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Weed Management in Transplanted Rice - A Review

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Abstract

Rice is an important food crop extensively grown in India. It is mainly grown as a wetland crop by transplanting seedlings into puddled fields. Conventional transplanting is the most common practice of rice cultivation in south India. Several factors are responsible for reducing the yield of transplanted rice. One of the cause for yield reduction is weed infestation. Weeds by the virtue of their high adaptability and faster growth dominate the crop habitat and reduce the yield potential of the crop. Normally the loss in yield ranges between 15-20 per cent, yet in severe cases the yield losses can be more than 50 per cent, depending upon the species and intensity of weeds. In this paper, we will summarize and review possible effect of weeds on transplanted rice, weed species, different methods of weed control, labour saving and economics of rice.

Keywords : Transplanted rice, Weed management, Economics

Rice (*Oryza sativa* L.) is one of the most important food crops of India. Rice is contributing 45 per cent to the total food grain production in India and is grown in an area of 44.1 million ha with a production of 106.64 million tones and productivity of 2.42 t/ha (Bhatt *et al*. 2017). It plays a vital role in food security and livelihood for almost every household. Out of the total 44 Mha area under rice cultivation, transplanting occupies 56 per cent (Anonymous, 2011).

Rice is grown under different ecological conditions as upland, medium and lowland with different cultural techniques through direct seeding, transplanting and system rice intensification. India has the low average productivity of rice, *i.e.,* 2.42 t/ha and additionally four million tons 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 from sowing/ emergence of the crop up to sensitive growth stages and need to be developed an effective weed management technique.

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 better weed control methods. Unavailability of manpower and skilled manpower, made farmers to use the herbicides for controlling the weeds in different times during the crop period under puddled conditions. Therefore, herbicides are dominant in Indian market and it shared16 per cent to pesticide consumption. The time and dosage of herbicides are very important factors for raising the healthy crop. Mechanical weed management practices through conoweeder / rotary weeders were more helpful during the Agricultural operation (Moorthy and Saha, 2001). Keeping this in view, attention was paid to compile advanced and progressive weed management practices that are followed in transplanted rice crop, to reduce the negative effect of weeds on grain yield.

Weeds remove a large amount of nutrients from soil. An estimate shows that weeds can deprive the crops by 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 as well as reduce the yield potential by harboring number of crop pests (Balasubramaniyan and Palaniappan, 2001). Hence successful weed control is essential for obtaining optimum yield of rice (Hussain and Aslam, 2008; Kumar *et al.,* 2007; Sathyamoorthy *et al.,* 2004).

The productivity of transplanted rice to a greater extent depends on adequate and efficient weed management. Transplanted rice faces diverse type of weed flora, consisting of grasses, broad-leaved weeds and sedges. They usually grow faster than rice and absorb available water, nutrient earlier than the rice and suppress rice growth. Effective control of weeds had increased the grain yield by 85.5 per cent (Mukherjee and Singh, 2005).

Weed free period during the critical period of competition is essential for obtaining optimum rice yield. This can be achieved by removing weeds manually, mechanically and through chemical sprays or by their combinations.

Weed Flora and Weed Dynamics in Transplanted Rice

A broad spectrum of weed flora infests rice crop. The composition and competition by weeds are dynamic and is dependent on soil, climate, cropping and management factors. Various studies were conducted regarding weed flora all over India (Table 1).

There is lot of variation in weed species observed. In spite of wide variation, the number of weed species that constitute the major portion of the weed flora, causing economic concern to the rice cultivation is usually less than 10 of the 350 species that are considered worldwide importance (Moody and Drost, 1981).

Yield Losses in Respect of Transplanted Rice

The incidence of weeds from the crop sowing/ emergence upto critical growth stages 28 to 42 days in transplanting rice has to be concentrated, because it affects not only the crop yield and habitat, also the crop micro climate and environment. Therefore, controlling of weeds at critical period (initial stage 4-6 weeks) is very essential (De Datta & Haque, 1982, Murthy and Shah 2001, Kim and Moody, 1989). Weedy check gives nearly 53 per cent and 91 per cent reduction of grain yield over the best treatment of rice crop grown under puddled and unpuddled condition (Ali and Sankaran, 1984). The loss in grain yield due to weeds varies from 30-50 per cent and 80 per cent (Sinha babu, Behera & Jha, 1992). In manually transplanted rice, the yield loss was minimum (46 %) when compared with 90 per cent losses with direct seeded rice (Hassan & Rao, 1993). 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 (Thapa & Jha, 2007).

