Bulletin of Environment, Pharmacology and Life Sciences
Bull. Env. Pharmacol. Life Sci., Vol 7 [2] January 2018 : 108-117
©2017 Academy for Environment and Life Sciences, India
Online ISSN 2277-1808
Journal's URL:http://www.bepls.com
CODEN: BEPLAD
Global Impact Factor 0.876
Universal Impact Factor 0.9804
NAAS Rating 4.95

REVIEW ARTICLE **OPEN ACCESS**

Weeds and Progressive Weed Management techniques in Rice (*Oryza sativa*. L.): A review

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ABSTRACT
Weed management is the foremost component in rice production especially in the countries like India, which depends 60% population on it. The losses occurred due to weeds in rice crop around India is 15 to 90 percent in different environments and under various establishment methods. Studies reported that ineffective weed management practices with respect to time and method led to total crop failure under direct seeded rice. Any single method of present available weed management methods would not control weeds effectively. Integrated weed management (IWM) practice offers widely usage of different weed management techniques together enhanced rice productivity with the same cost. IWM protects the environment sustainability and biodiversity by not depending on solely any one weed management practice. It provides environmental healthy and ecofriendly practices by using the natural resources and biological life cycles to reduce the competition from weeds and favours the crop production. In the review paper we enlisted broadly available weed management techniques in all aspects. Mainly evolved cultural, mechanical, biological and chemical weed management practices over the period of time in favoring crop growth and to reduce the weed competition in the field. Together using weed management practices are useful for effectively controlling of weeds in sustainable and eco-friendly manner. Apart from these, microorganisms used in the weed management and developing research on weed resistance and weed tolerance are the mostly concentrating methods in current scenario.
Keywords*: Rice crop, Weeds, Crop establishment method and Integrated weed management*

Received 11.10.2017 Revised 03.11.2017 Accepted 09.12.2017

INTRODUCTION

Cultivated area in India is 143 million ha, out of which 85 million ha (60%) is completely depends on rainfall received throughout the year. The average rainfall in India is 1194 mm and its intensity, distribution throughout the country is erratic (1). The most preferred crop in India is rice, which is cultivating in 43 million ha including under rainfed and dryland agroecosystems. Rice is grown under different ecological conditions like it is grown in up, medium and lowland with different cultural techniques through direct seeding, transplanting and SRI under puddle conditions. India has the low average productivity of rice, i.e., 2.3 t ha^{-1} and additionally 4 million tonnes of rice is required to satisfy the current demand of rice production. Meanwhile the production losses due to pests and diseases and weeds were increasing day by day. Losses due to weeds are the foremost importance to be concentrated in rice production systems, they interfere with all the activities involved in the field throughout crop growing period. They are very much competitive with crops for all the inputs like nutrient, sunlight, space, and water and negatively affected the crop growth and yield. It is required to reduce the weed competition in various crop establishment methods from sowing/emergence of the crop upto sensitive growth stages and need to be developed an effective weed management techniques. In developing countries like India, shortage/less availability of labour for agricultural work is the prominent factor led to inefficient management practices like untimely agricultural operations resulting to yield reduction. It is therefore imperative to look for alternative methods from transplanting like direct seeding, SRI etc. (2). The unavailability of manpower and skilled manpower to work with machinery, farmers are interested to use the herbicides for controlling the weeds in different times during the crop period or transplanting under puddled conditions. Therefore herbicides are dominant in Indian market and it shared16 percent to pesticide consumption. The time and dosage of herbicides are very important factors for raising the

healthy crop. During the herbicide application, these factors must be careful, because the sub lethal dosage of herbicide led to ineffective weed control and total crop failure some times. Mechanical weed management practices through conoweeder/rotary welders were more helpful during the agricultural operation (3). Effective weed management techniques are very important to get the potential yield of cultivars. Apart from these, currently microorganisms based biological weed control was successfully developed and practiced in some parts of the world. Knowledge regarding the weed growth habit, and its molecular structures are need to understand for developing effective weed management practices. Keeping on this view, we concentrated the advanced and progressive integrated weed management practices to reduce the negative effect of weeds on grain yield of rice crop in the present review paper.

