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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) [53]. 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) [57]. The major weed floras associated with direct seeded rice were *Echinochloa colona*, *Echinochloa crussgali*, *Digitaria sanguinalis*, *Cyperus iria*, *Eleusine indica* and *Eclipta alba etc*. (Mahajan and Timsina, 2011) [39].

Weed flora in direct seeded rice comprised of grasses (*Echinochloa crusgalli*, *Echinochloa colona*, *Eluesine indica*, *Leptochloa chinensis*, *Dactyloctenium aegyptium*); sedges (*Cyperus iria*, *Cyperus rotundus*) and broad leaved weed (*Trianthema portulacastrum*, *Portulaca oleracea*, *Ipomoea aquatic*) (Khaliq *et al*., 2012a) [30]. The most prevalent weed flora found in direct seeded rice were grasses like *Echinochloa crusgalli*, *Echinochloa colonum*, *Cynodon dactylon*; sedges like *Cyperus iria*, *Cyperus rotundus*, *Fimbristylis miliacea*; and broad-leaved weeds like *Caesulia axillaris* and *Eclipta alba* (Singh and Singh, 2010) [65]. The predominant weed flora in dry direct seeded rice were *Echinochloa crusgalli*, *Echinochloa colona*, *Cynodon 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*, *Eragrostris spp*. and *Acrachne racemosa*; and broadleaved weed namely, *Phyllanthus niruri*, *Euphorbia hirta*, *Trianthema portulacastrum* and *Ammannia baccifera* were found to be dominating (Singh *et al*., 2015) [64]. The major sedges; *Fimbristylis miliacea*, *Cyperus difformis*, *Cyperus iria*, *Schenoplectus pungens* and broad-leaved weed species; *Monochoria vaginalis*, *Ludwigia perennis* and *Sphenoclea zeylanica* were found in direct seeded rice (Raj *et al*., 2013) [54]. *Trianthema portulacastrum*, *Echinochloa colona*, *Dactyloctenium aegyptium*, *Echinochloa crusgalli* were the predominant weed flora found in direct seeded rice (Khaliq *et al*., 2012b) [31]. The predominant weed species found in dry seeded rice were *Trianthema portulacastrum*, *Echinochloa colona*, *Dactyloctenium aegyptium*, *Eleusine indica*, *Echinochloa crussgalli*, *Portulaca oleraceae*, *Ipomea aquatic*, *Leptochloa chinensis*, *Cyperus rotundus* and *Cyperus iria* (Khaliq 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*, *Cynodon dactylon*, *Echinochloa colona* and *Paspalum scrobiculatum*. The most prevalent dicot weeds were *Oldenlandia 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 sytsem were *Echinochloa crusgalli*, *Echinochloa colona*, *Dactyloctenium aegyptium*, *Leptochloa panicea*, *Caesulia axillaris*, *Euphorbia hirta*, *Lindernia spp*., *Commelina benghalensis*, *Eclipta prostrata*, *Trianthema portulacastrum* and *Portulaca oleracea* (Singh *et al*., 2006a) [66]. In direct dry seeded rainy season rice, grasses: *Echinochloa colonum* and *Cynodon dactylon*, sedges: *Cyperus iria*, *Cyperus rotundus* and *Fimbristylis milliacea*; and broad-leaved weeds: *Ageratum conyzoides*, *Ludwigia parviflora*, *Spilunthes paniculata*, *Enhydra fluctuans* and *Eclipta alba* were the predominant weed flora in Pundibari, West Bengal (Maity and Mukharjee, 2008) [41]. Most common weeds in Taraori, Haryana, were *Dactyloctenium aegyptium*, *Echinochloa colona*, *Echinochloa crusgalli*, *Leptochloa chinensis*, *Paspalum distichum*, *Cynodon dactylon*, *Ammannia robusta*, *Digera arvensis*, *Lindernia* spp., *Eclipta prostrate*, *Cyperus difformis*, *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*, *Trianthema portulacastrum*, *Cyperus iria* and *Cyperus rotundus* (Singh *et al*., 2016) [72].