TABLE 1

Major weed flora of transplanted rice in different regions

Major weed flora	Place	Reference
Echinochola crus-galli, Paspalum distichum and Caesulia axillaris	Pantnagar	Sarkar (2001)
Cyperus iria, Sphenoclea zeylanica, Leptochloa chinensis, Fimbristylis miliacea and *Eclipta alba*	Karnal	Chopra and Chopra (2003)
E.colona, E.crusgalli, Cyperus rotundus, Cyperus difformis, Fimbristylis miliacea, Ludwigia parviflora, and Ammania baccifera	Varanasi	Mukherjee and Singh (2004)
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 percent)	Pantnagar, Uttaranchal	Singh *et al.* (2004)
E.crusgalli, *Leersia hexandra*, *Marsilea quadrifolia*	West Bengal	Ghosh and Ghosh (2005)

Major weed flora	Place	Reference
Echinochloa crus-galli, E. colona, *Cyperus iria, C. rotundus, Fimbristylis miliacea*, *Ammania baccifera, Marsilea quadrifolia* and *Potamogeton distinctus*	Kashmir	Singh *et al.,* (2007)
Cyperus iria, *Cyperus difformis* and *Fimbristylis littoralis* Gaud and broad leaf weeds of semi-aquatic nature, including *Ludwigia parviflora* L	Kalyani, West Bengal	Bhowmickand Ghosh 2008
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*	Karnal	Yadav *et al.,* (2009)
At 30 days in transplanted rice, grasses *Echinochloa crusgalli* (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	Cuttack	Saha, 2009
Cyperus difformis, Fimbristylis miliacea, Scripus spp., *C. procerus, Echinochola colona, Panicum tripheron, Ludwigia parviflora, Spinanthus acemella, Rotala verticillaris, Lindernia veronicaefolia* and *Glinus oppositifolia*	Bangalore Karnataka	Ramchandra *et al.,* (2010)
Echinocloa crusgalli, Cynodon dactylon, Echinocloa colona, Cyperus rotundus and *Amaranthus viridis*	Varanasi	Sharma and Singh (2010)
Digitaria sanguinalis, *Echinochola crus-galli, E.colona, Panicum repens*, *Fimbristylis miliacea, Cyperus rotundus*, *Cyperus iria*, *Cyperus difformis*, *Ammania baccifera*, *Ludwigia parviflora*, *Eclipt prostrate*, *Eclipta alba*, *Lippanodi flora* Nich, *Marsilea quadrifolium*, *Sphenoclea zeylanica* and *Commelina benghalensis*	Orissa	Patra *et al.,* (2011)
Cyperus rotundus, Cynodon dactylon, Echinochloa colonum, Ceasulia axillaris, Phyllanthus niruri and *Parthenium hysterophorus*	Varanasi	Singh *et al.,* (2014)
Echinochloa crusgalli, Echinochloa colonum, Leptochloa, Chinensis Cyperus difformis, Cyperus iria, Fimbristylis miliacea, Eclipta alba, Ammania baccifera, Bergiaca pensis and *Ludwigiaparviflora*	Tamil Nadu	Parthipan and Ravi (2016)
Echinichloa sp., Panicum repens, Cynodondoctylon, Leptochloa chinensis, Eclipta alba, Ludwigia parviflora and Cyperus sp.	Raichur, Karnataka	Ramesha *et al.,* (2017)
Cyperus difformis, Cyperus iria (among sedges)*, Panicum repens, Paspalum distichum* and *Echinochloa colona* (among grasses), *Alternenthera sessilis, Monochoria vaginallis*, *Marselia quadrifoliata, Ludwigia parviflora* (among broad-leaf weeds)	Mandya Karnataka	Dhanapal *et al,* 2018

