A Review on Integrated Weed Management in Transplanted Rice

Abstract

Rice plays a pivotal role in agrarian economy of the most of the Asian and South east Asian nations particularly India. Transplanted rice crop suffers much from biotic production constraints among which weed competition is the important one. The reduction in paddy yield ranges from 9-51 per cent due to infestation of wide range of weed species viz. grasses, sedges and broadleaved weeds. The severity of yield loss is aggravated further when weed infestation coincides with critical period of rice growth depriving it from moisture, nutrients, sunlight and acting as alternate host to some pests and diseases. The cost of weed management in transplanted rice is higher than other operations due to exorbitant wage rate combining with low efficiency moreover due to scarcity of labour during peak period, weeding operation has become a cumbersome, time consuming and costly affair for rice farmers. Therefore, herbicide technology offers a mutual inclusive method of selective and economical control of weeds right from the beginning and forms a major component of integrated weed management of rice farming for reaping bumper yield.

Key words: Transplanted rice, biotic stress, herbicides, integrated weed management.

Introduction

Rice (*Oryza sativa* L.) is one of the most important food crops in the world, forms the staple diet of billions of people and provides 70% direct employment to the rural India. To maintain the food security of Asia, its cultivation is crucial as more than 90% of rice production and consumption is in this continent. Rice contributes 32-59% of the dietary energy and 25-44% of the dietary protein in 39 countries. The projected demand for rice is to be increased by 70% in next 30 years to maintain present per capita availability (69 kg/annum) considering the productivity of land constant. Rice production symbolizes the single largest land use for food production on earth and worldwide rice is grown on 164 million ha with an annual production of about 750 million tonnes of paddy. To meet the global rice demand, it is estimated that about 114 million tonnes of additional milled rice needs to be produced by 2035 and therefore, meeting ever increasing rice demand in a sustainable way with shrinking natural resources is a great challenge.

India is the second largest producer of rice after China. The area, production and productivity of rice in India are 45.76 million hectares, 124.36 million tonnes and 2717 kg/ha respectively. In India, major rice growing states are West Bengal, Punjab, Uttar Pradesh, Tamil Nadu, Andhra Pradesh, Telangana, Bihar, Odisha.

Most significant biological constraint in rice production is weed infestation. Manual weeding is not preferred now a days because of labour scarcity at critical time of weeding and increasing labour costs and is not much effective in controlling the weeds. Weed management using herbicides has become an integral part of modern agriculture. Herbicides have greater flexibility of operation and are often cost effective compared to any other method of weed management. New generation herbicides which are applied at very low doses are more effective with low mammalian toxicity and reduced risk of environmental pollution. Several new generation pre-emergence herbicides alone or supplemented with mechanical weeding have been reported to provide a fair degree of weed control.

Weed spectrum associated with transpalnted rice

Sangeetha *et al*. (2015) reported that the dominant weed flora in experimental field at Coimbatore in clay loam soils were *Echinochloa colonum* (L.) Link (Poaceae), *Cyperus difformis* L. (Cyperaceae), *Eclipta alba* (L.) Hassk. (Asteraceae), *Marsilea quadrifolia* L. (Marsileaceae), and *Ammannia baccifera* L. (Lythraceae). From Haryana, Kumar *et al*. (2014) reported that *Echinochloa colonum*, *Echinochloa crus-galli* (L.) P. Beauv., *Ammannia baccifera*, *Ludwigia parviflora* Roxb. (Onagraceae), *Lindernia* spp. (Linderniaceae), *Marsilea quadrifolia*, *Cyperus iria* L., and *Cyperus difformis* were dominated species in clay loam soils. In silty loam soils of Uttarakhand, the predominant weed flora observed were *Echinochloa colonum*, *E. crusgalli*, *Ischaemum rugosum* Salisb. (Poaceae), *Caesulia axillaris* Roxb. (Asteraceae), *Ammannia baccifera*, *Alternanthera sessilis* (L.) R. Br. ex DC. (Amaranthaceae), and *Cyperus iria* (Kabdal *et al.*, 2014). The grasses, sedges and broad leaf weeds in weedy check plot were 20, 32 and 48% respectively. The weed species noticed were *Cynodon dactylon* (L.) Pers. (Poaceae), *Cyperus rotundus* L., *Cyperus iria*, *Cyperus difformis*, *Digitaria sanguinalis* (L.) Scop.(Poaceae), *Fimbristylis miliacea* (L.) Vahl (Cyperaceae), *Eclipta alba*, *Echinochloa colonum*, *Echinochloa crusgalli*, *Marsilea quadrifolia*, *Eleusine indica* (L.) Gaertn. (Poaceae), *Phyllanthus niruri* L. (Phyllanthaceae), *Euphorbia hirta* L. (Euphorbiaceae), *Amaranthus viridis* L. (Amaranthaceae), and *Commelina benghalensis* L.