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) [36] 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 pre-dominant 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 miliacea*) (47.0%) dominated over broad leaf weeds (*Sphenochlea 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*, *Sphenochlea zeylanica*, *Leptochloa chinensis*, *Aeschynomene indica*, *Monochoria vaginalis*, *Limnophila heterophylla*, *Cleome viscosa* and *Melochia corchrifolia*) (43.2%) dominated over sedges (*Cyperus iria*, *Fimbristylis miliacea*, *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. Caesulia axillaris*, *Eclipta alba*, *Sphenochlea zeylanica;* grasses *viz. Echinochloa crusgalli*, *Ischaemum rugosum* and sedges *viz*. *Cyperus iria* (Ghuman *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 *Caesulia 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 (Duary *et al*., 2005) [17]. The most dominant weed flora in direct seeded autumn rice comprised of *Cynodon dactylon* and *Digitaria ciliaris* among grasses; *Cyperus iria* among sedges and *Ageratum houstonianum* and *Borreria articularis* amongst the broad leaved species whereas in case of transplanted winter rice, the dominant weed flora were *Leersia hexandra*, *Echinochloa crussgalli* and *Panicum repens* among grasses; *Scirpus juncoides*, 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 yielded similar to that of weed free period upto harvest (Ladu 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 upto 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 (Khaliq 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) [27].

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]. Choubey *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 upto 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 weedings 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 weedings 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 thiobencarb 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 m^2 and paddy yield of 3.42 and 4.11 t ha^{-1}, respectively in 2002 and 2003 (Baloch *et al*., 2006) [5]. In direct seeded upland rice, the highest yield attributing characters, *i.e*., effective tillers per m^2, number of grains per panicle and test weight was obtained by hand weedings 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 weedings 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 weedings at 28 and 40 DAS in dry direct seeded rice resulted in higher effective tillers per m^2, panicle length, panicle weight, grains per panicle, thousand grain weight and grain yield. Saqib and Ali (2015) [62] revealed that four hand weedings 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) [34] reported that two hand weedings 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 weedings 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) [1] 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 weedings at 20 and 40 DAS recorded weed dry weight (56.15 g m^{-2}) and grain yield (46.5 q ha^{-1}). Two hand weedings 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 m^2, number of filled grains per panicle and 1000 grain weight were highest in treatment involving integration of application of pretilachlor + hand weedings at 30 and 45 DAS (Raju *et al*., 2003) [55]. 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. 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 weedings 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 m^2 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) [42]. 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 bensulfuron 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) [69].

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.

References

1. Akbar N, Jabran K, Ali MA. Weed management improves yield and quality of direct seeded rice. Australian Journal of Crop Science 2011;5(6):688-694.
2. Arunvenkatesh S, Velayatham A. Evaluation of metamifop 10 EC for weed control efficacy and productivity of direct seeded rice. In: National conference on challenges in weed management in agro-ecosystems, present status and future strategies. TNAU, Coimbatore 2010,125p.
3. Bahar FA, Singh G. Effect of herbicides on dry seeded rice (*Oryza sativa* L.) and associated weeds. Indian journal of weed science 2004;36(3&4):269-270.
4. Balasubramanian P, Palaniappan SP. Principles and practices of Agronomy. Agrobios Publishing Co. Pvt. Ltd, New Delhi 2001,306-364p.
5. Baloch MS, Awan IU, Hassan G, Khakwani AA. Effect of establishment methods and weed management practices on some growth attributes of rice. Rice Science 2006;13(2):131-140.
6. Bhullar MS, Kumar S, Kaur S, Kaur T, Singh J, Yadav R, Chauhan BS, Gill G. Management of complex weed flora in dry-seeded rice. Crop Protection 2016;83:20-26.
7. Bhurer KP, Yadav DN, Ladha JK, Thapa RB, Pandey K. Effect of integrated weed management practices on performance of dry direct seeded rice (*Oryza sativa* L.). Agronomy Journal of Nepal 2013;3:53-63.
8. BRRI (Bangladesh Rice Research Institute). Bangladesh Rice Knowledge Bank. Bangladesh Rice Research Institute. http://riceknowledgebank.brri.org 2006.
9. Chander S, Pandey J. Effect of rice (*Oryza sativa*) culture, nitrogen and weed control on nitrogen competition between scented rice and weeds. Indian Journal of Agronomy 2001;46(1):68-74.
10. Chaudhary SK, Marahatta S, Chaudhary M. Performance of dry direct seeded rice and weeds on *Sesbania* brown manuring as compared to farmers' practice and chemical control method. International Journal of Applied Sciences and Biotechnology 2018;6(3):265-269.
11. Chauhan BS. Weed management in direct seeded rice systems. International Rice Research Institute. Los Baños (Philippines), 2012,20p.
12. Chauhan BS, Opena J. Effect of tillage systems and herbicides on weed emergence, weed growth, and grain yield in dry-seeded rice systems. Field Crops Research 2012;137:56-69.
13. Choubey NK, Kobe SS, Tripathi RS. Relative performance of cyhalofop butyl for weed control in direct seeded rice. Indian Journal of Weed Science 2001;33(3&4):132-135.