Among the different weed species, grassy weeds pose greater competition. They have an extensive and fibrous root system. Similarly, sedges grow huge in number and cause serious competition for nutrients. The roots of the sedges also dominate the surface feeding zone and obstruct nutrient flow to crop roots (Kim and Moody, 1989; Moorthy & Sanjoy Saha, 2002 and Singh *et al*., 2006). Weeds interfere with rice growing by competing for one or more growth limiting resources *i.e.,* nutrients, water, space, light and carbon dioxide, because of the limited supply of these valuable elements, their association therefore, leads to competition for these elements for the survival. Generally, one-third duration of the crop period should be maintained weed free. The critical crop weed competition from 28-45 DAT in transplanted rice was reported by various workers (Raju and Reddy, 1995; Nandal *et al.,* 1999 and Singh *et al.,* 2003). However, it was reported that crop and weed competition up to 60 days stage of transplanted rice resulted in 72 per cent reduction in grain yield (Singh *et al.,* 2004). Dhammu and Sandhu (2002) observed that *Cyperus iria* competition for the first 30 days caused less than one-fourth (12.9 %) of the total yield loss in transplanted rice while competition for 40 days resulted in more than half (43.5 %) of the total yield loss due to the weeds. Singh *et al.,* (2005) found that grasses constituted 14.1 per cent, sedges 71.4 per cent and broad leaf weeds 14.5 per cent of the total weed population in rice crop at 30 days stage. Mukherjee *et al.,* (2008) noticed that 20-40 days after transplanting was the most critical period of crop weed competition and found that weedy situation throughout the crop growth caused yield reduction to the tune of 57-61 per cent in transplanted rice.

Weed Management Approaches

There are different strategies, involved for obtaining the integrated weed management. These include combining preventive, cultural, mechanical and biological weed control methods in an effective, economic and ecological manner. Each of them has their own advantage and disadvantage and single method is rarely found effective so, summarized reviews are given below particularly in transplanted rice.

Preventive Approaches

This approach mainly concentrates and restricts the entry and establishment of weeds in to a new area. The commonly used crop seeds for sowing purpose should be pure and without any admixture of weeds. So, purchasing the seed from authorized dealers may be from government organizations, State Agricultural Universities and shop keepers are necessary for preventing the entry of weed seeds in to new zone. Weeds can also enter into the new area by moving of the machinery and inputs from one place to another place in the field, care need to be taken while moving machinery from one place to another so no weed propagules have adhered to the machinery. Weed propagules can also easily be disperses by water, wind, animal rudimentary and by partial decomposed farm yard manure etc. in the field. Hence, Sanitation should be followed in the field around one such procedure is before sowing, seed separations by dipping the seed in 20 per cent brine solution, which helps that weeds seeds float in brine solution can be separated and removed.

Cultural Approaches

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 in transplanting rice.

Flooding

Transplanting and growing rice in submerged conditions are probably the first two traditional steps towards weed control. Water serves as an effective cultural means of weed control in rice, as many weeds cannot germinate under flooded conditions. Research has shown that submergence of rice fields is required for few days only after transplanting so as to discourage weeds, subsequently soil saturation is enough (Gill, 1994).

Flooding is 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 are the major concerning components for flooding. Generally, 2 cm depth of flooding is recommended in the field at early growth stage. It is found to be more effective than the non flooded condition (Saha, 2005). Intermittent flooding is also an effective method to control the weeds. It negatively affects the weed density and population than the other methods of rice cultivation. Experiments have proved that increasing flooding upto 5 cm or 10 cm depth were effective than the 2 cm depth (Singh *et al*., 2004, Shailendra Singh *et al,* 2005), but crop growth stage have to consider. Herbicidal application followed by flooding reduces 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.

Subbulakshmi and Pandian (2005) found that adoption of continuous submergence registered lower weed density and weed dry matter production due to reduced weed population caused by possible inhibition of germination of weeds under anaerobic conditions. Shailendra Singh *et al.* (2005) reported that weeds were killed in transplanted rice due to puddling effect. In transplanted rice cultivation, weeds are suppressed by standing water and transplanted rice seedlings have a head start over germinating weed seedlings (Rajkumar *et al.,* 2010).

Tillage Practices and Land Preparation

Tillage is an important weed management tool to reduce the weed population at early 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 reduces the weed population and its density for the following season. Under zero tillage condition, weed emergence observed is more, for the reason that 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 deep ploughing. It should be rotated for every 2-3 years. Deep tillage brings the weed seed bank to the surface and weed seeds can be destroyed by exposing it to higher temperatures at field during summer season and are killed.

