed control in wet seeded rice. Application of different pre-emergence herbicides including thiobencarb, pendimethalin, butachlor, oxadiazon and nitrofen has been found to control weed satisfactorily in direct seeded rice (Moorthy and Manna, 1993; Pellerin and Webster, 2004) [42]. Among the post emergence herbicides, ethoxysulfuron, cyhalofop-butyl, pretilachlor, chlorimuron, metsulfuron, bispyribac sodium and penoxsulam effectively controlled weeds in direct seeded rice (Mann *et al*., 2007; Singh *et al*., 2008 and Mahajan *et al*., 2009) [36].

Effect of weed management practices on weed dynamics

Chopra and Chopra (2003) [12] determined the efficacy of 20 or 25g pyrazosulfuron ha^{-1}applied 3, 10 and 25 days after transplanting in rice cv. PNR-381. According to them Pyrazosulfuron at20 and 25g/ha significantly reduced the density and total dry weight of *Cyperus iria, Sphenoclea* *zeylanica, Echinochloa colona* and *Leptochloa panacea* when applied 3 or10 DAT.

Laskar *et al*. (2005) observed that hand weeding twice and 0.20 kg oxyfluorfen ha^{-1} + hand weeding at 40 DAS recorded the lowest weed densities (11 and 8 m^{-2}) and dry weight (10.67 and 8.47 g m^{-2}). DSR management system has been advocated, which includes weeding with a soil cultivator involving tillage between rows of rice twice at 2 and 4 weeks after seeding (Kabaki *et al*., 2003). In wet (row)-seeded rice, an improved and modified IRRI cono weeder (Parida, 2002) gave a weeding efficiency of 80% during the first weeding, with a field capacity of 0.02 ha^{-1}.

Shreedevi *et al.* (2007) [56] reported that the pre-emergence application of pretilachlor @ 0.600 kg *a.i.*ha^{-1} (3-5 DAT) was found effective against grassy weeds. Pendimethalin has residual activity and control annual grasses and some broadleaf weeds (Jordan *et al*., 1998b; Smith and Hill, 1990). Pendimethalin can be applied after rice has imbibed water for germination but before rice and weeds emerge. Subsequent weed flushes are generally controlled with postemergence herbicides (Jordan *et al*., 1998b). Pre-emergence application of pendimethalin followed by post-emergence application of bispyribac- sodium at 15 days after sowing (DAS) was most effective for controlling weeds in DSR (Mahajan *et al*., 2009). In another study, application of oxadiazon at 2 DAS followed by fenoxaprop + ethoxysulfuron applied at 28 DAS fetched the best result in DSR (Chauhan and Opena, 2013) [32].

Jadhav *et al.* (2008) [23] and Yadav *et al.*(2009) [68] reported that pre-emergence application of oxadiargyl at 75 gha^{-1} controlled the weeds effectively at early stage of crop growth followed by post-emergence application of bispyribac sodium at 30 gha^{-1} controlled the late coming weeds.

Singh *et al*. (2012) reported that *Echinochloa spp*. contributed 20 per cent of total weed density. Two hand weedings (20 and 40 days), controlled *Echinochloa* spp. effectively and resulted in the highest grain yield (6.4 t ha^{-1}6.6 tha^{-1}). Gopinath *et al.* (2008) reported that the hand weeding twice at 20 and 40 DAS recorded the highest grain yield (2439 kg ha^{-1}) and was significantly superior to all other treatments.

Effect of weed management practices on crop Growth and development

Prasad *et al.*(2001) [4] found that in rice crop, values of growth parameters *viz.* tillers number (259.6 m^{-2}) and plant dry weight (407.8 gm^{-2}) was recorded with hand weeding with the highest and the lowest was in weedy check (192.4 m^{-2} and 407.8 gm^{-2} respectively).

Singh *et al.* (2006) observed that maximum plant height was recorded in weed free (86.58 cm) followed by hand weeding at 20 and 40 DAS (84.05cm) and minimum plant height was recorded in un weeded check (69.78 cm) which was highly significant from the rest of treatment.

Ramana *et al.* (2007) [47] found significantly lower plant height was recorded in weedy check, followed by metsulfuron methyl 10% +chlorimuron ethyl 10% and metsulfuron methyl 10% + chlorimuron ethyl 10% +working with star weeder and the tallest plants were noticed in weed-free check which was on at par with sole application of metsulfuron methyl 10% + chlorimuron ethyl 10%.

Sharma *et al.* (2007) found that among weed management practices, 2 hand weedings at 20 and 40 DAS and application of butachlor at 1.5 kg ha^{-1} + 1 hand weeding at30 DAS caused significant increase in growth. They suggested that efficient control of weeds might have reduced the nutrient uptake by weeds and resulted in better growth of rice crop.