WEED FLORA AND WEED DYNAMICS IN DIFFERENT ESTABLISHMENT OF RICE

Weed Flora of line and drum seeded rice (Direct seeded)

Kolhe (4) reported that weeds species like *Echinochloa colonum, Ischaemum rugosum* among the grasses; *Borreria hispida, Alternanthera sessilis, Commelina benghalensis, Cyanotic axillaris, Splaelanthus indicus*, *Eclipta alba*, among the broad leaved weeds; *Cyperus microria, Cyperusdifformis, Cyperus iria, Cyperus esculatus*, among the sedges were dominant in direct-seeded rice under puddled condition at Raipur, Chhattisgarh. On alluvial, sandy loam soils of Central Rice Research Institute, Cuttack, Odisha, Moorthy and Saha (5) observed that *Cyperus difformis, Fimbristylis miliaceae, Ludwigia parviflora, Sphenoclea zeylanica* and *Scirpus articulates* were the predominant weeds in puddled-seeded rice. The predominant weed flora comprised of *Commelina benghalensis, Ammania baccifera, Scripus sp., Cyperus difformis,Cyperus iria, Echinochloa crusgalli, Panicum dichotomiflorum* and *Setaria glauca* were found in direct seeded puddled rice on clay loam soils of Himachal Pradesh, Palampur (5). Subramanian et al. (6) found that grasses like *Echinochloa colonum, Echinochloa crusgalli,* and *Cynodon dactylon*; sedges like *Cyperus rotundus, Cyperus iria, Cyperus difformis and Fimbristylis miliaceae*; and broad-leaved weeds like *Eclipta alba, Ammania baccifera, Ludwigia parviflora*, and *Phyllantus niruri* were the major weeds in drum seeded rice under puddled condition on sandy clay loam soils of Madurai, Tamil Nadu. Prasadet al. (7) observed that the dominant weed flora of the experimental site was by *Echinochloa colonum, Echinochloa crusgalli,* and *Panicum repense* among grasses; *Ludwigia parviflora*, and *Marselia minuta* among broad leaf weeds; and *Cyperus iria* (yellow nut sedge), *Cyperus difformis* (Umbrella sedge) among the sedges in puddled direct- seeded rice on clay soils of Gangavathi, Karnataka. Saha (8) observed that *Echinochloa colonum, Cyperus iria, Fimbristylis miliacea, Scirpus articulatus, Panicum repens, Leptochloa chinensis, Sphenoclea zeylanica, Ludwigia parviflora, Aeschynomene indica, Limnophila heterophylla., Cleome viscosa, Monochoria vaginalis* and *Melochia corchorifolia* were the major weeds infesting rice in direct-sown rainfed lowland rice in Cuttack, Orissa. The weed flora in drum seeded rice on sandy loam soils of Thanjavur consisted of *Echinochloa crusgalli, Cynodon dactylon* among grasses; *Cyperus difformis, Cyperus rotundus* among sedges; *Eclipta alba, Ammania baccifera, Marselia quadrifoliata* among broad leaved weeds (9). Important weed flora observed on sandy loam soils of Crop Research Station, Ghaghraghat, Bahraich, Uttar Pradesh were, *Fimbristylis miliacea, Cyperus rotundus, Leptochloa chinensis, cyanotis axillaries Alternanthera sessilis, Commelina benghalensis* (10). Singh and Singh (11) observed that monocot weeds were predominant in dry and drumseeded rice in Gangetic alluvial sandy loams of Varanasi, Uttarpradesh. The predominant weed species were *Echinochloa colonuum, Echinochloa crusgalli, Cyperus rotundus, Cyperus iria, Fimbristylis mulliaceae, Eclipta alba* and *Casuria oxilaris.* Pandey et al., (12) reported that *Echinochloa colanum, Casulia oxillaris, Alternanthera sessilis* and *Cyperus iria* were the most predominant weed species in direct seeded rice in Jabalpur conditions of Madhya Pradesh.

