Weed management in direct seeded rice: A review

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Abstract

Rice (Oryza sativa L.) is one of the staple food crops for more than half of global population and is mostly grown as transplanted crop. Recently, there has been a shift from transplanting to direct-seeding due to scarcity of water and labour. The transition towards direct seeded rice saves water, reduces duration to maturity as well as labour required. But weeds pose a serious threat in direct seeded rice compared to transplanting due to alternate wetting and drying. Thus, the success of direct seeded rice depends on effective weed management. Though manual weeding is the best but due to higher labour requirement, there is a need to use herbicide but the use of herbicides alone does not provide effective and sustainable weed control. Therefore, there is a need to integrate herbicide with alternate weed management approaches or pre-emergence herbicide followed by a post-emergence herbicide for effective weed management in direct seeded rice. In this review, we examine the extent of weed infestation, losses in direct seeded rice and earlier work on different weed management approaches in direct seeded rice.

Keywords: Direct seeded rice, herbicide, hand weeding, integrated weed management

Introduction

Rice (Oryza sativa L.) is one of the leading cereals of the world and two-third of the Asian people receives their daily calories from rice (Rahman and Masood, 2012) [31]. Asia accounted for 60% of the global population, about 92% of the world’s rice production and 90% of global rice consumption (FAO, 2012) [18]. Rice provides 30–75% of the total calories to more than 3 billion Asians (Khush, 2004) [32]. Rice is mostly 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 per cent of the total rice water requirement (Chauhan, 2012) [11]. This triggers the farmers to shift from manual transplanting to direct seeded rice systems. The advantages offered by direct seeded rice are early maturity, easy mechanization, less labour and water requirement. But, weeds are the number one biological constraint and major threat to the production and adoption of direct seeded rice systems and can cause rice yield losses of up to 50 to 91 per cent (Rao et al., 2007) [57].

In direct seeded rice, weeds could be managed by hand weeding (manual means). However, chemical weed management is replacing manual weeding due to meagre labour availability, escalating labour costs and drudgery involved. Sole use of herbicides may lead to the development of resistance in weeds, changes in the weed density and composition. Moreover, a single weed control approach may be unable to keep weeds below the economic threshold level. Therefore, adoption of integrated approach is essential for weed management in direct seeded rice to get targeted yield.

Weed flora associated with direct seeded rice

The extent of damage on crop growth and yield caused by weeds depend on weed species and their densities occurring in a crop community. The type of weed species and their persistence in a locality are highly influenced by crop, season, method of cultivation, date of sowing, climate, edaphic and biotic factors which limit their occurrence, density, range and distribution. Studies on the weed species and their densities competing with rice are more relevant to develop efficient weed control measures.