14. Dadsena T, Talla A, Mishra M. Effect of weed management practices on weed parameters, yield and nutrient uptake of direct seeded upland rice. Annals of Plant and Soil Research 2014;16(4):294-299.
15. Danmaigoro O, Ishaya DB, Adekpe DI. Post emergence herbicide efficiency and yield attributes of upland rice (*Oryza. sativa* L.) as influenced by weed control treatments, poultry manure and stand density. Nigerian Journal of Agriculture, Food and Environment 2016;12(3):37-42.
16. Deka J, Kakati P, Barua IC. Weed dynamics in direct seeded autumn rice–transplanted winter rice sequence. International Journal of Science, Environment and Technology 2016;5(6):4179-4185.
17. Duary B, Hossain A, Mondal DC. Integrated weed management in direct seeded dry sown rice in lateritic belt of West Bengal. Indian Journal of Weed Science 2005;37(1&2):101-102.
18. FAO. Rice and Us. (Food and Agriculture Organization of the United Nations) 2012, http://www. fao.org/rice2012/en/aboutrice. htm.
19. Ghuman RS, Brar LS, Walia US. Role of variety and plant geometry on weed management in transplanted rice (*Oryza sativa* L.). Indian Journal of Weed Science 2008;40(3&4):137-141.
20. Gowda PT, Shankaraiah C, Jnanesh AC, Govindappa M, Murthy KNK. Studies on chemical weed control in aerobic rice (*Oryza sativa* L.). Journal of Crop and Weed 2009;5(1):321-324.
21. Hasanuzzaman M, Ali MH, Alam MM, Akther M, Alam KF. Evaluation of pre-emergence herbicide and hand weeding on the weed control efficiency and performance of transplanted Aus rice. American-Eurasian Journal of Agronomy 2009;2(3):138-143.

22. Hossain A, Mondal DC. Weed management by herbicide combinations in transplanted rice. Indian Journal of Weed Science 2014;46(3):220-223.
23. Hussain S, Ramzan M, Akhter M, Aslam M. Weed management in direct seeded rice. Journal of Animal and Plant Sciences 2008;18(2&3):86-88.
24. Jabran K, Farooq M, Hussain M, Khan MB, Shahid M, Lee DJ. Efficient weeds control with penoxsulam application ensures higher productivity and economic returns of direct seeded rice. International Journal of Agriculture and Biology 2012;14:901–907.
25. Jannu N, Raju MS, Devi KBS. Effect of different herbicides on weed growth and grain yield of direct seeded rice under rainfed condition. International Journal of Pure and Applied Bioscience 2017;5(4)**:**1122-1126.
26. Kachroo D, Bazaya BR. Efficacy of different herbicides on growth and yield of direct wet seeded rice sown through drum seeder. Indian Journal of Weed Science 2011;43(1&2):67-69.
27. Karim RS, Man AB, Sahid IB. Weed problems and their management in rice fields of Malaysia: an overview. Weed Biology and Management 2004;4(4):177-186.
28. Kaur S, Singh S. Bio-efficacy of different herbicides for weed control in direct-seeded rice. Indian Journal of Weed Science 2015;47(2):106-109.
29. Khaliq A, Matloob A. Weed-crop competition period in three fine rice cultivars under direct-seeded rice culture. Pakistan Journal of Weed Science Research 2011;17(3):229-243.
30. Khaliq A, Matloob A, Ahmad N, Rasul F, Awan IU. Post emergence chemical weed control in direct seeded fine rice. Journal of Animal and Plant Sciences 2012a;22(4):1101-1106.
31. Khaliq A, Matloob A, Riaz Y. Bio-economic and qualitative impact of reduced herbicide use in direct seeded fine rice through multipurpose tree water extracts. Chilean Journal of Agricultural Research 2012b;72(3):350-357.
32. Khush GS. Harnessing science and technology for sustainable rice-based production systems. Proceedings of FAO Rice Conference “Rice is life”. Int. Rice Comm. Newslett 2004;53:17-23.
33. Kikon N, Gohain T. Growth and yield response of direct-seeded rice (*Oryza sativa* L.) cultivars under different sowing methods and weed management methods. International Journal of Agriculture Sciences 2016;8(8):1083-1086.
34. Kikon N, Gohain T, Ezung K, Angami T. Crop and weed growth in direct-seeded rice cultivars as affected by different weed management practices under rainfed conditions of Nagaland, India. International Journal of Current Microbiology and Applied Sciences 2018;7(2):590-601.