Weed flora and weed dynamics in transplanted rice

Singh et al. (13) observed that *Echinochloa colona* (33.1 per cent), *Caesulia axillaris* (18.5 per cent), *Cyperus iria* (14.0 per cent), *Commelina benghalensis* (11.5 per cent) and *Fimbristylis miliacea* (11.5 per cent) were the major weeds in the experimental plots of transplanted rice in Pantnagar, Uttaranchal.During dry season at the Kalyani, West Bengal, the major weeds in transplanted rice were *Cyperus iria*, *Cyperus difformis* and *Fimbristylis littoralis* Gaud and broad leaf weeds of semi-aquatic nature, including *Ludwigia parviflora* L. Roxb (14).Among the total weed population at 30 days in transplanted rice, grasses (*Echinochloa crusgalli*) constituted 16.9 per cent, sedges (*Cyperus iria* and *Fimbristylis miliaceae*) 47.0 per cent and broad leaf weeds (*Ludwigia parviflora, Commelina benghalensis* and *Sphenochlea zeylancia*) 36.1 per cent of the total weeds population on clay loam soils of Cuttack (15).Yadav et al. (16) found that transplanted rice field was infested with 85 per cent of grasses like *Echinochloa colona, Echinochloa glabrescens*, 8 per cent of broad leaved weeds like *Euphorbia sp*. and *Ammania baccifera* and 7 per cent of sedges like *Cyperus rotundus, Cyperus iria,* and *Cyperus difformis* in transplanted rice on clay loam soils of Karnal, Haryana.

Weed flora and weed dynamics in SRI method rice

The dominant weeds under puddle conditions were *Echinochloa cursgallli, Cyperus deformis, Eclipta prostrata, Ammanni abacifera* and *Marsilea quadrifolia* where as *Echinochloa colona, Cyperus iria, Eclipta prostrate* were dominant under non-puddled condition (16). Weed flora influenced by different crop establishment methods are presented in Table 1.

Table 1. Weed flora influenced by different crop establishment methods (17)

Particulars	Establishment method		
	Transplanted	Dry seeded	Wet seeded
Total weed species	21	50	57
Total weed species	18	38	44
Total weed species	13	22	28

YIELD LOSSES IN RESPECT OF DIFFERENT CONDITIONS

The incidence of weeds from the crop sowing/emergence upto critical growth stages is very integral part has to be concentrated, because it affect not only the crop yield and habitat also the crop micro climate and environment. Therefore controlling of weeds at initial stages are very essential (18). Weedy check gives nearly 53% and 91% reduction of grain yield over the best treatment of rice crop grown under puddled and unpuddled condition (19). The loss in grain yield due to weeds is varies from 30-50% and 80% (20,21,22) In manually transplanted rice, the yield loss was minimum (46 %) when compared with 90% losses with direct seeded rice (23). Yield reductions due to weeds were 26 to 46 % in Manawthukha, 49 to 62% in Shwethwey in 2002 and 38 to 47 % in Shwethwey in 2003. Weeds are the negative determinants for the production of rice grain yield. Early checking the weed growth found to be more important than later stages resulted for getting higher yield of rice (24).Loss of grain yield in different methods of rice establishment in India presented in Table 2.

Table 2 Loss of grain yield in different methods of rice establishment in India (25, 26)

S.no	Methods of rice establishment	Reduction in yield due to weeds (%)
1	Upland rice	97
2	Upland dry seeded rice	94
3	Dry seeded rice	17-73
4	Wet seeded rice	85