Seedrate, Plant Population and Crop Geometry

Number of seeds per unit area, which produces plant canopy, will dominate over the weeds for growth inputs. The plant canopy produced shows smothering effect on weeds resulted to less competition for available resources between crops and weed. It creates the less space to the weeds to flourish and available resources are limited for the weeds. Optimum plant spacing and plant population produced definite plant canopy which is determinant the competition between the plants and weeds for growth determining factors (Yadav *et al*., 2009). 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. Row spacing is one of the major factors for determining the plant population and weeds per unit area, the lesser density of plant population led to more space available for weeds and it's 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 up to critical crop growth period. This period is lower in case of less spaced crops compared to wider spaced crops, higher seeding rates 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 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 reduces the herbicide quantity use, manpower and easy access to control the weeds by using the chemical herbicide and general manual weeding (Mahajan & Chauhan, 2011). By providing the competitive cultivars the yield loss in rice gain yield may vary between 10-70 per cent. 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.

Allelopathy Principle

Recent study indicated regarding crop allelopathy (Belz, 2007) that refers to the process of the release of chemical compounds by living and intact roots of crop plants that affect plants of other species (Weston & Duke, 2000). Therefore, allelopathy is the important component in sustainable weed management. 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. These cultivars have strong root system at early stage compete better with weeds when leafs are to be developed.

Crop Rotation

Mono cropping offers the cultivation of the same crop or 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 act as favorable structures to the weeds propagation, and if on these structures are kept under below threshold level, it safeguard the crop plants from weeds. Therefore crop rotation is an effective tool to reduce the weed population. Recent 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 per cent, respectively, in comparison to continuous rice (Olofsdotter *et al.*, 2002). 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.

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 85 per cent small farmers are presented in India, this importance of this method has to be exploited in the farmer's beneficiary. Mechanical weeding can be done by unskilled labour and is generally economical, non-polluting without residual problems and is relatively safe to the operator (Mishra and Sahoo, 1971). Generally mechanical conventional weed management in the farmer's field has been done by different types of weeders and hoes, independently or 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 sensitive crop growth stages. It helps in minimizing weed competition, besides improving soil aeration.

Randriamiharison (2002) reported that mechanical weeding using a hand rotating hoe with small toothed wheels, employing square or rectangular planting pattern, increased the number of pores in soil that facilitates roots and micro organisms to access easy and more oxygen. The rotary weeding three times at 15, 30 and 45 DAT recorded better weed control and higher grain yield in rice (Vijayakumar *et al*., 2005). In the recent past, weed control is more by chemical means supplemented by hand weeding, this has led to higher efficacy in weed control over control. Increasing demand for labour and escalating cost of agrochemicals together with phytotoxicity pose the farming community to think of combining mechanical measures, which will help the rice production to free itself from the scourge of weed menace with limited labour.

Manual Weeding

The earliest ways of weed control in rice were cultural methods. In spite of labor intensive, hand weeding is still most common direct weed control method in rice in India using bare hands and hand tools. These practices are only effective when weeds attain height to provide better grip for uprooting Bhan *et al., (*1980).

Manual weeding is the traditional method of weed management in rice culture. Hand weeding in transplanted crop is relatively easy, because the seedlings are planted in rows between which the weeder can walk (Heinrichs *et al*., 1987). Hand weeding twice was found superior to other treatments with 100 per cent control of weeds in rice (Purshotam Singh *et al.,* 2007). According to Rajvir Sharma (2007), two hand weeding one as early as possible *i.e.,* 10-15 days after transplanting and the second 25-50 days later were generally sufficient in rice field.

Halder and Patra (2007) from Orissa reported that twice hand weeding at 20 and 40 DAT resulted in the minimum weed population and dry weight and the highest weed control efficiency at both the stages. Jayadeva *et al.,* (2009) from Karnataka observed that hand weeding twice (20 and 24 DAT) recorded lower weed dry weight and higher mean grain and straw yield in rice.