Mohan *et al.* (2010) [37] reported that pre-emergent application of butachlor @ 1.0$kgha^{-1}$+ safener followed by pretilachlor @ 0.4 $kgha^{-1}$ + safener have low toxicity on rice plant and plant stand was better compared to other treatments. They also recorded higher plant height.

Kaushik *et al.* (2012) revealed that almost all growth parameters, yield attributes and grain yield, and the lower weed density were noted under post emergence application of almix 4 g ha^{-1} at 20, 40, 70 and 90 DAS. Ravisankar *et al.*(2007) reported significantly higher crop growth rate due to application of pretilachlor-plus (0.3 kg ha^{-1}) 2 DAS + hand weeding at 45 DAS between tillering and flowering stage recording 12.09 and 12.52 $gm^{-2}day^{-1}$ during 2000 and 2001, respectively as compared to hand weeding twice at 20 and 45 DAS (11.74 and 11.72$gm^{-2}day^{-1}$, respectively) as well as un weeded check (1.92 and 2.37 g m^{-2} day^{-1}),respectively.

Yield attributes

Singh and Namdeo (2004) [60] reported that yield attributes like effective tillersm^{-2},length and weight of panicle, spikeletspanicle^{-1} and 1000 grain weight performed the bestunder hand weeding followed by application of pendimethalin 1.0 $kgha^{-1}$(PE). They observed that application of pendimethalin 1.0 $kgha^{-1}$ (PE) recorded effective tillers (419 m^{-2}), panicle length (17.9 cm), panicle weight(1.76 g), spikeletpanicle^{-1} (80.7) and 1000- grain weight(21.22g), which was significantly higher than the control plots i.e, 370 tillersm^{-2}, 15.3 cmpanicle length, 1.33g panicle weight, 73.3 spikeletspanicle^{-1} and 21.72 g 1000-grain weight, respectively.

Sharma *et al*. (2004) found that pyrazosulfuron applied at 24-40 gha^{-1} after 3 and 6days of transplanting resulted in higher number of tillers and grain yield. Yuan *et al.* (1990) found that pyrazosulfuron-ethyl at 30 gha^{-1} increased the tiller production by 19.4%, the proportion of filled grains by 16.4%, the grain weight by 0.15% and the grain yield of rice by 35.5% over those of control. Reviewing above cited references it can be inferred that in general rice yield attributes increased by chemical weed control and in many cases they were at par with two hand weeding.

Singh *et al.*(2005) [58] reported that application of almix post-emergence along with 0.2%surfactant registered higher grainspanicle^{-1} (118), panicle weight (2.9g), and 1000 grain weight(15.3g) over weedy check registering 65grainspanicles^{-1}, 2.1 g panicle weight and 14.7g 1000-grain weight.

Suganthi *et al.* (2005) reported that the application of pretilachlor at 1.5 and 3.0 $kgha^{-1}$ resulted in severe crop photo toxicity. The highest number of panicles (315 and 341m^{-2}) and grain yield (5680 and 5800 $kgha^{-1}$) were obtained with hand weeding twice, which was on at par with 1.0 kg pretilachlorha^{-1} (315 and 345 m^{-2}) and 5737 and 5822 kg ha^{-1}.

Subramanian *et al.* (2006) [64] reported that pre-emergence application of pretilachlor + 2hand weedings significantly increased the panicles number (367 m^{-2}), grain yield (59.38 q ha^{-1}) and straw yield (87.84 q ha^{-1}) which was comparable with weed free check recording 362 panicles m^{-2}, 58.73 q/ha grain yield and 82.40 qha^{-1} straw yield. These weed management practices recorded higher grain yield and produced 50.7% additional grain yield compared with the un weeded check.

Sanjay *et al*., (2006a) [54] stated that application of pre emergence herbicide pretilachlor + safener @1 litre ha^{-1} fb one hand weeding at 30 DAS resulted in significantly higher grain yield (5333kg ha^{-1}) of rice irrespective of method of establishment.