CROP WEED COMPETITION

Crop must be free from weeds from the crop emergence to the critical crop growth stage it is also called as critical period for competition, the period between early growth during which can grow without affecting the crop yield and point after which weed growth does not affect the yield. During the crop weed competition period, weeds can also be maintained under critical threshold level to maximize usage of available resources for the production of higher grain yield (27). The competition between the crops and weeds meanly for the available resources and it varies depends on the particular crop variety, soil factors, crop duration, rainfall, spacing for the light, nutrient and spacing among the variables (28). Generally the critical crop weed completion period is 2-8 weeks from the date of emergence of the crop and practicing of additional weeding during the period resulted in yield increase of 43-80% (29).Direct seeded rice was more vulnerable for loss of grain yield due to the presence of weeds compared to transplanted rice and it adversely affect not only the grain yield and crop quality. The advantage of transplanted rice was well grown rice seedlings established better and continuous water present in stagnant condition reduces the weed emergence. Weed competition with plants from the emergence to 45/60 days after transplanting of sowing. Weed competition from the later stages have a significant reduction in grain yield negative effect (30). It is most important that early weed control is the foremost important in the direct seeded rice compared to transplanted rice. Because it forms crop leaf canopy and reduction of grain yield or complete failure of the crop. Critical period of crop weed completion in rice is influenced by different rice establishment methods was presented in Table 3.

Table 3 Critical period of crop weed completion in rice is influenced by different rice establishment methods (31,32,33,34)

S.No	Rice establishment method	Critical period of crop-weed cmpetition
1	Transplated rice	20-40 DAT
2	Wet seede rice	15-60 DAT
3	Drys eeded rice	15-60 DAS
4	Rainfed direct seeded rice	0-90 DAS
5	Upalnd direct seeded rice	30DAS

*DAT: Days after trnsplanting; DAS: Days after sowing

PRINCIPLES OF WEED MANAGEMENT

The principles that underline ecologically and economically viable weed management system in rice are: (a) adapting the weed management options that suits to the environment of the region, including soil, water, climate and biota present at the site; (b) optimizing the use of biological and chemical/physical resources for effective management of weeds in rice. An important principle underlying long-term weed management is that weed seed banks maintain emergent populations, and therefore, seed banks must be managed at low densities to reduce the potential for a buildup of intractably high weed populations. There is no single weed control method for effectively and economically managing weeds in rice to attain optimal rice productivity and production. Hence, integrated weed management strategy using a combination of several weed control methods is often envisaged.

WEED MANAGEMENT APPROACHES

There are different strategies are involved for obtaining the integrated weed management. These are combines preventive, cultural, mechanical and biological weed control methods in an effective, economical and ecological manner.

Preventive approaches

This approach mainly concentrate and restrict the entry and establishment of weeds in a new area. The commonly used crop seeds for sowing purpose should be very pure and without any admixture of weeds. So, purchasing the seed from government authorized shop keepers is necessary for eliminating the weeds. Apart from seeds, wees can also entry into the new area by moving of the machinery and inputs from one place to another place in the field. Sanitation should be followed in the field around. Need to take care of using the machinery need to be free from any weed propagules. These weed propagules can disperses by water, wind, animal rudimentary and by partial decomposed farm yard manure etc. in the field. Soil solarisation is a preventive method that exploits solar heating to kill weed seeds and therefore reduce weed emergence. Generally Polythene film can be used as a soil solarisation material. Before sowing, seed separations by dipping the seed in 20 % brine solution, which helps that weeds seeds float in brine solution can be separated and removed.

Cultural Approaches

Generally followed intercultural operations are the part of cultural approaches and some other practices has been following to reduce the weed competition with plants and for higher input use efficiency. In the approaches several weed management practices can be followed either by single and integration of couple of methods.

Flooding

Flooding is a conventional primitive method generally followed in rice crop, which is useful to reduce the weed emergence and its population at the early stages of the crop growth. It gives the earliest advantage to the crop by reducing the competition upto critical period. The depth and timing were the major concerning components need to be studied. Generally recommended 2 cm depth of flooding in the field at early growth stage was more effective than the non-flooded condition (8). Intermittent flooding is also a effective method to control the weeds. It negatively affect the weed density and population than the remaining methods. Increasing flooding upto 5cm or 10 cm depth were effective than the 2cm depth (13), but crop growth stage have to considered. Herbicidal application followed by flooding reduce the weed growth and it could largely reduce the subsequent weed growth and reduce the need for further weeding. It is very much useful practice to reduce the cost of cultivation and saving of time and large inputs on weed controlling.