(Commelinaceae). Emergence of broad leaf weeds was noticed earlier than of sedges and grasses at Bihar (Kumar *et al.*, 2013a). In clayey soil of Rajasthan, the major weeds observed were grasses like *Echinochloa colonum* and *Echinochloa crusgalli*, sedges like *Cyperus rotundus*, *Cyperus difformis* and *Cyperus iria* and broad-leaved weeds like *Eclipta alba* and *Ammannia baccifera* (Prakash *et al.*, 2013b). Weed survey study indicated that in South Asia, 65 species were found in deep water rice, 194 species in dry seeded rice, 559 species in transplanted rice, 558 species in upland rice and 180 species in wet seeded rice (Muthukrishnan *et al*., 2010). Identification of weeds is the basic step for planning sound weed management programme. Depending upon the weed species, different weed management options are given keeping in view their susceptibility. The dominant grass weed species were *Echinochloa crusgalli* and *Echinochloa colonum*, sedges were *Cyperus iria*, *C. rotundus* and *Fimbristylis miliacea* and broad-leaved weed species were *Ammannia baccifera*, *Marsilia quadrifolia* and *Potamogeton distinctus* A. Benn. (Potamogetonaceae) under puddled condition of sandy clay loam soil during rainy season (Walia *et al*., 2008). The predominant weed species at Tirupati, in Andhra Pradesh were *Echinochloa crus-galli*, *Cynodon dactylon* (L.), *Cyperus iria* and *Cyperus rotundus*, *Eclipta alba*, *Ammannia baccifera*, *Phyllanthus niruri*, and *Commelina bengalensis* (Subramanyam *et al.*, 2007). In Tamil Nadu, experimental plots comprised of the following weed species *Echinochloa colonum* (26.1%) and *Echinochloa crus-galli* (21.6%) among grasses and *Cyperus rotundus* (2.9%) and *C. difformis* (4.4%) among sedges, *Sphenoclea zeylanica* Gaertn. (Sphenocleaceae) (40.3%), *Bergia capensis* L. (Elatinaceae) (2.2%), *Asteracantha longifolia* (L.) Nees (Acanthaceae) (0.8%) and *Eclipta alba* (1.4%) among broad leaved weeds in transplanted rice (Natarajan and Kuppusamy, 2001). At Agricultural Research Station, Raichur, Ramesha *et al.* (2019) reported that the dominant weeds like *Echinocloa* sp., *Cynodon dactylon, Panicum repens* L. among grasses and *Ludwigia parviflora*, *Eclipta alba* among broad leaved weeds and *Cyperus rotundus* among sedges in Direct seeded rice.

Critical period of crop weed competetion in transplanted rice

Ghosh (2010) observed that 3-4 weeks after transplanting was the critical crop weed competition. A weedy situation for the first 15 days only or weed free situation for the first 60 or 75 days produced grain yields comparable with weed free conditions (Muthukrishnan *et al*. (2010). Chinnusamy *et al*. (2000) reported that maintaining a weed free period up to 45 days after transplanting (DAT) was essential to augment the yield of medium duration rice. Critical period for crop weed competition in rice was up to 40 DAT (Thapa and Jha, 2002). For higher productivity of lowland wet seeded rice as well as transplanted rice, weed free situation upto 45 days after seeded (DAS) and (DAT) is necessary (Sathyamoorthy and Kandasamy, 1998). Maintaining a weed free period up to 45 DAT was essential to realise higher yield in medium duration rice (Chinnusamy *et al*., 2000). During early establishment, weeds make 20 to 30 per cent of their growth, while the crop makes 2-3 per cent of its growth (Moody, 1990b). The competition period up to 45 DAS had the greater impact on yield of wet seeded rice (Sathyamoorthy and Kandasamy, 1998). Weed competition for 30-50 days reduced the yield by 62 to 65 per cent in rice crop. Weed control after the critical period did not result in any positive effect on the growth and development of the crop (Hosmani, 1995). There is evidence that the critical period exists during which weeds should be controlled to prevent losses (Radosevich *et al*., 1995). Weeding frequencies had an impact on several conditions in both rice and weeds. *E. crus-galli* dominated the field with low weeding frequencies. When *E. crus-galli* growth was suppressed, *Monochoria vaginalis* (Burm. *f*.) C. Presl ex Kunth (Pontederiaceae) became the dominant weed. We found that higher frequencies of weeding applied increased both the tiller number and biomass of the rice, which were 48 and 267% higher at 8 weeding frequencies (WF) than at 0WF at 110 DAT, respectively (Maimunah *et al.* 2021). In a two-year experiment it was observed that the best transplant spacing for Super Basmati rice is 25 cm × 25 cm and critical weed competition period is 20 days after transplanting (DAT). Therefore, a weed management strategy must be employed within this period to obtain the maximum yield (Chadhar *et al*., 2020).

Yield losses due to weeds in transplanted rice

Duary *et al.* (2015) reported that weeds are recognized as major biological constraints that hinder the attainment of optimal rice productivity. Direct yield loss has been estimated to the range from 16-86% depending on weed species and density, cropping season, duration and time of weed infestation. In severe cases the yield losses can be more than 76% depending upon the species and intensity of weeds (Singh *et al*. 2004). Under transplanted condition uncontrolled weeds causes grain yield reduction upto 35-45% (Gupta and Sharma, 2010), 30-50% (Nagarajan and Chinnusamy, 2010). Research reports over past 25 years have shown yield losses due to weeds to vary considerably from season to season and from year to year with an average of about 60 per cent of weeded plots (Moody, 1990b). Yield reductions in transplanted rice due to weeds have been reported to be 28-45% (Singh *et al.,* 2014). Weeds are considered to be major constraints in achieving higher rice yield that cause a reduction of 10-90 per cent grain yield in Indian rice fields (Nair *et al*., 2000). Weed-free condition at early stage of growth was found more important than at later stages for getting higher yield of rice (Thapa and Jha, 2002). Weeds form a serious negative factor in crop production and are accounted for a marked yield loss of 11-20% in transplanted rice (Ghosh and Moorthy, 1998). Depending upon weed infestation and management practices adopted, losses in paddy yield due to weed competition may vary from 25-55 per cent under transplanted conditions (Saikia and Purushothaman, 1996). Rice suffers heavily due to infestation of wide variety of weeds and the losses range between 30 and 50 per cent (Lakhwinder *et al*., 1995). From an experiment on transplanted rice it was recorded that yield loss in rice due to competition with *Echinochloa colona*, *Leersia hexandra* Sw., *Cyperus iria*, *Ludwigia parviflora* and *Monochoria vaginalis* was 64% compared with weed-free control (Benukar Biswas *et al.,* 2020).