Kumar *et al.* (2007) recorded that hand weeding resulted in maximum increase in effective tillers (105.5 m^{-2}) and number of grains panicle (157.8) and proved superior to the rest of the weed control treatments. Singh and Namdeo (2004) [60] observed that hand weeding (20 and 40 DAS)recorded maximum effective tillersm^{-2} (468), panicle length (19.8 cm), panicle weight (2.22 g), spikeletspanicle^{-1} (98.6) and 1000-grain weight (22.15 g) followed by pendimethalin. Singh *et al.* (2005) [58] found that maximum effective panicles m^{-2}, panicle weight (g), grains panicle^{-1} and 1000-grain weight (g) was registered in two hand weeding i.e.331, 3.8, 133 and 16.5 respectively. Singh *et al.* (2006) conducted an experiment in Faizabad during 2002 and 2003and observed that yield attributes *viz.* panicle m^{-2}, length of panicle, grains panicle^{-1} and1000-grain weight increased significantly by all weed control treatments compared to weedy check. He also recorded that panicle m^{-2}, length of panicle (cm), grains panicle^{-1} and 1000-grain weight (g) was maximum in weed free i.e, 26.02, 3.84, 149.4 and 23.63respectively which was at par with hand weeding at 20 and 40 DAS i.e, 25.46, 3.64,137.1 and 23.28 respectively and recorded significantly lower in weedy check i.e, 9.59panicle m^{-2}, 1.23 length of panicle (cm), 63.87 grains panicle^{-1} and 20.2 (g) 1000-grainweight, respectively.

Thakur *et al.* (2011) [65] reported that intercropping of sesbania and incorporation of the same at 4 weeks after sowing besides application of pendimethalin @ 1 kg ha^{-1} was observed to be superior with 44.5% of the total dry matter, higher grain yield (2091 kg ha^{-1}), net return (Rs. 8902 ha^{-1}) and benefit: cost ratio (1.84) owing to more number of effective tillers (124 m^{-2}), having maximum grainspanicle^{-1} (77) and bolder grains (1000 grain weight - 24.3 g). However two hand weeding sat 4 and 6 days after sowing was found to at par with the former one in terms of grain yield as well as economic return.

Yield

Bayan and Kandasamy (2002) [5] observed that among weed control methods, cultural + manual method, which resulted in highest crop growth and yield attributes. The highest grain yield (6607 kg ha^{-1}) maximum energy use efficiency (8.76 kgha^{-1}) and highest benefit cost ratio were also recorded with the same treatments.

Dhiman-Mukherjee (2005) reported that the efficacy of metsulfuron-methyl (4, 6 or 8 g/ha), chlorimuron-ethyl (10, 15 or 20 g ha^{-1}) and hand weeding at 20, 40 and 60 DAT for weed control in rice (CV. Sarju 52). Hand weeding and Almix registered the highest mean grain yields (5-9 and 5-8 tha^{-1}), straw yields (7.3 and 7.1 tha^{-1}) and harvest index (44.88 and 44.90 %). Halder *et al.* (2007) [21] reported that the application of almix 0.004 kg + butachlor 1.0 kgha^{-1} and butachlor 1.0 kg, followed by almix 0.004 kg ha^{-1} increased the grain yield by 36.8 and 36.6%, respectively, over the un weeded check.

Kumar *et al.* (2007) observed that hand weeding recorded significant increase grain (2401 kg ha^{-1}) and straw (5229 kg ha^{-1}) yield. A 62.6% reduction in rice grain yield was found by under weedy check, while maximum grain yield of rice recorded with hand weeding was 67.09and 65.45 q ha^{-1}.Manual weeding is therefore often practiced late as evidenced by yield loss comparisons of the effects of manual weeding at 21-30 DAS with those from the use of early post emergence herbicides (Singh *et al*., 2005a) [58].

Rajkhowa *et al.* (2007) [46] stated that uncontrolled weed growth reduced the grain yield of rice by 60%. The highest grain yield (2.13t ha^{-1}) was registered with pretilachlor0.75kg ha^{-1}+safener. The maximum and minimum yield was obtained in weed free and weedy check respectively (2.43t ha^{-1} and 0.91 t ha^{-1}). Weeds caused 30-32 % loss in grain yield in weedy check (48q ha^{-1}) as compared to weed free treatment (70q ha^{-1}) (Ramana *et al.*, 2007 and Singh *et al.*, 2007) [47].

Mukherjee *et al.*(2008) observed maximum and minimum grain yields (59.3qha^{-1}) in weed free and minimum in un weeded (31.4qha^{-1}) situation respectively. Thein crease in grain yield was 85.5% over un weeded check. Among herbicidal treatments, maximum grain yield (58.3q ha^{-1}) was obtained with almix 15 g ha^{-1}, which was on par with hand weeding thrice (59.3q ha^{-1}). These results are in close conformity with the results reported by Mukherjee and Bhattacharya (1999) and application of almix 4g +butachlor 1.0 kg ha^{-1} and butachlor 1.0 kg ha^{-1} followed by almix 4g ha^{-1} increased grain yield by 36.8 and 33.6% respectively, over the un weeded check (Halder *et al.*,2007) [21].