Tillage practices and Land preparation

Tillage is an important weed management tool to reduce the weed population at earliest crop stage. Generally farmers followed tillage at top 15 cm, but deep tillage once in a year at summer season is effective practice to reduce the weed propagules in soil. It has eventually reduce the weed population and its density for the following season. Under zero tillage condition, weed emergence observed more than

the conventional tillage condition (35). As a result of continuous following zero till condition led to a profound seed bank gets accumulated in the soil layers, it must be removed or eradicated by following the deep tillage upto a depth of 30 cm by large implements. It should be rotated for every 2-3 years in the mainly problematic areas. Deep tillage brings the weed seed bank to the surface and it can be destroyed by exposing the higher temperatures at field especially in the summer season. By brought out the weed propagules to the surface from deeper layers exposed to the sun in summer season, it prevents the germination and emergence by desiccation and their emergence. By following the deep tillage in the summer season is more important practice in mainly problematic areas.

Stale seed bed technique

Stale seedbed technique is an effective method for controlling the weeds mainly in the areas of upland, dryland and rainfed rice ecosystems. This practice significantly reduced the weed density, weed population and weed drymatter in the many areas of the country. This method useful where the weed problem is severe and difficult to control. The stale seedbed technique can result in improved weed management in problematic areas or with problematic weed species (24). This method is followed at the early stages of the crop growth to reduce the weed emergence and its completion with the crop plants. It includes allowing the weed seeds to grow on the seed bed or field after a light irrigation or a small received rainfall, and later the weeds would be controlled by application of herbicide chemicals (paraquat or glyphosate) or mechanical methods could be used to control the weeds before sowing. It is very useful in direct seeded rice and to control the problematic weeds at the early crop growth stages.

Seedrate, plant population and crop geometry

Number of seeds per unit area produced plant canopy which is dominating over the weeds for growth inputs. The plant canopy produces vigorous dry matter and it showed smothering effect on weeds resulted to less competition for available resources between crops and weed. It creates the less space to the weeds for flourish and the natural available resources are limited in case of weeds under the less space availability. Optimum plant spacing and plant population produced definite plant canopy which is determinant the competition between the plants and weeds for growth determining factors (16). The dominance effect of plants over the weeds are resulted to reduction of weed population at the early growth stages of plants led to efficient utilization of available resources for higher plant growth and biomass. In direct seeded rice increased seed rate, plant population per unit area resulted to suppress the weed growth and anchorage the optimum plant establishment. The number of seeds 200-300 per m^2 resulted in a significant increase in the grain yield, decrease in the weed density, biomass, and its dry matter compared over 500 seeds per m^2 (36). Row spacing is one of the major factor for determining the plant population and weeds per unit area, the lesser density of plant population led to more space available for weeds and its favorable for its growth. It follows the reduction in the grain yield and occurrence of weed seed bank in the surface soil layers. So, the field must be maintained free from weeds upto critical crop growth period. This period is lower in case of less spaced crops compared to wider spaced crops, higher seeding rates are suppress the weed growth and density. It can be used as a tool in the integrated weed management. An optimum seed rate and maintaining the optimum plant population per unit area helps in dominant over the weeds and provide favorable environment to the crop for its growth.

Crop cultivars

Fast growing and large canopy producing crop cultivars were the better competitors with weed for limited availability of inputs like nutrients, moisture and light. These cultivars having the characters like early producing crop canopy than the weeds are better suited for reducing the weed competition with the plants. Competitive cultivars suppress the weed growth and hence it substantially reduce the herbicide quantity use, manpower and easy access to control the weeds by using any one of the chemical herbicide and general manual weeding (37). Because the using of competitive cultivars is an effective method of weed management and it plays an important role in integrated wed management practices (38).By providing the competitive cultivars the yield loss in rice gain yield may varies range between 10-70 %. The occurrence of weed growth at specific time and produces crop dry matter is the majorly negatively correlating with grain yield. Crop dominance over weeds and its suppression are the major determinants for choosing the cultivar specific. Therefore, breeding of the more crop dominance and suppressed weeds are concentrated factor in future. The cultivar characteristics are early achieving plant height and produced vigorous plant dry matter, biomass accumulation, dropsy and large leaves, maximum leaf area index maintained during the most part of the crop growing period, high individual leaf weight during vegetative stage, and fast canopy closure and early vigour. Recent study indicated regarding crop allelopathy (39), it refers to the process of the release of chemical compounds by living and intact roots of crop plants that affect plants of other species (40). Therefore, allelopathy is the important component in sustainable weed management and it plays an important role in integrated wed management methods for