Direct seeding results in change in the relative abundance of weed species. In particular, Echinochloa spp., Ishaemum rugosum, Fimbristylis miliacea and Cyperus difformis were widely adapted to the conditions of direct seeded rice (Rao et al., 2007) [37]. The major weed floras associated with direct seeded rice were Echinochloa colona, Echinochloa crus-galli, Digitaria sanguinalis, Cyperus iria, Eleusine indica and Eclipta alba etc. (Mahajan and Timsina, 2011) [38].
Weed flora in direct seeded rice comprised of grasses (Echinochloa crusgalli, Echinochloa colona, Eleusine indica, Leptochloa chinensis, Dactyloctenium aegyptium); sedges (Cyperus iria, Cyperus rotundus) and broad leafed weed (Triannaema portulacastrum, Portulaca oleracea, Ipomoea aquatica) (Khalil et al., 2012a) [30]. The most prevalent weed flora found in direct seeded rice were grasses like Echinochloa crusgalli, Echinochloa colonaum, Cyndon dactylon; sedges like Cyperus iria, Cyperus rotundus, Fimbristylis milicacea; and broad-leaved weeds like Caesalia axillaris and Eclipta alba (Singh and Singh, 2010) [65]. The predominant weed flora in dry direct seeded rice were Echinochloa crusgalli, Echinochloa colona, Cyndon dactylon, Cyperus iria, Cyperus rotundus, Fimbristylis dichotoma, Phyllanthus nirui etc. (Bhurer et al., 2013) [7]. In dry direct seeded rice, weed flora such as, sedges namely, Cyperus rotundus and Cyperus compressus; grasses namely, Echinochloa crusgalli, Echinochloa colona, Dactyloctenium aegyptium, Digitaria ciliaris, Eleusine indica, Eragrostis spp. and Acracline racemosa; and broadleaved weed namely, Phyllanthus nirui, Euphorbia hirta, Triannaema portulacastrum and Ammannia baccifera were found to be dominating (Singh et al., 2015) [64]. The major sedges; Fimbristylis milicacea, Cyperus diffimis, Cyperus iria, Schoenoplectus pugens and broad-leaved weed species; Monochoria vaginalis, Ludwigia perennis and Sphenoclea zeylanica were found in direct seeded rice (Raj et al., 2013) [54]. Triannaema portulacastrum, Echinochloa colona, Dactyloctenium aegyptium, Echinochloa crusgalli were the predominant weed flora found in direct seeded rice (Khalil et al., 2012b) [31]. The predominant weed species found in dry seeded rice were Triannaema portulacastrum, Echinochloa colona, Dactyloctenium aegyptium, Eleusine indica, Echinochloa crusgalli, Portulaca oleracea, Ipomea aquatic, Leptochloa chinensis, Cyperus rotundus and Cyperus iria (Khalil and Matloob, 2011) [29]. In direct seeded upland rice, the most dominant monocot weeds were Digitaria ciliaris, Cyperus esculentus and Cyperus rotundus followed by Sporobolus diander, Eleusine indica, Cyndon dactylon, Echinochloa colona and Paspalum scrobiculatum. The most prevalent dicot weeds were Oldelandia corymbosa followed by Ludwigia parviflora, Ageratum conyzoides, Borreria hispida, Celosia argentea, Eclipta alba, Cleome viscosa and Commelina benghalensis (Mishra et al., 2006) [45]. The major weed flora associated with dry-seeded rice in the furrow irrigated raised bed systes were Echinochloa crusgalli, Echinochloa colona, Dactyloctenium aegyptium, Leptochloa panicea, Caesalia axillaris, Euphorbia hirta, Lindernia spp., Commelina benghalensis, Eclipta prostrata, Triannaema portulacastrum and Portulaca oleracea (Singh et al., 2006a) [66]. In direct dry seeded rainy season rice, grasses: Echinochloa colonaum and Cyndon dactylon, sedges: Cyperus iria, Cyperus rotundus and Fimbristylis milicacea; and broad-leaved weeds: Ageratum conyzoides, Ludwigia parviflora, Spilanthus paniculata, Enhydra fluctuans and Eclipta alba were the predominant weed flora in Punjabi, West Bengal (Maiti and Mukharjee, 2008) [41]. Most common weeds in Taraori, Haryana, were Dactyloctenium aegyptium, Echinochloa colona, Echinochloa crusgalli, Leptochloa chinensis, Paspalum distichum, Cyndon dactylon, Ammannia robusta, Digera arvensis, Lindernia spp., Eclipta prostrate, Cyperus diffimis, Cyperus rotundus and in Madhuban, Haryana were Echinochloa colona, Echinochloa crusgalli, Leptochloa chinensis, Paspalum distichum, Ammannia robusta, Digera arvensis, Eclipta prostrate, Euphorbia hirta, Phyllanthus niruri, Triannaema portulacastrum, Cyperus iria and Cyperus rotundus (Singh et al., 2016) [22]. In DSR, types of weed flora prevail depending on the soil seed bank, crop-season and weed control methods etc. In Nagaland, Ladu and Singh (2006) [66] recorded broad-leaved weeds as predominant (60 %) and narrow leaved-weeds (40 %) in direct seeded rice. Whereas, in Pantnagar, Bahar and Singh, (2004) [3] reported narrow leaved weeds were predominant accounting about 73 per cent of total weeds in direct seeded rice. In semi dry direct seeded rice in Guntur, Andhra Pradesh, dominating weed species were; grasses accounting around 50 per cent of the population followed by broad leaved weeds (45 %) and sedges (5 %) (Rao et al., 2008) [58]. With different crop establishment and weed control methods, significant variation occurs in dominance of the abundant weed species (Singh et al., 2005) [70]. The shift from transplanting to direct seeding of rice leads to variation in the dominance of different species of weed flora. In Cuttack, Orissa, among the major weeds at 30 days after transplanting, sedges (Cyperus iria, Fimbristylis milicacea) (47.0%) dominated over broad leaf weeds (Sphenoechloa zeylanica, Ludwigia parviflora and Commelina benghalensis) (36.1%) and grasses (Echinochloa crusgalli) (16.9%) (Saha, 2009) [61]. But, in direct seeded rice in Cuttack, Orissa, broad leaf weeds (Ludwigia parviflora, Sphenoechloa zeylanica, Leptochloa chinensis, Aeschynomene indica, Monochoria vaginalis, Limnophila heterophylla, Cleome viscosa and Melochia corchorifolia) (43.2%) dominated over sedges (Cyperus iria, Fimbristylis milicacea, Scirpus articulates) (32.6%) and grasses (Echinochloa colona, Panicum repens) (24.2%) (Saha, 2005) [59]. In Punjab, weed flora in transplanted rice consisted of broad leaf weeds viz. Caesalia axillaris, Eclipta alba, Sphenoechloa zeylanica; grasses viz. Echinochloa crusgalli, Ischaemum rugosum and sedges viz. Cyperus iria (Ghumar et al., 2008) [19], whereas weed flora in direct seeded rice consisted of sedges such as Cyperus rotundus, Cyperus iria and Cyperus compressus; grasses such as Digitaria sanguinalis, Echinochloa spp., Eleusine aegyptiacum, Leptochloa chinesis and Eragrostis spp. and broadleaves such as Ammania baccifera and Caesalia axillaris (Walia et al., 2012) [77]. The predominant weed species in transplanted rice in West Bengal were Ludwigia parviflora, Cyanotis axillaris, Commelina diffusa and Spilanthes acmella (Hossain and Mondal, 2014) [22] and in direct seeded rice, Digitaria sanguinalis, Cyperus iria and Ludwigia parviflora were the predominant weed species at initial stage and Spilanthes acmella at the later stage of crop growth (Duany et al., 2005) [17]. The most dominant weed flora in direct seeded autumn rice comprised of Cyndon dactylon and Digitaria ciliaris among grasses; Cyperus iria among sedges and Ageratum houstonianum and Borressia articulus among the broad leaved species whereas in case of transplanted winter rice, the dominant weed flora were Leersia hexandra, Echinochloa crusgalli and Panicum repens among grasses; Scirpus juncoideus, among sedges and Monochoria vaginalis and Ludwigia linifolia among broad-leaved weeds (Deka et al., 2016) [16].