Jagadeesha *et al.* (2009) reported that the pre-emergence application of sofit at 0.45 kg a.i. ha^{-1} +cono weeder at 30 DAS+ hand weeding at 30 DAS provided a broad spectrum weed control throughout the crop season in drum seeded rice. In resulted of sofit at 0.45 kg a.i/ha+cono weeder at 30 DAS +hand weeding at 30 DAS recorded the highest grain and straw yield (64.70 q/ha and 830 tha^{-1}, respectively) followed by sofit at 0.45 kg a.i. ha^{-1}+ hand weeding at 30 DAS (59.35 qha^{-1} and 8.10 tha^{-1}, respectively). The lowest grain and straw yield was observed with weedy check (21.17 q ha^{-1} and 3.50 tha^{-1}, respectively).

Mohan *et al.*(2010) [37] observed that better weed control and higher grain yield of rice (5334 kg ha^{-1}) was achieved with pre-emergent application of butachlor 1.0 kg a.i. ha^{-1} + safener followed by pretilachlor 0.4 kg a.i. ha^{-1} + safener (5100 kg ha^{-1}). However, the minimum yield (5562 kg ha^{-1}) was recorded with hand weeding twice at 20 and 40 DAS.

Singh and Singh (2010) reported that application of pretilachlor (0.75 kg a.i.ha^{-1} pre-emergence) followed by 2,4-D (0.50 kg a.i.ha^{-1} post-emergence) proved to be most effective in minimizing the density of weeds and their dry weight, and in enhancing the weed control efficiency (84.24%), grain yield (4.73 tha^{-1}), N-P-K uptake by crop, net returns (Rs 26,110) and benefit: cost ratio (1.92).

Choudhury *et al.* (2012) identified and enlisted the important weed flora of different crops in Upland Rice; studied the effect of different weed control measures (e.g. hand weeding, herbicides, mulching etc.) on the yield of crops in sequence and cost effectiveness of different weed control measures. Rice exhibited the maximum yield when treated with two hand weedings, but it may be profitably replaced by the application of herbicides (Rekha *et al*., 2002). Subramanian *et al.* (2006) [64] registered higher grain yield (5744 kg ha^{-1}) with application of pretilachlor with safener + diancha intercropping + azolla dual cropping on 30 DAS in wet seeded rice.Rajkhowa*et.al,* (2007) [46] found that maximum panicle length (19.6cm) wasregistered with pretilachlor 0.75kg ha^{-1} + safener.

Economics

Sanjay *et al* (2006) [53, 54] revealed that drum sowing in combination with herbicide (pretilachlor + safener) application and hand weeding 20 and 40 days after sowing resulted in the lowest weed density (4.19/0.25m^2) and dry matter weight (35.1 kg ha^{-1}), and the highest grain (7061 kg ha^{-1}) and straw yield (9265 kg ha^{-1}), and net income (Rs. 25 208 ha^{-1}).

Subramanyam *et al.* (2007) recorded that highest net returns and benefit: cost ratio were registered with oxadiargyl 75gha^{-1} + hand weedings at 40 DAT (Rs 25479.5 ha^{-1})followed by hand weeding twice at 20 and 40DAT. This might be due to less cost of weeding and higher grain and straw yield in these treatments. According to Upasani *et al.* (2010) among the weed control methods, maximum net return (Rs 9459ha^{-1}) and benefit-cost ratio (1.98) was recorded with application of pretilachlor + safener 0.5 kg ha^{-1} followed by butachlor 1.5 kg ha^{-1}(Rs7479ha^{-1} and 1.64)with one hand weeding at 25 days after sowing, chlorimuron+metsulfuron 4 g/ha(Rs7259ha^{-1} and 1.79) and weed free (Rs 5029ha^{-1} and 1.40) and minimum in weedy check (Rs366ha^{-1} and 1.04) treatment. In most of the cases it has been observed that chemical weed control is economical than other methods (Mukhopadhyay, 1997 and Duary and Mukhopadhyay, 2004) [15]. In wet-seeded rice in Vietnam, Chin *et al*. (2000a) considered that hand weeding twice was the most effective treatment in terms of both controlling weeds and crop safety but noted that the labour cost was high and often prohibitive. Hand weeding treatment, though improved grain and straw yields, yet owing to higher labour cost reduced the net return and benefit: cost ratio (3.6) (Mukherjee *et al.*,2008).

Conclusion

Weeds are the major constraint in DSR production systems. In this article, we discussed several approaches to managing weeds in DSR systems. The use of any singleapproach, however, would not provide season-long and sustainable weed control because of the variation in dormancy and growth habits of weeds (Chauhan 2012b) [9]. There is a need to integrate as many weed management approaches as possible to achieve effective, sustainable, and long-term weed control in DSR. In India, future research in DSR systems should focus on the integration of appropriate management practices with suitable cultivars and appropriate herbicide application timing and combinations. There is also a need to study weed biology and ecology in DSR systems in different rice ecosystems.

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