controlling the weeds. The breeding resulted cultivar should be well adapted to the specific environment and habitat should be sustainable to health. Scientists have concentrated on that such type of breeding cultivars in furthermore it should be accepted by farmers and finally end-users. These cultivars have strong root system at early stage compete better with weeds when leafs are to be developed.

Crop Rotation and Green/Brown Manuring

Mono cropping offers the cultivation of the same crop varieties year after year at the same piece of land, it establishes the favorable relationship between the specified crop, and its volunteer plants around the field. These volunteer plants transfers the weed propagating materials from one season to another season. These are more favorable structures to the weeds propagation, and keeping concentration on these structures and keep it under below threshold level causes safeguard to the crop plants from weeds. Repetitive cultivation of same crop and using of same mode of action of herbicide creates the opportunity to weeds for developing the weed resistance or tolerance capacity itself. Therefore crop rotation is an effective tool to reduce the weed population and it is an important component in the integrated weed management without affecting the sustainable environment. Resent research stated that crop rotation can be used for minimizing the crop damage from weeds. The terms crop associated and crop bound weeds are mainly present in the crops like rice and wheat, these can be most effectively controlled by crop rotation. Crop rotation mainly affect the weed habitat already present in the environment and break those life cycles and make it favorable to the crop growth. Changing in cropping pattern along with agronomic practices helps the crop survival from the weeds. Recent study reported that cultivation of Hyacinth bean and velvet bean rotations reduced weed cover, total weed dry matter accumulation, and weed density by about 70, 80, and 90 %, respectively, in comparison to continuous rice (41). By following the optimum plant spacing in the intercropping systems, weeds have narrow plant available spacing led to dominance of the crop over there weeds is make to favorable for crop growth. Narrow spacing cropping led to maximize the input use efficiency and ultimately improves the crop growth and yield. Green manuring with cowpea and sesbania resulted higher nutrient uptake and maximum production of crop yield at the same time reduces the weed flora, weed density, wed population and weed dry matter. Because these cowpea and sesbania have a smothering effect on weeds and reduced the weed competition with plants. Therefore, green manuring acts a s effective tool in the weed management and important component in the integrated weed management practices. Brown manuring an operation to control the weeds effectively in rice, application of herbicide on weeds make it desiccate at flowering instead of using cultivation. The plant residues are left stand standing. It is practiced in rice cropping systems on sesbania plants. After sesbania plants grown for 30 days application of 2,4-D @500g ha^{-1} on sesbania plant helps in desiccate the sesbania leaves in the field and make it useful for manuring purpose for further. This technology is useful for weed management and important toll in integrated weed management practices mainly used in rice and wheat based cropping systems.

Mechanical Weed Control

Mechanical weed control in rice crop is common in India and its scope depending on the condition of the soil, land holdings of the farmers and financial affordances of the farmers. Being an 85% small farmers are presented in India, this importance of this method is very limited and it has to be exploited in the farmer's beneficiary. Generally mechanical conventional weed management in the farmer's field has been done by different types of weeders and hoes are used independently of together. Mechanical weeding methods such as finger weeder, wheel hoe, or conoweeder, helps to control weeds effectively at early stages in lowland rice fields. It has recommended mainly at different crop periods at sensitive crop growth stages. Recent studies reported that mechanical weeding resulted 72% reduction in the total weed density compared with the control (42). Mechanical weed management followed by chemical application led to higher efficacy in weed control over the control.