Nature of crop weed competetion

Weeds are self-grown and appear simultaneously with crop plant creating severe competition for nutrient, space, moisture and solar energy resulting in low yield of crop. Grassy weeds were heavy competitors with rice crop and were followed by sedges and broad leaved weeds (Umapathi and Sivakumar, 2000). Deepa and Jayakumar (2008) reported that the uptake of nitrogen by weeds increased and reduced the crop uptake as weed density increased and resulted in decreased yield. Weeds usually grow faster than the crop plants and absorb added nutrient more rapidly and in larger quantities than by crops and thus deprive the supply of nutrients in time to the crop plants. Weeds removed nutrients (N, P and K) eight times higher under direct seeded rice compared to that of puddled transplanting (Singh *et al*., 2002). Balasubramanian and Palaniappan (2001) reported that weeds remove large amount of plant nutrients from the soil. An estimate shows that weeds can deprive the crops 47 per cent N, 42 per cent P, 50 per cent K, 39 per cent Ca and 24 per cent Mg of their nutrient uptake. Nitrogen responsive crop species are more competitive under high N- fertilization, but if the associated weed is also responsive to N, it utilizes more of the applied N and no advantage in crop yield may be obtained *Echinochloa crus-galli* may remove up to 80 % of nitrogen from the soil especially in the first half of growing season (Holm *et al*., 1991). Islam *et al.* (2021) from his two years of experiment in transplanted rice concluded that, In all seasons (*Kharif, Rabi, summer* and *winter* respectively), the same number of weed species was found in the trial field and barnyard grass, *E. crus-galli*, was the most dominant weed. The possible reason for the same number of weed species is that both experiments were conducted in the same experimental fields. Although the weed species were the same in the both seasons, their dominance sequence varied and the variation was mainly due to the differences of seasonal weather and microenvironmental variation.

Effect of cultural practices on yield and yield parameters of transplanted rice

Higher yield attributes *viz.,* number of panicles (398 and 302 m^{-2}) and panicle weight (3.88 and 3.90 g) was recorded in twice hand weeded plot over weedy check treatment in clay soils of Rajasthan (Prakash *et al*., 2013). Singh *et al*. (2013) reported more number of effective tillers (185.2 m^{-2}), grains $panicle^{-1}$ (162.7) and 1000 grain weight (25 g) with hand weeded treatments and was at par with the treatments where hand hoeing was done at 20 DAT (182.9, 158.2 and 24.9) in clay loam soils of Jabalpur. Weed free condition and weed density at 250 m^{-2} was found to be more effective to get more productive tillers and fertile grains per panicle compared to weed density at 500 to 2000 m^{-2} (Begum *et al.*, 2009). Among the weed control treatments, weed free treatment recorded significantly higher No. of effective tillers and grain yield as compared to partial weedy treatment (Walia *et al.*, 2009). The infestation of *Echinochloa crusgalli* significantly decreased productive tillers (171 No.m^{-2}), crop biomass (970 g m^{-2}) and grain yield (360 g m^{-2}) as compared to weed free plots. The *Echinochloa crusgalli* (40-120 m^{2}) infestation showed more decrease in ear length (19.2 cm), filled grains (91 $panicle^{-1}$) and 1000 grain weight (31.8 g) compared to *Echinochloa colonum* (15 plants m^{-2}) on ear length (20.4 cm), filled grains (136 $panicle^{-1}$) and 1000 grain weight (33.2 g) (Paradkar *et al*., 1998). The lower number of panicles per plant, panicle length (18.4 cm) and number of grains per panicle (85) was noticed due to suppressed crop growth (Ghosh and Ghosh, 2005; Sangeetha *et al*., 2009).

In another study the reduction in panicle number was to the extent of 24-38% spikelets $panicle^{-1}$, spikelet fertility by 6-8% and 1000 grain weight by 6-11% in rice during rainy seasons at Palampur (Angiras and Rano, 2005). In another study Ahmed *et al.* (2000) also reported that plots kept weed free gave yield which was at par with those obtained with different herbicide applications. Raju and Reddy (1995) reported that hand weeding twice recorded higher effective tillers m^{-2} compared to chemical weed control. Hand weeding resulted in maximum increase in effective tillers (105.5 m^{-2}) and number of grains $panicle^{-1}$ (157.8) and proved superior to the rest of the weed control treatments. Further hand weeding recorded significant increase in both grain (2401 kg ha^{-1}) and straw (5229 kg ha^{-1}) yield. Mabbayed and Moody (1992) reported that reduction in tiller number, panicle length, thousand grain weight and crop growth rate, delayed ripening and reduced light transmission due to weed competition in rice. Among the crop establishment techniques of rice Stale Seed Bed (ploughing and keeping fallow + paraquat application and normal transplanting) and among the weed management practices use of Cono-Weeder at 20 and 40 Days after Transplanting (DAT) registered the lower density and dry weight of weedy rice at all the growth stages. These treatments also recorded the higher values of growth parameters, yield attributes and yield of rice, gross return, net return and B:C ratio (Anupam *et al.*, 2022).

Effect of herbicides alone on yield and yield parameters of transplanted rice

Yoshida (1981) reported that 1000 grain weight was not influenced significantly due to different weed control treatments. According to Singh *et al*. (2012) 1000 grain weight is a stable varietal character because the grain size is rigidly controlled by the hull. Kumar *et al*. (2014) at Haryana reported that weed free treatment resulted in significantly higher yield attributes, effective tillers m^{-2}, filled grains $panicle^{-1}$, 1000 grain weight and grain yield were influenced significantly yield, though at par with pretilachlor 750 g ha^{-1} (3DAT), pyrazosulfuron 20 g ha^{-1} (3 DAT) butachlor 1500 g ha^{-1} (3 DAT) and bispyribac sodium 25 and 30 g ha^{-1} (20 DAT) treatments. These treatments were also found equally effective in reducing unfilled grains per panicle.

