WEED MANAGEMENT IN DIRECT - SEEDED RICE [ORYZA SATIVA]: A REVIEW

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The major weed species of direct seeded rice are Echinochloa colona, Echinochloa crusgalli, Leptochloa chinensis among grasses, Cyperus rotundus, Cyperus difformis, Cyperus iria, Fimbristylis miliacea among sedges and CASELLA axillaris, Commelina benghalensis, Ammannia spp., CAESALII axillaris, TRIANTHEMA portulacastrum, and DIGER a renvensis among broadleaved weeds. The risk of yield loss from weeds in direct-seeded rice is greater than transplanted rice. Direct seeding of rice under zero tillage lowers the production costs by saving fuel and labour. Sesbania co-culture reduced broadleaf and grass weed density by 76-83% and 20-33%, respectively and total weed dry matter by 37-80% compared with a sole rice crop. Post-emergence application of bispyribac sodium and penoxsulam at 25 g/ha provided effective control of all the weeds in DSR. Integrated weed management approach based on critical period of crop weed competition, involving different direct and indirect control measures, has been developed and widely adopted by farmers to overcome weed problem in direct seeded rice in a sustainable way. Keeping these points in view, this review is focused to different weed management methods suitable for the direct seeded rice.

Rice is the world’s one of the most important cereal crop and is a staple food for more than half of the world’s population1-2. Worldwide, rice is grown on 160.1 million hectares, with an annual production of about 713.5 million tonnes of paddy3. About 90% of the world’s rice is produced in Asia with the contribution of 157.2 million tonnes from 43.0 million hectares by India4. With the increasing population growth, world’s rice demand is projected to increase by 25% from 2001 to 20255, and thus, fulfilling the increasing rice demand in a sustainable way with shrinking natural resources is a great challenge.

Certain factors like weeds, insects, diseases and other management practices are responsible to restrict the crop’s potential. Among the several production constraints, weeds are most important, causing enormous losses in yield and quality of rice6-7. Crop losses due to weed competition, are greater than those resulting from combined effect of insect pests and diseases8. More than one third of the total loss (33%) is caused alone by the weeds9. Weeds reduce the crop yield, deteriorate quality and reduce market value of grains. The left over parts of weeds either living or dead also hamper the rice crop by secreting toxic root exudates or leaf leachates. Besides, the weeds are also sink of different pest and disease that cause adverse affect on rice production. If left uncontrolled, the weeds in rice field are capable of reducing yields by more than 76 per cent10. The weed control by conventional method is weather dependent, laborious, and expensive. So, there is a need to find a substitute of traditional methods, which may reduce cost of production, conserve natural resources, save time and labour, enhance productivity and effectively control weeds while sustaining environmental quality11-12. Thus, resource conserving technology like direct seeded rice is being promoted, as it is cost-effective, can save water through earlier rice crop establishment and allows early sowing of wheat13. Also, appropriate and economical weed management technology is to be developed for the sustainable rice cultivation. Keeping these points in view, this review is focused to different weed management methods suitable for the direct seeded rice.

Direct seeding rice as an alternative of transplanting rice: Transplanting in puddled soils with continuous flooding is the most common method of rice crop establishment in the Asian countries2,14-15. The basic fate now-a-days with this system is the less availability of agriculture labour and high wage rates. An average annual reduction of 0.2% in agricultural labour has been reported for Asia2. Moreover, there is also risk in growing of rice nursery, along with the loss of time, energy and money spent, as the failure of nursery may result in failure of the entire transplanted crop under specific situations. Transplanting decreases rice plants ability to withstand moisture stress, renders deleterious effects on the soil environment for the succeeding crops due to the dispersion of soil particles, compactness and difficulties in tillage operations2 requiring

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more energy and time in succeeding crops such as wheat\textsuperscript{16}. Transplanting requires continuous tillage operations for better crop production that accounts for 15\% of the total production cost in irrigated rice\textsuperscript{17}. Current energy crises coupled with increasing fuel prices has escalated cultivation and irrigation costs by many folds. Under these circumstances, rice production through traditional system of transplanting is becoming less profitable.

To overcome problems associated with traditional rice cultivation, direct seeding of rice seems only viable alternative\textsuperscript{2,15,18}. It has emerged as a popular method of rice cultivation being practiced on large areas in many Asian countries (Fig.-1). It fulfills the challenges faced by water and labour shortage, time, soil and money conflicts, thereby promising system sustainability\textsuperscript{2,19}. Reduction in labour input to the tune of 11-75\% depends on the type of rice direct seeding, location, season and weed infestation\textsuperscript{2,20,22}. Thus, weed management is important option for sustaining the production of rice.