Critical period of crop-weed competition

There exists a critical period in the crop growth period during which the crop is very sensitive to weed competition. This is the period when weed control is necessary to avoid significant yield loss. The duration of critical period of weed competition depends on the nature of crop, its competing ability, variety and growing conditions. Thus, to develop effective and
Economical weed control measures in upland rice, establishing the critical period of competition is essential. Weed free for the first 30 days after sowing (DAS) in direct seeded rice yields similar to that of weed free period upon harvest (Lalu and Singh, 2006) [36]. By the effective control of weeds at initial stages of rice growth i.e. 0 to 40 DAS, the productivity of direct seeded rice could be improved (Maity and Mukherjee, 2008) [41]. According to Singh et al. (2008) [68], the critical period of crop-weed competition for direct seeded rice is 15 to 45 DAS, whereas, the period within 20 to 50 DAS is critical for crop-weed competition by Khaliq and Matloob (2011) [29].

Extent of yield loss
Any yield loss depends on several factors like infestation of any pest, its ecosystem, growing season, cultivar, management practices and other biotic and abiotic factors. Among all, in direct seeded rice, the weeds adversely affect yield and quality as well as increase cost of production due to the competition for different growth factors. Depending on cultural methods, rice cultivars, weed species associated, their densities and duration of competition, the extent of rice yield loss varies from 10 per cent to complete failure of the crop (Singh and Singh, 2008) [63].