At Pantnagar single application of pretilachlor @ 750 g ha^{-1} recorded a grain yield of 4843 kg ha^{-1} and penoxsulam @ 22.5 g ha^{-1}, resulted 5156 kg ha^{-1} (Raj *et al*., 2014). Similar results were registered by Veeraputhiran and Balasubramanian (2013). At Jabalpur, Singh *et al*. (2013) reported that chlorimuron ethyl 12 g ha^{-1} recorded higher number of tillers m^{-2} (179.6), grains $panicle^{-1}$ (157.3) and 1000 grain weight (24.3 g). The control plot recorded lower effective number of tillers m^{-2} (144.2), grains $panicle^{-1}$ (93.2) and 1000 grain weight (22.2 g). Higher number of panicles m^{-2} (381 and 278) and panicle weight (3.70 and 3.80 g) were recorded with pretilachlor @ 0.750 kg a.i. ha^{-1} at 3-5 DAT over other treatments viz., pretilachlor @ 0.5 kg a.i. ha^{-1} at 3-5 DAT, bensulfuron methyl @ 0.05 kg a.i. ha^{-1} at 20-25 DAT in clay soils of Rajasthan (Prakash *et al.*, 2011). During 2010 and 2011 higher number of panicles m^{-2} 420 and 312, panicle length 24.2, 23.4 cm and grain yield of 7.14 and 6.93 t ha^{-1}, respectively were recorded by weed free plot which was at par with all the doses of bispyribac sodium (25, 35 and 50 g ha^{-1}) application. There was 44.8 and 51.3% yield reduction under unweeded plot over weed free plot at Madurai in clay loam soils (Veeraputhiran and Balasubramanian, 2013). Grain yield of rice crop was higher under weed free situation (4196 kg ha^{-1}), and was statistically at par with metsulfuron methyl 10% + chlorimuron ethyl 10% (3900 kg ha^{-1}) and ethoxysulfuron @ 18.75 g ha^{-1} (3873 kg ha^{-1}) applications. All the herbicide treatments enhanced the grain yield by 50% over weedy check (2880 kg ha^{-1}) at Jabalpur (Sondhia and Dixit, 2012).

There was more than 58% reduction in the grain yield of rice due to competition with weeds in weedy plots (2805 kg ha^{-1}). Pyrazosulfuron ethyl at 25-30 g ha^{-1} recorded less than all the doses (30, 40, 50 and 60 g ha^{-1}) of bensulfuron methyl 6560 -6967 kg ha^{-1} at Pantnagar in clay loam soils (Singh *et al*., 2009b). Harvest index of paddy crop was higher under hand weeding treatment (53.7%) comparable with the treatment having application of pyrazosulfuron ethyl 42.0 g ha^{-1} (52.6%) (Pal *et al*., 2012). Significantly more No. of panicles m^{-2} and grains $panicle^{-1}$ were recorded with application rate of 30.0-35.0 g a.i. $ha^{-1}$of azimsulfuron over pretilachlor 625 g a.i. ha^{-1} at Cuttack (Saha and Rao, 2007). In an alluvial clay loam soil of Cuttack, all the herbicide treated plots gave significantly more grain yield than the weedy plots. The higher grain yield of rice (61.2 q ha^{-1}) was obtained in weed free check and was on a par with that of triasulfuron + pretilachlor at 9 + 500 g ha^{-1}. The traditional herbicides, *viz*., butachlor at 1,500 g ha^{-1} and pretilachlor at both the doses (500 and 750 g ha^{-1}) yielded significantly less than all the doses of different sulfonylurea herbicides, i.e. pyrazosulfuron ethyl, bensulfuron methyl and triasulfuron whether applied alone or as tank mixture with pretilachlor at 500 g ha^{-1} (Saha, 2006). At Nadia under new alluvial zone, the higher rice grain yield (3.7 t ha^{-1}) was recorded in hand weeded plot which was statistically at par with pyrazosulfuron ethyl applied @ 42.0 g ha^{-1} (3.3 t ha^{-1}). Lower grain yield of rice was observed in untreated check (2.1 t ha^{-1}) (Chopra and Chopra 2003).

Effect of sequential herbicides application on yield and yield parameters of transplanted rice

Raj *et al*. (2014) reported higher grain yield with pre emergence application of pretilachlor 750 g ha^{-1} followed by bispyribac sodium 20 g ha^{-1} (5729 kg ha^{-1}) in silty loam soils of Pantnagar. In silty loam soils of Uttarakhand, Kabdal *et al*. (2014) reported that the higher rice grain yield (6.74 tha^{-1}) was recorded in weed free plots which was at par with pre emergence application of pretilachlor at 750 g ha^{-1} followed by post-emergence application of chlorimuron ethyl + metsulfuron methyl at 4 g ha^{-1} (6.39 t ha^{-1}). Similar results were reported by Kumar *et al.* (2013b). The higher grain yield was recorded in weed free (4.89 t ha^{-1}) treatment, which was statistically at par with cyhalofop butyl (70 g ha^{-1}) followed by 2, 4-D sodium 800 g ha^{-1} (4.62 t ha^{-1}) and penoxsulam 25 g ha^{-1} (4.60 t ha^{-1}) at Pantnagar (Nath and Pandey, 2013). In clay loamy soils of Jharkhand chlorimuron ethyl + metsulfuron methyl at 4 g ha^{-1} followed by 2,4-DEE @ 0.5 kg ha^{-1} recorded yield of 45.2 q ha^{-1} was at par with two hand weeding (42 q ha^{-1}). Minimum grain yield of 25.2 q ha^{-1} was obtained in weedy check (Saha and Rao 2007). In another experiment Reddy *et al*. (2012) reported that pre emergence application of bensulfuron methyl 0.6% + pretilachlor 6.0% G @ 75 + 750g ha^{-1} recorded higher rice grain yield of 5.58 and 6.55 t ha^{-1} and remain on par with pre emergence application of bensulfuron methyl + pretilachlor @ 60 + 600 g ha^{-1} followed by PoE hand weeding (5.27 and 6.32) over weedy check recording 3.58, 5.48 t ha^{-1} during 2006 and 2007, respectively in deep black clay soil of Karnataka. Sowjanya *et al* (2020) at Agricultural Research Station, Rajendranagar, Hyderabad recorded grain yield (2737 kg ha^{-1}) and B:C ratio (1.64) with application of pendimethalin @ 1 kg a.i ha^{-1} as pre-emergence *fb* penoxsulam + cyhalofop-butyl (25 +127 g a.i ha^{-1}) as post-emergence at 2-4 leaf stage of weeds fb mechanical weeding at 50 DAS in semi dry rice. Nagarjun *et al* (2019) at Main Research Station, Hebbal, Bengaluru revealed that with application of pendimethalin *fb* Trifamone and Ethoxysulfuron and pendimethalin (38.7% CS) *fb* penoxsulam + cyhalofop butyl the grain yield was found to be 4320 kg $ha^{-1}$and 4150 kg ha^{-1}.