**Weeds in Direct-Seeded Rice:** A Major Constraint Weeds are a major constraint to the success of DSR\textsuperscript{1-2,14,23}. Weeds in DSR are diverse and higher in abundance than transplanted rice\textsuperscript{1} causing higher weed pressure in DSR\textsuperscript{24}. In the transplanted rice, weeds that emerge early in season are suppressed due to anaerobic environment formed by immediate flooding, which is not the case for DSR. Thus, weed management is a serious challenge to DSR.

*Echinochloa colona* and *E. crusgalli* are the most serious weeds affecting DSR. Some other weed species are *Leptochloa chinensis* among grasses, *Cyperus rotundus*, *Cyperus difformis*, *Fimbristylis miliacea* among sedges and *Caseulia axillaris*, *Commelina benghalensis* and *Digera arvensis* among broadleaved weeds\textsuperscript{25-32}. Increased dominance of *E. indica* and *L. chinensis* in DSR\textsuperscript{33-34}.

Among the major weeds, grasses constitute 77.8\%, sedges 17.2\% and broad leaved weeds only 5\%\textsuperscript{35}. Largest number of weed species viz. *E. colona* (30.8\%), *E. crusgalli* (15.8\%), *Caesulia axillaris* (10.3\%), *Ischaemum rugosum* (26.4\%), *Caesalia axillaris* (59.8\%), *Echinochloa colona* (14.7\%), *Panicum maximum* (11.7\%), *Cyperus iria* (5.7\%), *Ischaemum rugosum* (2\%), *Commelina diffusa* (7.6\%) and others (8.9\%), were observed at Pantnagar in direct seeded rice\textsuperscript{36-37}.

**Yield losses in Direct-Seeded Rice:** Due to weed infestation, there is considerable yield loss in direct seeded rice. Losses due to weeds are much higher than those caused by nutrient deficiency, pests or diseases\textsuperscript{6} and are even more worsening in direct sown than in transplanted crops\textsuperscript{1-2,24}. Weeds compete with DSR for space, water, nutrients and sunlight\textsuperscript{15}. Rice yield losses due to pests may amount to 40\%, nonetheless, weeds have the greatest potential (32\%) of inflicting yield loss\textsuperscript{1}.

The key issue for the successful cultivation in DSR is control of weeds like *Echinochloa* spp., *Cyperus* spp. The yield losses in DSR ranges between 30-98\%\textsuperscript{1,38-39}. Recently, 39-41\% yield loss in DSR due to weeds (one weeding at 28 DAS) relative to weed free yield\textsuperscript{40}. The extent of yield loss due to uncontrolled weeds in direct seeded rice varied from 40-100\%\textsuperscript{31,41,42} and 50-60\% in upland direct seeded rice\textsuperscript{43}. The reduction in grain yield of rice due to uncontrolled weed control was about 53.8-98.6\%\textsuperscript{14,36,44-45}. Season-long weed competition in direct seeded aerobic rice may cause yield reduction up to 80\%\textsuperscript{46}.

**Weed Management Methods:** Weed control methods are grouped into cultural, manual, mechanical, chemical and biological methods. Each of them has their own advantage and disadvantage, so summarized reviews have been given below for weed control in direct seeded rice.

**Cultural Methods:** Cultural methods provide competitive advantage to crop against weeds by reducing weed establishment\textsuperscript{47}. These practices alter the competitive relationship between rice crop and weeds. Hence, proper agronomic management practices like suitable crop rotation and tillage systems; efficient fertilizer use, mixed cropping, tolerance cultivars and spacing\textsuperscript{48} and timely weed control have to be planned to attain the better food production. The close spaced crop effectively smothered the weeds growing under crop canopy by not providing sufficient space for weed growth. Also crop rotation with different life cycles disrupts the development of crop weed associations, through different planting and harvest dates preventing weed establishment and therefore, weed seed production\textsuperscript{49}, mainly by smothering and allopatic effect\textsuperscript{50}. Competitive cultivar suppresses weed seed production, limit future weed infestation and become a safe, environmental sustained and low cost tool for weed management\textsuperscript{50}. Difference in fertilizer placement significantly reduced the density and dry matter accumulation of weed and
produced higher grain yield than broadcast method of fertilizer application\(^6\). Multi storied cropping also enhances weed control by capturing a great share of available resources\(^5\) and probability by increasing shade and crop competition with weeds\(^5\). Tillage systems greatly influence the composition of weed communities\(^4\) through their effects on vertical distribution of weed seeds in soil\(^5\), relative time of emergence, abundance of a particular weed species\(^6\), weed seed survival\(^7\) and proportion of annual versus perennial weeds\(^8\). The yields of direct seeded rice in dry fields as well as direct seeding of sprouted rice seeds in puddled situation were proved to be more sustainable for the productivity of rice-wheat system than growing of rice by transplanting methods\(^9\). Direct seeding of rice under zero tillage lowers the production costs\(^2\), by saving fuel and labour. Sesbania co-culture technology can reduce the weed population by nearly half without any adverse effect on rice yield\(^10\). It involves seeding rice and sesbania crops together and then killing sesbania with 2, 4-D ester about 25-30 DAS. Sesbania grows rapidly and suppresses weed. This practice is found more effective in suppressing broadleaf weeds than grasses and therefore, if combined with pre-emergence application of pendimethalin, its performance in suppressing weeds increases. Sesbania co-culture reduced broadleaf and grass weed density by 76-83% and 20-33%, respectively and total weed dry matter by 37-80% compared with a sole rice crop\(^11\).