35. Kundu CK, Biswas U, Kundu A, Bera PS, Sathish G. Studies on bio-efficacy and phytotoxicity of pretilachlor 30.7% EC in direct seeded rice. International Journal of Chemical Studies 2017;5(5):1847-1850.
36. Ladu M, Singh MK. Crop-weed competition in upland direct seeded rice under foot hill conditions of Nagaland. Indian Journal of Weed Science 2006;38:131-132.
37. Lakshmi NV, Rao YH, Chandrasekhar K. Effect of weed management practices on growth and yield of dry sown rice. The Andhra Agricultural Journal 2006;53:8-9.
38. Madhukumar V, Kalyana Murthy KN, Prashanth R, Basavaraj K, Dinesha MS. Relative efficacy of different herbicides for weed control in aerobic rice (*Oryza sativa* L.). International Journal of Science Nature 2013;4(3):473-477.
39. Mahajan G, Timsina J. Effect of nitrogen rates and weed control methods on weeds abundance and yield of direct-seeded rice. Archives of Agronomy and Soil Science 2011;57(3):239-250.
40. Maity SK, Mukherjee PK. Effect of brown manuring on grain yield and nutrient use efficiency in dry direct seeded kharif rice (*Oryza sativa* L.). Indian Journal of Weed Science 2011;42(1&2):61-66.
41. Maity SM, Mukherjee PK. Integrated weed management in dry direct seeded rainy season rice (*Oryza sativa* L.). Indian Journal of Agronomy 2008;53(2):116-120.
42. Mandal D, Singh D, Kumar R, Kumari A, Kumar V. Effects on production potential and economics of direct seeded rice sowing dates and weed management techniques. Indian Journal of Weed Science 2011;43(3&4):139-144.
43. Mann RA, Ahmad S, Hassan G, Baloch MS. Weed management in direct seeded rice crop. Pakistan Journal of Weed Science Research 2007;13(3&4):219-226.
44. Matloob A, Khaliq A, Chauhan BS. Weeds of direct-seeded rice in Asia: problems and opportunities. In Advances in Agronomy 2015;130:291-336.
45. Mishra GC, Rath AK, Rath BS, Sahoo J, Mohapatra PK. Weed management in direct seeded rice under rain fed upland eco-system. Journal of Crop and Weed 2006;2(2):52-57.
46. Mishra JS, Singh VP. Integrated weed management in zero-till direct-seeded rice (*Oryza sativa*)-wheat (*Triticum aestivum*) cropping system. Indian Journal of Agronomy 2007;52(3):198-203.
47. Naresh RK, Gupta RK, Singh RV, Devi S, Singh B, Satya P et al. Promotion of integrated weed management for direct-seeded rice in North West India. Progressive Agriculture 2011;11(2):215-232.
48. Naseeruddin R, Subramanyam D. Performance of low dose high efficacy herbicides in drum seeded rice. Indian Journal of Weed Science 2013;45(4):285-288.
49. Nogargade M, Singh MK, Tyagi V. Ecologically sustainable integrated weed management in dry and irrigated direct-seeded rice. Advances in Plants & Agriculture Research 2018;8(4):319-331.
50. Oerke EC, Dehne HW. Safeguarding production-losses in major crops and the role of crop protection. Crop Protection 2004;23(4):275-285.
51. Pasha LM, Reddy MD, Reddy MG, Devi MU. Effect of irrigation schedule, weed management and nitrogen levels on weed growth in rice (*Oryza sativa*) under aerobic conditions. Indian Journal of Weed Science 2011;43(1&2):54-60.
52. Payman G, Singh S. Effect of seed rate, spacing and herbicide use on weed management in direct seeded upland rice (*Oryza sativa* L.). Indian Journal of Weed Science 2008;40(1):11-15.
53. Rahman MM, Masood M. Aerobic System: A potential water saving boro rice production technology. Adaptation of aerobic system for boro rice cultivation in farmer’s field for saving irrigation water and attaining food security-Project 2012,1-2p.
54. Raj SK, Jose N, Mathew R, Leenakumary S. Chemical management of non-grassy weeds in direct-seeded rice. Indian Journal of Weed Science 2013;45(3):159-162.

55. Raju M, Pandian BJ, Thukkaiyannan P, Thavaprakash N. Effect of weed management practices on the yield attributes and yield of wet-seeded rice. Acta Agronomica Hungarica 2003;51(4):461-464.
56. Ramzan M. Evaluation of various planting methods in rice–wheat cropping system, Punjab, Pakistan. Rice Crop Report 2003,4-5p.