Hemalatha *et al.* (2017) revealed that pre-emergence application of pendimethalin *fb* post-emergence application of metsulfuron methyl + chlorimuron ethyl registered the highest weed control efficiency (WCE) (89.7 %) which was comparable with weed free check (90.6 %). Ramesha *et al.* (2017) stated that pre-emergence application of pretilachlor + pyrazosulfuron-ethyl (600 + 15 g/ha) and twice hand weeded check (20 and 40 DAS) recorded significantly lower grassy and broad leaved weeds with higher WCE compared to bispyribac-sodium (25 g ha^{-1}), penoxsulam (25 g ha^{-1}) and pyrazosulfuron ethyl (20 g ha^{-1}) application alone. Gupta and Tomar (2019) analyzed that N, P and K removal by weeds in unweeded control recorded highest mainly because of higher dry matter accumulation by weeds which enabled them to absorb more nutrients in this treatment. The study conducted by Arya and Ameena (2016) at college of Agriculture, Thiruvananthapuram, revealed that with application of oxyfluorfen @0.15 kg a.i ha^{-1} have not shown visual phytotoxicity but the crop density and growth was lower at the initial stage in semi-dry rice. Patil *et al.* (2014) observed that application of penoxsulam + cyhalofop-butyl 6 % OD @ 135 g ha-1 at 2-4 leaf stage significantly reduced the weed density, weed dry weight and showed higher weed control efficiency under dry direct seeded rice. They also reported that the concentration of herbicide and at the moment of application are found important to reduce weed menace in rice. Application at lower concentration either @ 105 or 120 g ha^{-1} at later part of crop growth (5-8 leaf stage of weeds) was not found to be effective.

Effect of integrated weed management on yield and yield parameters of transplanted rice

In red loamy soils early post emergence application of azimsulfuron 30.0 g a.i. ha^{-1} + 0.2% S followed by one hand weeding at 40 DAT recorded higher grain yield (6834, 6683, 6102 and 6540 kg ha^{-1} in summer 2008, *kharif* 2008, *kharif* 2009, respectively) and straw yield (7008, 7030, 6494 and 6844 kg ha^{-1} in summer 2008, *kharif* 2008, *kharif* 2009, respectively) of transplanted rice at Karnataka. (Jayadeva *et al.*, 2011). Gnanavel and Anbhazhag**e**n (2010) reported that pre-emergence application of oxyfluorfen at 250 g ha^{-1} followed by post emergence application of bispyribac sodium at 50 g + metsulfuron methyl at 10 g ha^{-1} recorded the least weed count (11.0 m^{-2}) and weed dry weight production (114.6 kg ha^{-1}) and higher weed control efficiency (90.1 %) favoured high grain yield (5.32 t ha^{-1}). Chinnamuthu *et al.* (2008) also reported that pre emergence application of pretilachlor at 0.45 kg a.i. ha^{-1} on 3 DAS + roto cylindrical weeder weeding on 45 DAS resulted in the least total weed density and weed dry weight. Pre emergence application of pretilachlor with safener + rotary weeding (25 DAS) + hand weeding (45 DAS) recorded lower weed biomass and accounted for high weed control efficiency (93.0 %). Further Ghosh (2010) reported that pre emergence application of pyrazosulfuron 20 g ha^{-1} followed by one mechanical weeding at 40 DAT recorded higher grain yield (3640 kg ha^{-1}) in sandy loam soils of Ranchi. Integrated weed management approach of pre-emergence application of pretilachlor at 0.45 to 0.75 kg a.i. ha^{-1} followed by hand weeding at 25 to 30 DAS effectively controlled grasses, sedges, broad leaved weeds and thus minimized the nutrient removal by weeds due to improved weed control efficiency and contributed to higher grain yield and B: C ratio (Ramphool *et al.*, 2007). Among herbicide-based IWM options, mefenacet + bensulfuron-methyl as preemergence followed by (fb) either bispyribac-sodium or penoxsulam as postemergence fb one hand-weeding were the most profitable alternatives, with reductions in labor requirement by 11 to 25 person-days ha^{-1} (Ahmed *et al.*, 2021). Planting rice at 15 cm row spacing suppressed the weeds by 11.4–20.4% with 10.0–13.4% higher grain yield over planting at 20 cm spacing and use of hand weeding at 20 and 40 DAT, provided 78.0–84.7% weed control with 83.6– 89.1% higher grain yield followed by application of bispyribac sodium at 25 g ha^{-1} over control. Therefore, under labour scarcity situation bispyribac sodium at 25 g ha^{-1} would be a better alternative (Choudhary *et al*., 2021)

Conclusion:

Weed management assumes lot of importance in rice as it hosts a wide range of weed species of which some are problematic and few are mimic type. Losses when quantified it has recorded a range of 16-86 % depending on the intensity of weeds and weed management option adopted. Wide range of weed management options are available across the rice growing regions and each practice has its own advantages and disadvantages and no single practice offers cent per cent effectiveness, it is all relative efficiency we need to assess before opting any particular management option and choose the best fit one that provides maximum economic benefits. Using herbicides alone or mechanical or cultural practices alone will not be effective enough rather a combination of all these practices, what we call as Integrated Weed Management (IWM) has been recorded as best weed management strategy in most of the studies reviewed.