Globally, rice yield losses due to pests have been estimated to be 40 per cent, of which weeds caused the highest loss of 32 per cent, as reported by Rao et al. (2007) [57]. Average rice yield losses from weeds were 35 per cent as recorded by Oerke and Dehne, (2004) [50], whereas, Hasanuzzaman et al. (2009) [21] recorded an average rice yield losses range from 15-20 per cent but in severe cases the yield loss may exceed up to 50 per cent depending on species and intensity of weeds. In Bangladesh, due to weeds the rice yield losses were estimated to be 70-80 per cent in Aus rice (early summer), 30-40 per cent in transplanted Aman rice (late summer) and 22-36 per cent in Boro rice (winter rice) (BRRI, 2006) [8]. In Nepal, yield loss is direct seeded rice due to weeds accounts for as high as 93 per cent, while in Pakistan it is more than 80 per cent (Khalil and Matloob, 2011) [29] and is more than 70 per cent in Philippines (Chauhan and Opena, 2012) [12]. The weed competition with rice in Malaysia causes a 10-35 per cent reduction in rice yield (Karim et al., 2004) [24].

Generally, yield loss under direct seeded rice is more than transplanted rice. Ramzan (2003) [56] reported that in transplanted, direct-seeded in flooded conditions and direct-seeded in dry soils, the yield reductions were up to 48, 53 and 74 per cent respectively, due to weeds. Singh et al. (2011) [74] reported that rice yield losses due to weed were least in transplanted rice amounting 12 per cent but otherwise as large as 85 per cent for rice sown in dry cultivated fields or to puddled soil and rising to 98 per cent in dry seeded rice sown without soil tillage. Naresh et al. (2011) [47] reported that the complex weed flora caused yield losses of 65-92 per cent in direct seeded rice. Loss of rice grain yield due to weed competition ranged from 38-92 per cent in aerobic direct seeded rice (Singh et al., 2008) [68]. Chouhey et al. (2001) [13] reported 40-100 per cent yield reduction in direct seeded upland rice due to weeds. The complex weed flora causes grain yield loss of 65-92 per cent in direct seeded rice (Singh et al., 2009) [67].

Throughout the growing season, weeds compete for nutrients, light, space and moisture in direct seeded rice. Unless kept weed-free during a part of its growing period, the crop is likely to experience yield reduction (Nogargade et al., 2018) [49]. Weeds and rice emerge simultaneously, and compete with each other for light, nutrients and moisture resulting in reduction of grain yield up to 80 per cent in dry seeded rice ecosystems (Pasha et al., 2011) [51]. An estimate shows that weeds can deprive the crops from nutrient uptake by 47, 42, 50, 39 and 24 per cent of N, P, K, Ca and Mg, respectively (Balasubramanian and Palaniappan, 2001) [4].

Effect of different weed management practices on weed dynamics, growth and yield of direct seeded rice
Application of pretilachlor 0.75 kg ha⁻¹, pendimethalin 0.75 kg ha⁻¹ and thiobencarb 1.5 kg ha⁻¹ significantly reduced the total weed infestation resulting in higher weed control efficiency and higher rice yield attributes which ultimately resulted in higher grain yield as compared to weedy check (Payman and Singh, 2008) [52]. Application of pretilachlor 0.5 kg ha⁻¹ resulted in weed dry matter of 459.9 and 408.2 g m⁻² and grain yield of 0.95 and 0.74 t ha⁻¹ in 2008 and 2009, respectively (Singh et al., 2012) [73]. Saha (2006) [60] reported that pretilachlor + safener (750 g ha⁻¹) applied 7 DAS in wet direct sown rice provided weed control efficiency of 91.4 per cent. Kundu et al. (2017) [35] revealed that pretilachlor 30.7 % EC 1200 g a.i. ha⁻¹ came out as the best one being with respect to population of weeds, weed dry weight, weed control efficiency, yield parameters and rice yield are concerned, but pretilachlor 30.7 % EC 600 g a.i. ha⁻¹ was found to be cost effective among all the treatments with significant increase in grain yield. Raj et al. (2013) [54] reported that carfentrazone-ethyl 40 DF 20 g ha⁻¹ resulted in higher weed control efficiency of 90.7 per cent and weed index of 9.5 per cent with grain yield (3.68 t ha⁻¹). It was comparable with 2,4-D Na salt 800 g ha⁻¹ with grain yield of 3.65 t ha⁻¹ and weed control efficiency of 96.7 per cent and weed index of 10.5 per cent. Penoxsulam @ 15 g a.i. ha⁻¹ was more effective than pendimethalin at 825 g a.i. ha⁻¹, for weed control causing substantial increase in grain yield (Jarban et al., 2012) [24].