**Manual Weeding:** The earliest ways of weed control in rice were cultural methods. In spite of labour intensive, hand weeding is still the most common direct weed control methods in rice in India using bare hands and hand tools. Hand weeding is very easy and environment-friendly but tedious and highly labours intensive, and thus is not an economically viable option for the farmers. It increased grain as well as straw yields compared to herbicides and weedy check because of frequent elimination of weeds that resulted in the reduced weed competition, required particularly at the most rapid tillering stage of rice crop\(^2\). Two hand weedicings (20 and 40 DAS) and pendimethalin 1.0 kg/ha + anilofos 0.4 kg/ha applied as pre-emergence recorded efficient control of all weeds (grasses, non-grasses and sedges) and greater weed control efficiency as compared to weedy check as well as other weed control treatments in direct seeded rice\(^3\).

**Mechanical Weeding:** Mechanical weeding is through incorporation of weeds in situ which help in effective recycling of the depleted nutrients which in turn augment the nutrient pool of the rhizosphere together with aeration of the root zone. Rotary weedicers and conoweeders have been found effective in controlling weeds in DSR. The mechanical hand weeder pruned some of the upper roots and encouraged deeper root growth\(^4\). The implements like conoweeder helped to save labour, time and reduced man-days required for weeding from 30 to 10\(^5\). A well-leveled zero-tilled land coupled with a stale seedbed and residue mulch can be an effective method for suppressing weeds in dry-DSR. Application of pretilachlor + safener @ 0.45 kg/ha on 3 DAS and conoweeding on 45 DAS recorded higher weed control efficiency of 86.7% which lead to highest grain yield of 6,216 kg/ha in direct seeded rice\(^6\). The yields of direct seeded rice in dry fields as well as direct seeding of sprouted rice seeds in puddled situation were proved to be more sustainable for the productivity of rice-wheat system than
growing of rice by transplanting methods. With retention of wheat residue @ 5 t/ha the emergence of grassy, broadleaf and sedges species reduced in the range of 73 to 76%, 65 to 67% and 22 to 70%, respectively, compared with no residue control in ZT-DSR. Also, the residue mulch from the previous rice crop of 6 and 8 t/ha reduced emergence of *Phalaris minor* by 45 and 75%, respectively in zero tillage wheat.

Chemical Method: In direct seeded rice, herbicides hold great promise as they can arrest weed growth from the beginning of crop growth. Chemical method of weed control is easy and has been found economical. In direct seeded rice, herbicides are considered as an alternative or supplement to hand weeding. Significance of herbicides in DSR is overwhelming as weeds and rice emerge at the same time necessitating early weed control. Some mimicry grassy weeds (*Echinochloa sp*.,) and too small weed seedlings to be pulled out restricts manual weeding leaving chemical weed control as a viable option. Over the years, chemical weed control has expanded manifold in DSR and is likely to increase further as the labour scarcity, rising wage rates and shift from transplanting to direct seeding are emerging as the dominant compelling forces. Several authors have concluded that chemical weed control is feasible as it is quick, easy and economical, also the herbicide application in dry-seeded rice reduced weed biomass by 89% to 99% compared with the non-treated control. Subsequent weed flushes (after residual effects of pre-emergence herbicides are lost) are controlled by suitable post-emergence herbicides. Skipping post-herbicide treatment might result in a grain yield loss of 9-60% in DSR.