References

Ahmed GJU, Mamun SAA, Hossain MA, Mridha AJ, Hossain ST. Agro-economic study of weed control in direct seeded Aus rice in the farmer's field. *Annals of Bangladesh Agriculture*. 2000;8 (2): 111-118.

Ahmed S, Kumar V, Alam M, Dewan MR, Bhuiyan KA, Miajy AA, Saha A, Singh S, Timsina J, Krupnik TJ. Integrated weed management in transplanted rice: options for addressing labor constraints and improving farmers' income in Bangladesh. Weed Technol. 2021;35: 697–709.

Angiras NN, Rano SS. Integrated Weed management in direct seeded puddled sprouted rice *(Oryza sativa)*. *Indian Journal of Agronomy*. 2005;43(4): 644-649.

Anupam M, Buddhadeb D, Chinanshuk G. Effect of crop establishment techniques and weed management practices on management of weedy rice. 2022. SATSA Mukhapatra - Annual Technical Issue 26.

Arya SR, Ameena M. Efficacy of new generation herbicides for weed management in semi dry rice. *Journal of Tropical Agriculture*. 2016;54(1):55.

Balasubramanian P, Palaniappan SP. *Principles and practices of Agronomy*, Agrobios publishing Co. Pvt. Ltd., New Delhi, 2001; pp. 306-364.

Begum M, Juraimi AS, Amartalingam R, Omar SRS, Man AB. Effect of *Fimbristylis miliacea* competition with MR 220 rice in relation to different nitrogen levels and weed density. *International Journal of Agriculture Biology*. 2009;11: 183-187.

Benukar Biswas, Jagadish Timsina, Sourav Garai, Mousumi Mondal, Hirak Banerjee, Saju Adhikary, Sahely Kanthal. Weed control in transplanted rice with postemergence herbicides and their effects on subsequent rapeseed in Eastern India. *International Journal of Pest Management*. 2020;DOI: 10.1080/09670874.2020.1853276

Chadhar AR, Nadeem MA, Ali HH, Safdar ME, Raza A, Adnan M, Hussain M, Ali L, Kashif MS, Javaid MM. Quantifying the impact of plant spacing and critical weed competition period on fine rice production under the system of rice intensification. *International Journal of Agriculture & Biology*. 2020;24:1142–1148.

Chinnamuthu CR, Chinnusamy C, Ravisankar D. Efficiency evaluation of mechanical weeders in wet seeded lowland rice. *Proceedings of biennial Weed Science Conference*. 2008;February 27-28, Pusa, p. 87.

Chinnusamy C, Kandasamy OS, Sathyamoorthy K, Chandrasekar CN. Critical period of crop-weed competition in lowland rice ecosystems. *Proceedings of State level Seminar on Integrated Weed Management in New Millennium*. Ratnagiri. 2000; pp. 27-28.

Chopra NK, Chopra N. Effect of dosages and stages of application of pyrazosulfuron- ethyl on Weeds in transplanted rice. *Indian Journal of Weed Science*. 2003;35: 27-29.

Choudhary VK, Deepak N, Anil D. Weed prevalence and productivity of transplanted rice influences by varieties, weed management regimes and row spacing. *Archives of Agronomy and Soil Science*. 2021. DOI: 10.1080/03650340.2021.1937606

Duary B, Mishra MM, Dash R, Teja KC. Weed management in lowland rice. *Indian Journal of Weed Science*. 2015;47(3): 224–232.

Deepa S, Jayakumar R. Studies on uptake of N, P and K as influenced by different rates (doses) of pretilachlor in transplanted rice. *Madras Agricultural Journal*. 2008;95 (7-12): 333-338.

Ghosh P, and Ghosh RK. Bioefficacy and phytotoxicity of clomazone + 2, 4 –DEE for Weed control in transplanted rice. *Indian Journal of Agronomy*. 2005; 38(1): 298-299.

Ghosh RK. Weed management in transplanted and direct seeded rice in India. *Proceedings of biennial Conference Indian Society of Weed Science*. 2010;February 25-26, Raipur. P. 83.

Ghosh A, Moorthy BTS. Weed management deserves more attention in rainfed lowland cultivation. *Indian Farming*. 1998;48 (6): 15-18.

Gnanavel I, Anbhazhagen R. Bio-efficacy of pre and post emergence herbicides in transplanted aromatic basmathi rice. *Research Journal Agricultural Science*. 2010;1(4): 315-317.

Gupta DK, Sharma S. Effect of rice *(Oryza sativa)* planting method and weed management in rice. *Proceedings of biennial Conference of Indian Society of Weed Science*. 2010;February 25-26, Raipur. P.180.

Gupta PK, Tomar AK. Weed management in transplanted rice with special reference to *Commelina benghalensis* in the Kymore Plateau Satpura hills region of Madhya Pradesh. *Indian Journal of Weed Science*. 2019;51 (3): 236-239.