Among different herbicides, Nominee 100SC (bispyribac sodium) and Sunstar Gold 60WG (Ethoxy sulfuron) proved to be the best with 90.5 and 87.19 per cent weed control efficacy, respectively and higher paddy yield. Though, the significantly better results were reported in hand weeding but as it is more time consuming and laborious hence cannot be recommended at large scale (Hussain et al., 2008) [23].

Nasseruddin and Subramanyam (2013) [48] reported that in wet drum seeded rice, pre-emergence application of pretilachlor @ 500 g ha⁻¹ followed by bispyribac @ 30 g ha⁻¹ recorded higher weed control efficiency (90.1%), grain yield (5.1 t ha⁻¹) and B:C (3:01) compared to single application of pretilachlor @ 500 g ha⁻¹ and weedy check where the weed control efficiency, 75.02 and 0 per cent; grain yield, 3.81 and 2.82 t ha⁻¹, and B:C, 3.01 and 1.91, respectively. Sequential, application of pendimethalin (pre-emergence) and bispyribac (post-emergence) recorded the lowest weed biomass and 100 per cent weed control efficiency. Two hand weedicings resulted in the maximum grain yield, which was at par with follow-up application of bispyribac after pendimethalin, butachlor, thiobencarb and oxadiargyl (Kaur and Singh, 2015) [28].

Among different herbicide treatments, pre-emergence application of bensulfuron methyl @ 60 g + pretilachlor @ 600 g a.i ha⁻¹ recorded significantly higher weed control efficiency, growth, yield attributes, grain and straw yield followed by two hand weedicings at 20 and 40 DAS which was at par with oxyfluorfen @ 90 g a.i. ha⁻¹ (pre-emergence) + 2, 4-DEE @ 500 g a.i. ha⁻¹ (post emergence) at 25 DAS (Madhukumar et al., 2013) [38].
The control of *Echinochloa crusgalli* and *Echinochloa colona* was improved by 43-69 per cent by the tank mixture of fenoxaprop with ethoxysulfuron as compared to fenoxaprop alone. However, an antagonistic effect was recorded by the tank-mix of azimsulfuron with fenoxaprop and reduced the control of *Leptochloa chinensis* by 86 per cent as compared to fenoxaprop alone. Again, mixture of azimsulfuron or ethoxysulfuron and bispyribac did not improve the control of grass weeds as compared to bispyribac alone (Bhullar et al., 2016) [6]. Application of OrizoPlus® (a mixture of propanil at 360 g l-1 + 2.4-D at 200 g l-1) @ 1.8+1.2 kg a.i. ha-1 resulted higher weed control efficiency, longer panicle, more number of spikelets per panicle, more number of grains per panicle than the other rates (0.6+0.4 and 1.2+0.8 kg a.i. ha-1) (Danmaigoro et al., 2016) [15]. Integration of post-emergence application (30 DAS) of bispyribac (25 and 30 g ha-1) or azimsulfuron (20 g ha-1) with pre-emergence application of pendimethalin 0.75 kg ha-1, pretilachlor 0.5 kg ha-1 and thioben carb 1.25 kg ha-1 provided effective control of weeds and produced significantly higher grain yields (Walia et al., 2012) [77].