Examples of post-emergence herbicides include bispyribac sodium, penoxsulam, pyrazosulfuron, bentazone, bensulfuron, carfentrazone, clomazone, cyhalofop, molinate, propanil and fenoxaprop. Post-emergence application of bispyribac sodium and penoxsulam at 25 g/ha provided effective control of all the weeds in DSR. Post-emergence application (15-25 days after sowing) of bispyribac-Na 25 g a.i./ha in direct seeded rice was found very effective on most of grasses like *Echinochloa sp*., but it was weakly effective on perennial sedges, *Digera arenis*, *Leptochloa*, *Eragrostis* sp etc. Bispyribac-Na works well in saturated soil conditions. A study conducted in India found that wheat residue mulch of 4 t/ha reduced the emergence of grassy weeds by 44-47% and of broadleaf weeds by 56-72% in dry drill-seeded rice and resulted in 17-22% higher grain yield. With the application of different treatments the average grain yield from direct seeded rice ranges from 1.77 t/ha to 3.5 t/ha and found significantly higher yields with application of bispyribac-Na @ 80/ha supplemented with one hand weeding.

Biological Method: Generally, weeds are managed either manually or by using herbicides but this manual is costly, time consuming and soon regenerates, thus was not feasible, however, chemical application creates soil and water pollution and needs technical know-how for its application. Thus, to overcome such problems, a pollution free and economic option for weed control is biological control of weeds. Some biotic agents for weed controlling are insects, mites, nematodes, plant pathogens, animals, fish, birds and their toxic products; out of which insects are one of the important groups. Also, use of myco-herbicides is now being studied to reduce herbicide dependency. Moreover biological control strategy is not something on which one can solely depend to control weeds especially in direct seeded rice where weed pressure is tremendous. Biological strategy should be used in conjunction with herbicides. However this is an interesting area of research where efforts can be made to develop biological control strategy which is compatible with other methods.

Integrated Weed Management: Weed-rice ecological relationships are never static. The continuous adoption of any particular rice production practice causes a shift in dominance and distribution of rice weeds. Thus, adoption of Integrated Weed Management, also called "ecological approaches of weed management" for weed management is suitable for long term weed management by combining the use of cultural, mechanical, thermal, biological and chemical means based on ecological approaches, that prevents weed reproduction, emergence, promote weed seed bank depletion and minimize weed competition. So, a brief description about Integrated Weed Management in rice is given below: A study conducted in India found that wheat residue mulch of 4 t/ha reduced the emergence of grassy weeds by 44-47% and of broadleaf weeds by 56-72% in dry drill-seeded rice and resulted in 17-22% higher grain yield. Integrated weed management in dry-DSR through Pendimethalin 30 EC (stomp) @ 1 kg a.i./ha as pre-emergence application followed by 2,4-D or 2,4-D sodium salt 80 WP @ 0.5-1 kg a.i./ha at 25 DAS followed by one hand weeding at 45 DAS or Bispyribac @ 25
g a.i./ha as post-emergence application + Azimsulfuron @ 17.5 g a.i./ha at 20 DAS and one hand weeding at 35 DAS or stale seed bed followed by pendimethalin 30 EC (Stomp) @ 1 kg a.i./ha as pre-emergence followed by post-emergence bispyrribac (Nominee gold) @ 25 g a.i./ha at 20 days of seeding resulted best alternative for manual hand weeding practices giving higher net return per unit investment\(^{52,53}\).

**Economics of Different Weed Management Practices:** Among the different weed management practices, hand weeding is laborious and generally more expensive; however, cheapest practices are chemical control. Sesbania as brown manuring was as effective as the mulch in realizing higher economic returns\(^{77}\) with highest gross return from the intercropping Sesbania in two rows interval of rice; where the lowest gross return was obtained from rice sole rice\(^{85}\). Double row rice alternating with single row cow pea gave the highest net income with a corresponding low cost/benefit ratio of 0.25\(^{86}\). The direct seeded rice-wheat sequence with conventional tillage produced maximum rice equivalent yield 7.44 t/ha (for 3.1 t/ha rice and 3.6 t/ha wheat) and 99.8% higher net return and 90.6% higher net benefit cost ratio\(^{86}\).

**CONCLUSION**

DSR with suitable conservation practices has potential to produce slightly lower or comparable yields as that of TPR and appears to be a viable alternative to overcome the problem of labour and water shortage. Weeds being dynamic in nature are one of the major constraints to the successful cultivation of rice. Weed management is a fundamental practice and a great challenge for the weed researchers and rice farmers. Therefore, there is a need of appropriate and economical weed management technology for the sustainable rice cultivation. There is a need to integrate different weed management strategies for sustainable weed control in direct seeded rice, such as the use of a stale seeded practice, the rotation of different systems, the use of crop residue as mulches, appropriate agronomic practices (row spacing, seeding rates and manual or mechanical weeding) and appropriate herbicide mixtures.

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