Jayadeva HM, Bhairappanavar ST, Somashekharappa PR, Rangaswamy BR. Efficacy of azimsulfuron for weed control in transplanted rice. *Indian Journal of Weed Science*. 2011;41 (3&4):172-175.

Holm LG, Plucknett DL, Pancho JV, Herberger JP. The world's worst Weeds: Distribution and Biology. The University Press of Hawaii, Malabar, Florida. 1991.

Hosmani MM. *Integrated Weed management in field crops*. Venkatardri Printers, Bangalore. 1995; 113-145.

Hemalatha K, Ramana AV, Bisen N, Rani M. Effect of weed management practices on yield and economics of semidry rice. *Journal of Pure and Applied Microbiology*. 2017;11(2): 1027-1032.

Islam AKMM, Nasir M, Akter Mou M, Yeasmin S, Islam MS, Ahmed S, Anwar MP, Hadifa A, Baazeem A, Iqbal MA, Abdul SJ, Ayman ELS. Preliminary reports on comparative weed competitiveness of bangladeshi monsoon and winter rice varieties under puddled transplanted conditions. *Sustainability*. 2021;13, 5091.

Kabdal P, Pratap T, Singh VP, Singh R, Singh SP. Control of complex Weed flora in transplanted rice with herbicide mixure. *Indian Journal of Weed Science*. 2014; 46(4):377-379.

Kumar B, Kumar R, Kalyani S, Haque M. Effectiveness and of integrated Weed management in transplanted rice (Oryza sativa). *Trends in Bio Sciences*. 2013b;6(2):212-215.

Kumar N, Nandal DP, Punia SS. Efficacy of post-emergence herbicides for Weed control in transplanted rice. *Indian Journal of Weed Science*. 2014;46(4):380-382.

Kumar S, Rana S, Chander N, Ramesh K. Mixed Weed flora management by bispyribac-sodium in transplanted rice. *Indian Journal of Weed Science*, 2013a;45(3):151-155.

Lakhwinder S, Brar J, Kolar S, Brar LS. Efficacy of naproanilide, Bentazone and Metasulfuron against *Caesulia axillaris* Roxb. in transplanted rice. *Indian Journal of Weed Science*. 1995;27 (3&4): 127-130.

Mabbayed MO, Moody K. Herbicide seed treatments for Weed control in wet seeded rice. *Journal of Plant Protection in the Tropics*. 1992;2: 117-124.

Maimunah MA, Kautsar V, Bimantara PO, Kimani SM, Torita R, Tawaraya K, Murayama H, Utami SNH, Purwanto BH, Cheng W, Weeding frequencies decreased rice–weed competition and increased rice n uptake in organic paddy field. *Agronomy*. 2021;11, 1904.

Moody K. Yield losses due to weeds in rice in the Phillipines.Crop loss assessment in rice. International Rice Research Institute, Phillipines. 1990b; pp. 193-202.

Muthukrishnan P, Subbalakshmi L, Sathiya K. Weed distribution and management in rice. *Proceedings Annual Weed Science Conference*, 30th November & 1st December, TNAU, Coimbatore.15. 2010.

Nagarajan R, Chinnusamy C. Evaluation of bensulfuron methyl and butachlor on Weed control and productivity of transplanted rice (*Oryza sativa* L.). *Proceedings Annual Weed Science Conference*, 29-30th November, TNAU, Coimbatore. 2010; p. 145.

Nagarjun P, Dhanapal GN, Sanjay MT, Yogananda SB, Muthuraju R. Energy budgeting and economics of weed management in dry direct-seeded rice. *Indian Journal of Weed Science*. 2019; 51(1):1-5.

Nair AK, Pramanik SC, Ravisankar N, Dinesh R. Effect of varieties and Weed control practices on productivity of rice (*Oryza sativa*) and Weed growth in lowlands of south Andamans. *Indian Journal of Agricultural Science*. 2000;72(8): 477-479.

Natarajan S, Kuppusamy G. Weed management in transplanted rice. *Journal of Ecobiology*. 2001;13(3): 213-216.

Nath CP, Pandey PC. Evaluation of herbicides on grain yield and nutrient uptaken in rice (Oryza sativa L.). *Bioinfolet*. 2013;10 (1B): 282-287.

Pal S, Ghosh RK, Banerjee H, Kundu R, Alipatra A. Effect of pyrazosulfuron-ethyl on yield of transplanted rice. *Indian Journal of Weed Science*. 2012;44(4) : 210-213.

Paradkar NR, Kurchania SP, Tiwari JP, Bhalla CS. Competitive impact of *Echinochloa crus-galli* (L.) Beauv on yield attributes and yield of rice. *World Weeds*.1998;5: 57-60.

Patil VB, Reddy BM, Desai BK, Umesh MR, Ibrahim M. Effect of penoxsulam+ cyhalofop–butyl 6% OD application on weed control and performance of dry direct seeded rice. *Biochemical and Cellular Archives*. 2014;14(2):319-322.

Prakash C, Shivran RK, Koli NR, Sharma. Bio efficacy of new herbicides on Weed dynamics, yield attributes, yield and Weed control efficiency in transplanted rice. *Trends in Bio Sciences*. 2011;4(2):224-227.

Prakash C, Shivran RK, Koli NR. Bioefficacy of penoxsulam against broad-spectrum Weed control in transplanted rice. *Indian Journal of Weed Science*. 2013;45(4):228-230.

Prakash C, Shivran RK, Koli NR, Sharma J. Efficacy of different herbicides for Weed control in transplanted rice (*Oryza sativa* L.) under vertisols of Rajasthan. *Trends of bio Sciences*. 2013b; 6(1):112-114.

Raj VY, Pratap VS, Usha A, Rekha S. Integrated Weed management in transplanted rice. *Indian Journal of Weed Science*. 2014;46 (2): 176-179.