In wet direct seeded rice, hand weeding resulted in higher plant population, panicles per m² and paddy yield of 3.42 and 4.11 t ha-1, respectively in 2002 and 2003 (Baloch et al., 2006) [9]. In direct seeded upland rice, the highest yield attributing characters, i.e., effective tillers per m², number of grains per panicle and test weight was obtained by hand weedicings and hence resulted in significantly highest yield (3.49 t ha-1) (Dadsena et al., 2014) [14]. Chander and Pandey (2001) [9] observed that hand-weeding significantly decreased weed dry matter accumulation and increased the grain as well as straw yield compared with herbicides and weedy check. According to Lakshmi et al. (2006) [37], hand weedicings twice at 20 and 40 DAS recorded higher crop growth parameters, yield attributing characters, grain yield (5444 kg ha-1) and straw yield (5759 kg ha-1) in dry sown rice. Chaudhary et al. (2018) [10] reported that two hand weedicings at 28 and 40 DAS in dry direct seeded rice resulted in higher effective tillers per m², panicle length, panicle weight, grains per panicle, thousand grain weight and grain yield. Saqib and Ali (2015) [62] revealed that four hand weedicings at 15, 25, 35 and 45 DAS in direct seeded rice recorded higher yield attributes and grain yield. Hand weeding at 25 and 50 DAS in direct dry seeded rainfed rice recorded lower weed dry weight and higher grain yield (Singh et al., 2006b) [71]. Kikon et al. (2018) [54] reported that two hand weedicings at 20 and 40 DAS was found to record significantly higher weed control efficiency with lower weed population and dry matter resulting in better crop growth and superior yield attributes and ultimately recorded the highest grain yield of 34.21 and 35.71 q ha-1 during 2009 and 2010, respectively. Kikon and Gohain (2016) [33] revealed that hand weedicings at 20 and 40 DAS in direct seeded rice effectively minimized weed population and dry weight and recorded the highest weed control efficiency (92.57 % during 2009 and 94.64 % during 2010) as well as grain yield (3.42 t ha-1 in 2009 and 3.57 t ha-1 in 2010). The highest gross return ha-1 and net return ha-1 and also the highest B: C (2.26 in 2009 and 2.38 in 2010) was observed in the same treatment. Akbar et al. (2011) [11] reported that hand pulling resulted higher weed suppression and rice yield than the mechanical hoeing. Both hand pulling and mechanical hoeing were better than herbicides in suppression of weed and increasing yield and the order of performance of herbicides in suppressing the weeds and increasing rice yield was pretilachlor followed by butachlor and pendimethalin. Kachroo and Bazaya (2011) [26] reported that in direct wet seeded rice sown through drum seeder, pretilachlor @ 0.5 kg ha-1 at 6 DAS recorded lower weed dry weight (73.80 g m-2) and higher grain yield (46.0 q ha-1) whereas hand weedicings at 20 and 40 DAS recorded weed dry weight (56.15 g m-2) and grain yield (46.5 q ha-1). Two hand weedicings at 20 and 45 DAS was found effective in controlling weeds and recorded lower weed population and dry weight, higher growth and yield attributing characters and yield among various treatments. It was on par with herbicide treatment pyrazosulfuron ethyl @ 30 g a.i. ha-1 (Gowda et al., 2009) [20].

The significance of herbicides in direct seeded rice is overwhelming, as weeds and rice emerge at the same time in direct seeded rice, necessitating early weed control. Mimicking grassy weeds (e.g., *Echinochloa spp.*) with rice seedlings which are too small to be pulled out, impede manual weeding, leaving chemical weed control as the only viable option. But weed control programme focusing entirely on herbicides is no longer economically feasible, ecologically sound and effective against diverse weed flora, and may result in the evolution of herbicide-resistant weed biotypes (Matloob et al., 2015) [44]. Manual weeding is not only labour-intensive but their timely availability is also a problem. No single method of weed control would be sufficient to provide effective and season-long weed control due to the diversity of weed problems in different rice cultures. So, there must be integration of herbicides with some other weed control methods to achieve effective, sustainable and long-term weed control in direct seeded rice.