Hand weeding twice at 20 and 40 DAT resulted in significantly lower weed density and dry weight and recorded highest weed control efficiency (Bhanu Rekha *et al.,* 2003, Kathirvelan and Vaiyapuri, 2003; Patra *et al.,* 2006, Pal et *al*., 2009 and Jayadeva *et al*., 2009). The maximum values of yield attributing characters like highest plant height, tillers m^{-2}, panicle length, dry matter production, grains $panicle^{-1}$, grain weight $plant^{-1}$, test weight, nutrient uptake as well as grain yield recorded under manual weeding twice was also reported by Dave and Sahu (2006), Jayadeva *et al*. (2009) and Subha Lakshmi and VenkataRamana (2009)

Manual weeding is although effective and most common method, however, scarcity and high wages of labour particularly during peak period of agricultural operations make this method uneconomic. Further, it is possible only when the weed growth is to a size large enough for hand removal, by that time the weeds have done considerable damage to the crop. Further, mechanical method of weed management is also time taking, cost intensive, much tedious and also does not remove all the weeds.

Chemical Weed Management

In general, cultural, manual and mechanical methods of weed control are time consuming, cumbersome and laborious. Due to scarcity of labour at peak times of agricultural operations, different herbicides based weed management technologies have been developed and test verified. Chemical weed control by pre-sowing, pre-emergence, early post-emergence, post emergent and combinations of them are all effective for weed control. Herbicidal weed management becomes a competitive and promising way to control weeds in transplanted rice, at least for first few weeks after transplanting of crop. The use of herbicides therefore appears to be the only alternative (Alstorm, 1990) and in the present context, it is most preferable and farmer can easily go for it, because day by day labour scarcity increased. Effect of these management practices on yield components and yield of transplanted rice is reviewed hereunder.

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. 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. Repeated application of same herbicides on the same plot led to shifting of weed flora and emerging of secondary type of weed as major weeds in the field. 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 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.

Weed management in transplanted rice through herbicide application may be the best suited option. It is practiced by farmers for past several years as it offers selective and economic control of weeds right from the beginning of crop growth and thus, minimize the crop weed competition. It also saves valuable time by covering more area in short period and also cost effective. Raising cost of labour and their reduced availability has led to search for alternative methods such as herbicide use either alone or in combination (Hugar, 2011).

Chemical weed management is proved to be effective in weed management and an important component in integrated weed management technique in around the globe.

Pre Plant Application (PPA)

Weed infestation before puddling may cause severe crop weed competition during early growth stage of rice by their re-emergence. Application of foliage active pre plant herbicide glyphosate 2.5 kg/ha or glufosinate ammonium 1.0 kg/ha at 15 days before puddling gave effective weed control as well as higher productivity and profitability of transplanted rice. As these herbicides would not have much soil activity, succeeding transplanted rice will not be affected. Controlling of emerged weeds leads to exhaustion of weed seeds in the top soil and also the problematic weeds like *cyperus* results in less crop weed competition (Manishankar *et al.,* 2020).

Pre-Emergence Herbicide

Butachlor : Butachlor belongs to acetamides (Anilides) family of herbicide. This is also known as 'chloro-acetanilides' since chlorine is invariably present in almost every herbicide. They are most effective against seedling grasses, but also control some broad leaf weeds. Butachlor is a pre emergent or early post emergent herbicide and controls *Eleusine indica, Fimbristylis* sp., *Cyperus iris* in rice @ 1.25-2 kg/ha.

Application of butachlor at 1.25 kg a.i./ha gave the efficient weed control and ultimately gave the maximum number of effective tillers /ha (Mirza Hasanuzzaman *et al.,* 2008). Singh *et al*. (2006) found that pre-emergence application of butachlor along with 2, 4-D (1.5 + 0.5 kg /ha) followed by one hand weeding were effective ways to minimize weed competition and enhance grain yield of rainfed lowland rice. Pre-emergence application of butachlor at 1.25 kg a.i./ha recorded significantly higher grain and straw yield of 6084 and 6835 kg /ha respectively in transplanted rice (Nasimulbari (2010), Jayadeva *et al.,* 2011).

Oxadiargyl : Oxadiargyl belongs to Oxadiazoles group. It controls annual grasses, annual sedges and broad leaf weeds in rice. Oxidiargyl at 75 g a.i./ha supplemented with one hand weeding at 40 DAT recorded the lowest density and dry weight of weeds with higher weed control efficiency, which was comparable with hand weeding twice at 20 and 40 DAT (Subramanyam *et al.,*2006a). Ramana *et al.* (2008) noticed that pre-emergence application of oxadiargyl at 80 g a.i./ha + mechanical weeding with star weeder resulted in improved weed control and higher grain and straw yield and proved economically remunerative over butachlor and pretilachlor treatments. The highest number of filled grains panicle^{-1}, 1000 grain weight and grain yield of rice were recorded with pre-emergence application of oxadiargyl @ 75 g a.i./ha, which was on par with hand weeding twice at 20 and 40 DAT (Yadav *et al.,* 2009; Deepthi Kiran and Subramanyam, 2010). Mirza Hasanuzzaman *et al.* (2009) recorded that the highest harvest index with pre-emergence application of oxadiargyl + one hand weeding treatment.