Radosevich M, Traina SJ, Hao YI, Touvinen OH. Degradation and mineralization atrasine by a soil bacterial isolate. *Applied Environmental Microbiology*. 1995;61: 297-302.

Raju RA, Reddy MN. Performance of herbicide mixtures for Weed control in transplanted rice *(Oryza sativa* L.). *Indian Journal of Weed Science*.1995;27: 106-107.

Ramphool P, Pandey PC, Bisht PS, Singh DK. Nutrient uptake by crop and Weeds as influenced by trisulfuron, trisulfuron+pretilachlor and bensulfuron-methyl in transplanted rice (Oryza sativa L.). *Indian Journal of Weed Science*. 2007;39 (3&4): 239-240.

Ramesha YM, Anand SR, Krishnamurthy D, Bhanuvally M. Weed management effect to increase grain yield in dry direct-seeded rice. *Indian Journal of Weed Science*. 2019; 51(1):6-9.

Ramesha YM, Manjunatha B, Gaddi AK, Krishamurthy D, Umesh MR. Weed management in irrigated dry-seeded rice. *Indian Journal of Weed Science*. 2017; 49(2):113-116.

Reddy M, Ravishankar BG, Subash G, Joshi VR, Negalur RK. Efficacy of bensulfuron methyl plus pretilachlor for controlling Weeds in transplanted rice. *Oryza*. 2012;49(1):65-67.

Saha S. Comparative study on efficacy of sulfonylurea herbicides and traditional recommended herbicides in transplanted rice (Oryza sativa).*Indian Journal of agronomy*. 2006;51(4):304-306.

Saha S, Rao KS. Efficacy of azimsulfuron against complex Weed flora in transplanted summer rice. *Oryza*. 2012;49(3):183-188.

Saha S, Rao KS. Weed management in rice. Research Buletin No. 2, Central Rice Research Insitiute, Cuttack, Orissa. 2007;1-20.

Saikia M, Purushothaman S. Competitive ability of Weed flora in lowland rice *(Oryza sativa)*. *Indian Journal of Agricultural Science*. 1996;66 (1): 70-72.

Sangeetha M, Jayakumar R, Bharathi C. Effect of slow release formulations of pretilachlor on growth and yield of lowland transplanted rice (*Oryza sativa* L.). *Green Farming*. 2009; 2(2): 997-999.

Sangeetha C, Velayutham A, Thavaprakaash N, Chinnusamy C, Crop establishment and Weed management effects on rice productivity and Weed dynamics. *Indian Journal of Weed Science*. 2015;47(1): 6–10.

Sathyamoorthy K, Kandasamy OS. Critical period of crop Weed competition in different rice culture (lowland transplanted and wet seeded rice). *In*: summary and research achievement, AICRPWC (ICAR), Coimbatore Centre, Tamil Nadu Agricultural University, Coimbatore, India. 1998.

Sondhia S, Dixit A. Bioefficacy and persistence of ethoxysulfuron in rice. *Oryza*. 2012;49(3):178-182.

Sowjanya V, Goverdhan M, Prakash TR, Srinivas A. Weed dynamics under semidry rice as influenced by integrated weed management. *International Journal of Chemical Studies*. 2020;8(6):1739-1743.

Singh LN, Chongloi KL, Singh AI. Effect of plant population on rice yield during early wet season in Manipur. *Oryza*. 2002;40(3&4) : 79-80.

Singh VP, Govindra S, Mahendra S. Effect of fenoxaprop-p-ethyl transplanted rice and associated Weeds. *Indian Journal of Weed Science*. 2004;36(1&2):190-192.

Singh BR, Singh RV, Rajput OP. Effect of nitrogen, phosphorous and zinc on growth, yield and nutrient uptake of wheat. *Current Advances in Agricultural Sciences.* 2009;1: 133 – 134.

Singh PC, Jha AK, Monika S. Efficacy of chlorimuron-ethyl against Weeds in transplanted rice. *Indian Journal of Weed Science*. 2013;45 (2): 135-136.

Singh, A.P., Singh, A.K., Chaturvedi, S. Singh,S. and Mishra,O.P. Bio-efficacy of sulfonylurea herbicides on mixed Weed flora in transplanted rice. *Indian Journal of agriculture research*. 2012; 46(1):9-15.

Singh R. Influence of pendimethalin application with different fertilizers on soil enzyme activities in bulandshahr soil. *International Journal of scientific and Research Publications*. 2014;4 (5): 1-6.

Subramanyam D, Reddy DS, Reddy CR. Influence of integrated Weed management practices on growth and yield of transplanted rice (*Oryza sativa* L.). *Crop Research*. 2007;34 (1, 2 & 3): 1-5.

Thapa CB, Jha PK. Paddy crop-Weed competition in Pokhara, Nepal. *Geobios,* 2002;29 (1): 51-54.

Umapathi K, Sivakumar C. Studies on crop-Weed competition in rice-rice cropping system. *Proceedings of state level seminar on integrated Weed management in new millennium*. 2000; Feb. 27-28. Dapoli chapter of Indian Society of Agronomy, Maharastra. P. 57.

Veeraputhiran R, Balasubramanian R. Evaluation of bispyribac-sodium in transplanted rice. *Indian Journal of Weed Science*. 2013; 45(1):12-15.

Yoshida S. Fundamentals of rice crop Science. International Rice Research Institute. 1981; 112-114.

Walia US, Bhullar MS, Nayyar S, Singh SA. Control of complex Weed flora of dry-seeded rice *(Oryza sativa)* with pre and post emergence herbicides. *Indian Journal of Weed Science*. 2008;40(3&4):161-164.

Walia US, Bhullar MS, Nayyar S, Singh S A. Role of seed rate and herbicides on the growth and development of direct dry- seeded rice. *Indian Journal of Weed Science*. 2009;41(1&2):33-36.