The yield attributes, viz. productive tillers per m², number of filled grains per panicle and 1000 grain weight were highest in treatment involving integration of application of pretilachlor + hand weedicings at 30 and 45 DAS (Raju et al., 2003) [15]. Saha (2005) [59] reported that in direct sown rainfed rice, application of pretilachlor @ 750 g ha-1 alone recorded lower weed dry matter (75.7 g m-2) and higher grain yield (4.48 t ha-1), however the herbicide supplemented with one hand weeding at 50 DAS reduced weed dry matter to 46.8 g m-2 and increased grain yield to 4.76 t ha-1. But the most effective method was found to be three hand weeding at 20, 40 and 60 DAS as it recorded the lowest weed density (8.9 g m-2) and the highest grain yield (5.25 t ha-1). Mishra and Singh (2007) [46] reported that application of pretilachlor at 750 g ha-1 + one hand weeding at 30 DAS was at par with hand weeding twice. P Pretilachlor @ 0.45 kg a.i. ha-1 + one hand weeding at 30 to 35 DAS registered higher weed control efficiency (Arunvenkatesh and Velayatham, 2010). Jannu et al., (2017) [25] revealed that early post-emergence application of cyhalofop-buty + (chlorimuron-ethyl+ mestulfuron-methyl) @ 90+20 g ha-1 applied at 20-30 DAS resulted in lower weed density and weed dry matter production, thus higher weed control efficiency (82.13%). The same treatment recorded higher grain yield (3820 kg ha-1) and found at par with two hand weedicings treatment (at 20 and 40 DAS). The highest B: C of 2.44 was found with cyhalofop-buty + (chlorimuron-ethyl+ mestulfuron-methyl). In wet seeded rice, hand weeding twice and pretilachlor with safener at 400 g ha-1 followed by one hand weeding recorded higher weed control efficiency at later stage of the crop (Subramanian and Martin, 2006) [75]. Least weed population, dry matter and good weed control efficiency, significantly higher plant height, tillers per m row length, leaf area index (LAI), crop growth rate (CGR), net assimilation rate (NAR) and dry matter accumulation of plant, yield attributes *i.e.* panicles per m² and fertile grains per...
panicle and yield were obtained in weed free environment closely followed by IWM, i.e., pre-emergence application of butachlor 1.5 kg ha\(^{-1}\) followed by one hand weeding (Mandal et al., 2011) (43). Application of either ethoxysulfuron (18 g a.i. ha\(^{-1}\)) at 35 DAS + one hand weeding at 45 DAS or pendimethalin (750 g a.i. ha\(^{-1}\)) (pre-emergence) + one hand weeding at 45 DAS provided effective control of weeds and higher grain yield of dry seeded rice (Mann et al., 2007) (43). Pre-emergence application of bensulforuron methyl + pretilachlor @ (0.06 + 0.60 kg a.i ha\(^{-1}\)) + one inter cultivation at 40 DAS recorded significantly lower weed population and dry weight; higher grain yield and straw yield (4425 kg ha\(^{-1}\) and 5020 kg ha\(^{-1}\), respectively) along with higher net returns and B:C (Sunil et al., 2010) (76). Pendimethalin (1000 g a.i. ha\(^{-1}\)) and pretilachlor with safener (500 g a.i. ha\(^{-1}\)) as pre-emergence applications followed by hand weeding are equally effective in controlling weeds and increasing the rice grain yield of dry-seeded rice, resulting in higher net returns (Singh et al., 2007) (40).

Among the integrated weed management practices, butachlor 1.5 kg ha\(^{-1}\) as pre-plant surface application followed by practices of brown manuring and post-emergence application of 2,4-D 0.50 kg ha\(^{-1}\) at 40 DAS recorded the highest grain yield, net returns and benefit : cost during two years of investigation. The grain yield was statistically at par with the grain yield obtained from season long weed free condition (Maity and Mukherjee, 2011) (41).

Conclusion

The land area under direct seeded rice system is expected to increase in the future because of labour and water crisis. Weeds are the major constraints to direct seeded rice system and its management is of prime importance to reduce severe losses in terms of yield and economic return. It can be inferred that no single herbicide can provide an effective weed management in direct seeded rice. Judicious integration of more than one method can keep weed under control and lead to higher productivity in direct seeded rice. Hence, integrated use of herbicide with manual or mechanical weed control should be given emphasis to get targeted yield in direct seeded rice.

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