57. Rao AN, Johnson DE, Sivaprasad B, Ladha JK, Mortimer AM. Weed management in direct seeded rice. Advance Agronomy 2007;93:153-255.
58. Rao AS, Ratnam M, Reddy TY. Weed management in direct seeded semi dry rice. Indian Journal of Weed Science 2008;40(3&4):153-156.
59. Saha S. Evaluation of some new herbicide formulations alone or in combination with hand weeding in direct sown rainfed lowland rice. Indian Journal of Weed Science 2005;37(1&2):103-104.
60. Saha S. Efficacy of herbicides in wet direct-sown summer rice. Indian Journal of Weed Science 2006;38(1&2):45-48.
61. Saha S. Efficacy of bensulfuron-methyl for controlling sedges and non-grassy weeds in transplanted rice (*Oryza sativa*). Indian Journal of Agricultural Sciences 2009;79(4):313-316.
62. Saqib M, Ali S. The influence of weed management on the growth and yield of direct seeded dry-rice (*Oryza sativa* L.). Planta Daninha 2015;33:1-8.
63. Singh G, Singh Y. Integrated weed management in direct-seeded rice. Direct seeding of rice and weed management in the irrigated rice-wheat cropping system of the Indo-Gangetic Plains 2008,161-176p.
64. Singh M, Bhullar MS, Chauhan BS. Influence of tillage, cover cropping, and herbicides on weeds and productivity of dry direct-seeded rice. Soil and Tillage Research 2015;147:39-49.
65. Singh M, Singh RP. Influence of crop establishment methods and weed management practices on yield and economics of direct-seeded rice (*Oryza sativa*). Indian Journal of Agronomy 2010;55(3):224-229.
66. Singh S, Bhushan L, Ladha JK, Gupta RK, Rao AN, Sivaprasad B. Weed management in dry-seeded rice (*Oryza sativa*) cultivated in the furrow-irrigated raised-bed planting system. Crop Protection 2006a;25(5):487-495.
67. Singh S, Chhokar RS, Gopal R, Ladha JK, Gupta RK, Kumar V et al. Integrated weed management: a key to success for direct-seeded rice in the Indo-Gangetic plains. Integrated Crop and Resource Management in the Rice–Wheat System of South Asia. *International Rice Research Institute*. Los Banos, Philippines 2009,261-278p.
68. Singh S, Ladha JK, Gupta RK, Bhushan L, Rao AN. Weed management in aerobic rice systems under varying establishment methods. Crop Protection 2008;27(3&5):660-671.
69. Singh S, Ladha JK, Gupta RK, Bhushan L, Rao AN, Sivaprasad B et al. Evaluation of mulching, intercropping with *Sesbania* and herbicide use for weed management in dry-seeded rice (*Oryza sativa* L.). Crop Protection 2007;26(4):518-524.
70. Singh S, Singh G, Singh VP, Singh AP. Effect of establishment methods and weed management practices on weeds and rice in rice-wheat cropping system. Indian Journal of Weed Science 2005;37(1&2):51-57.
71. Singh UP, Singh RP, Singh Y. Integrated weed management in direct dry seeded rainfed lowland rice. Indian Journal of Weed Science 2006b;38(1&2):49-53.
72. Singh V, Jat ML, Ganie ZA, Chauhan BS, Gupta RK. Herbicide options for effective weed management in dry direct-seeded rice under scented rice-wheat rotation of western Indo-Gangetic Plains. Crop Protection 2016;81:168-176.
73. Singh VP, Singh SP, Kumar A, Banga A, Tripathi N. Effect of monsoon and weed management on growth and yield of direct-seeded rice. Indian Journal of Weed Science 2012;44(3):147-150.
74. Singh Y, Singh VP, Singh G, Yadav DS, Sinha RKP, Johnson DE *et al*. The implications of land preparation, crop establishment method and weed management on rice yield variation in the rice–wheat system in the Indo-Gangetic plains. Field Crops Research 2011;121(1):64-74.
75. Subramanian E, Martin GJ. Effect of chemical, cultural and mechanical methods of weed control on wet seeded rice. Indian Journal of Weed Science 2006;38(3&4):218-220.
76. Sunil CM, Shekara BG, Kalyanmurthy KN, Shankaralingapa BC. Growth and yield of aerobic rice as influenced by integrated weed management practices. Indian Journal of Weed Science 2010;42(3&4):180-183.
77. Walia US, Walia SS, Sidhu AS, Nayyar S. Bioefficacy of pre-and post emergence herbicides in direct-seeded rice in Central Punjab. Indian Journal of Weed Science 2012;44(1):30-33.