Chemical weed management

Chemical weed control through application of herbicides is essential tool in rice crop as they produce maximum weed control and their use is more energy and labour efficient than cultural/ manual or mechanical methods. As cultural, mechanical weed management practices are too much time taking, laborious, and chemical weed management offers fast weed control in rice field. Along with advantages of herbicides, the concerned measures like safety, ground water and atmospheric contamination, increased weed resistance to herbicides, destruction to beneficial organisms, and concerns about endangered species have also been made with the indiscriminate use of herbicides have to be considered. Repeated application of same herbicides on the same pant led to shifting of weed flora, and emerging of secondary type of weed as a major weeds in the field. Some studies reported that repeated application of butachlor, thiobencarb, and 2,4-D to rice resulted in predominance of perennial sedges, *Cyperus serotinus*, and *Eleocharis kurogawa* (43). In India, due to continuous use of butachlor and anilofos in rice, particularly in northwest India, the weed flora is shifting to sedges, such as *Cyperus sp., Scirpus sp., Fimbristylis sp*.,

Eleocharis sp., etc., and broad-leaved weeds, such as *Caesulia axillaris*. In puddled transplanted rice, pre emergence herbicides (butachlor, thiobencarb, nitrofen, anilofos, oxadiazon, and pendimethalin) are very effective. These pre emergence herbicides are applied 4–7 days after transplanting but before weed emergence. Recently, a number of low dose sulfonyl herbicides such as metsulfuron, bispyribac, and azimsulfuron have been developed that have a broad spectrum of weed control. For effective weed control in DSR, sequential application of pre- (2–3 days after sowing) and post emergence herbicides (25–30 days after sowing) proved useful. For efficient use of herbicides, the application method should be perfect. Nozzles, spray tips, multiple nozzle booms, pressure regulation, and spray calibration are the essential components of right spray application technology. Chemical weed management is proved to be effective in weed management and an important component in integrated weed management technique in around the globe.

Bio-herbicides

Micro-organisms and their secondary metabolites were used for preparation of chemicals, which inhibit the weed growth and provide favorable environment for crop growth. These are important, cheaper, effective and current available in the present day market in large quantities and more sustainably economical to the eco-friendly environment. It clearly defined by by four strategies, viz. classical, bioherbicidal, phytotoxins, and integrated weed management approaches. Some of the example have been given in table 4 list of biocontrol agents reported to be effective in weed management in rice followed around the globe successfully. The success of the approach is mainly depends on the specific host and its habitat in the concerned environment. In the bio herbicide approach, the abundance of a natural enemy is increased by culturing it in favorable conditions and then these enemies are applied in large amounts to the weed population.

Table 4 List of biocontrol agents reported to be effective in weed management in rice (44, 45, 46, 47)

S No	Weed species	Biocontrol agent
1	*Cyperus esculentus*	*Puccinia canaliculata*
2	*Eichornia crassipes*	*Fusarium pallidoroseum*
3	*Cyperus difformis*	*Curvularia tuberculata*
4	*Aeschynomene virginica*	*Colletotrichum gleosporoides*
5	*Eichinochloa crusgalli*	*Cochliobolus lunatus*
6	*Altannanthera phyloxeroides*	*Fusarium sp.*

INTEGRATED WEED MANAGEMENT

Weed management concentrates the reducing the weed population below the economic threshold level which cannot affect the crop growth. Recommended weed management practice aimed to keeping the weed population which don't have negative effect on crop yield and economically feasible at the same time environmentally sustainable. In the different weed management practices any one of the weed management practice cannot reduce the weed population, therefore combining of cultural, mechanical, chemical and biological weed management practices needs to be established to reduce the weed population below the ETL for achieving higher yields. So, integrated weed management provides the opportunity for reducing the weed biomass, weed density and weed population and coordinates the combining use to reduce in sustainable manner (48). The most effective weed management practices are involved the combined use of preventive, cultural, mechanical, chemical, and biological weed control techniques in an effective and economical way. In transplanted rice, flooding followed by puddling with 2-5 cm of depth of water controls the grasses, broadleaf weeds and sedges effectively. Recent studies stated that at higher nitrogen rate with optimum plant population recorded maximum weed control efficiency [49]. An optimum seed rate and maintaining the optimum plant population per unit area helps in dominant over the weeds and provide favorable environment to the crop for its growth. Competitive cultivars suppress the weed growth and hence it substantially reduce the herbicide quantity use, manpower and easy access to control the weeds by using any one of the chemical herbicide and general manual weeding. Crop rotation can be used for minimizing the crop damage from weeds. The terms crop associated and crop bound weeds are mainly present in the crops like rice and wheat, these can be most effectively controlled by crop rotation. Mechanical weeding resulted 72% reduction in the total weed density compared with the control. In puddled transplanted rice, pre emergence herbicides (butachlor, thiobencarb, nitrofen, anilofos, oxadiazon, and pendimethalin) are very effective. These pre emergence herbicides are applied 4–7 days after transplanting but before weed emergence. Recently, a number of lower dose sulfonyl herbicides such as metsulfuron, bispyribac, and azimsulfuron have been developed that have a broad spectrum of weed control. For effective weed control in DSR, sequential application of pre- (2–3 days after sowing) and post emergence herbicides (25–30 days after sowing) proved useful.

Recent studies reported that crisscross sowing plus one hand weeding plus herbicide application and one hand weeding plus herbicide application, provided better results than the results obtained by the use of only one weed control method, i.e., two hand weedings (50).

Table 5 Influence of IWM on the rice grain and biological yield of the direct sown puddled rice (50)

S.No	Weed control measures	Grin yield (t ha^{-1})	Biological yield (t ha^{-1})
1	Weedy	0.7	7.7
2	Two hand weedings	5.0	12
3	Herbicide+one hand weeding	5.3	12.6
4	Criss cross sowing+one hand weeding	3.8	11.5
5	Criss cross sowing+one hand weeding +herbicide	5.5	13.3
LSD at 5%		0.1	2.8

BIOTECHNOLOGY ASPECT IN WEED MANAGEMENT

Transgene technology has been used to generate herbicide-resistant crops, which have profound effects on the herbicide market. The technology has the potential to make crops better competitors with weeds through improving competitive traits or making the crop more allelopathic. It has wide application in agronomy and horticulture by transgenic bio control agents. Molecular Systematics helps to provide information on weed identification and characterisation. These are mainly selective sulfonyl urease; aminoacid synthesis and acetolactate synthetase.

CONCLUSION AND FUTURE RESEARCH

In developing countries like India, shortage/less availability of labour for agricultural work is the major prominent factor led to alternative methods from transplanting to direct seeding methods. Weed occurrence under direct weeding is the maximum compared to remaining crop establishment methods of rice. Hence there is a need to establish the effective weed management practice under direct seeding method which is economically feasible to farmers and sustainable and eco-friendly manner. The usage of herbicides in direct seeding is maximum and keep the weed population under ETL, but it is not safeguards to the environment. Breeding of high competitive crops cultivars resulted more competitive with weeds at the initial stages provide favorable environment to the crop. Therefore, based on the available resources, combinations of many strategies (cultural, chemical, and prevention measures) as possible would control weeds more effectively than with the use of one weed control strategy. In future of climate change direct seeding rice is the adaptation strategy for mitigation the climate change on specifically rice production. So, using the integrated different weed management strategies offers the opportunity for reducing the weed infestation in rice crop effectively. These methods are long-term effective and sustainable manner.

The primary focus of integrated weed management should be on practices that adversely affect the weed propagule production, survival, and the propagule–seedling transition within the agroecosystem. The complex weed problems can be solved by breeding of herbicide resistance crop cultivars are possible. It is a challenge for weed scientists to develop integrated weed management systems that are innovative, effective, economical, and environmentally safe for current and future cropping systems and which can bring a more diverse and integrated approach to weed management.

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CITATION OF THE ARTICLE

T. Arunbabu and S. N. Jena. Weeds and Progressive Weed Management techniques in Rice (*Oryza sativa*. L.): A review. Bull. Env. Pharmacol. Life Sci., Vol 7 [2] January 2018: 108-117