Post-Emergence Herbicide

Bispyribac Sodium : Bispyribac sodium belongs to the pyrimidinal thiobenzoates group of herbicides. It is recently introduced herbicide have the similar mode of action as the sulfonylureas. It is highly selective, post-emergence, low mammalian toxic and low dose (15-40 g/ha) herbicide. Hence, popular to control weed in rice growing area either transplanting or direct seeded (Das, 2008). The highest net benefit was obtained by the application of bispyribac sodium 100 SC followed by ethoxysulfuron 60 WG treatments while the lowest net benefit was provided by control (weedy check). No doubt, the result of hand weeding is significantly better as it is time consuming and laborious hence cannot be recommended at large scale (Hussain *et al.,* 2008). Veeraputhiran and Balasubramanian (2012) conducted an experiment during 2010 and 2011 at Madurai (Tamil Nadu) recorded that the total weed population and dry weight under post emergence application of bispyribac - Na at 25 g/ha was on par with its higher doses 50 g/ha. Weed control efficiency and weed index at its lower dose (25 g/ha) were comparable with the higher doses *i.e.,* 35 and 50 g/ha. Post-emergence application of bispyribac sodium at 25 g/ha recorded significantly higher grain yield 6838 and 6510 kg/ha during 2010 and 2011, respectively over pre emergence application of butachlor at 1500 g/ha, twice hand weeding and weed free. Parthipan and Ravi (2016) found that post emergence application of bispyribac sodium at 25 g ai/ha at 15 DAT followed by hand weeding at 45 DAT produced higher grain yield and was at par with two hand weedings due to lower crop weed competition.

The study conducted by Anay kumar *et al*., (2013) indicated that the grain yield was minimum in weedy check plots (8.12 q / ha) where weeds were allowed to grow throughout the crop season, but, it was increased when bispyribac-sodium was applied from 100 to 800 ml / ha. The hand weeding twice (20 and 40 DAT) produced higher (51.13 q / ha) yield which was significantly superior over other treatments followed by bispyribac-sodium at 200 ml / ha (42.08 q / ha) and bispyribac-sodium at 300 ml / ha (38.58 q / ha) and both were comparable to each other.

Penoxsulam : Penoxsulam is a triazolopyrimidine sulfonamide herbicide used to control grasses, broad leaf and sedges weeds in rice crop. It is early post-emergence herbicide absorbed mainly via leaves and secondarily via roots. It is a new acetolactate synthase (ALS) inhibitor herbicide for post-emergence control of annual grasses, sedges and broad leaf weeds in rice culture (Jabusch and Tjeerdema, 2005).

It is commercialized in European Union as oil dispersion (OD) containing 20 g/l, requiring no additional adjuvant. It has a favourable toxicological and environmental profile that controls *Echinochola spp.,* major broad leaf weeds and sedges. Pal *et al.,* (2009) found that penoxsulam (24 SC) at 0.0225 kg a.i./ha applied at 8-12 days after transplanting was most effective in reducing the weed population in broad spectrum as well as of weeds growth. This treatment also gave the maximum grain yield (35.3 q/ha) and straw yield (47.3 q/ha) of rice resulting in lowest weed index (5.6 %). Yadav *et al.,* (2010) from Karnal reported that penoxsulam at 25 g/ha as pre-emergence (3 DAT) and 22.5 g/ha as post-emergence (10-12 DAT) application provided satisfactory control of all types of weeds consequently resulting in grain yield of transplanted rice similar to weed free plot.

Chlorimuron-ethyl + Metsulfuron-methyl : Chlorimuron-ethyl (10 %) + Metsulfuron-methyl

(10 %) + 0.2 per cent surfactant (Ready-mix) belong to the sulfonylureas group of the herbicide. It is herbicidal formulation applied as post-emergence to control broad leaf weed in rice field. Patra *et al.,* (2011) observed that application of chlorimuron-ethyl + metsulfuron-methyl 0.004 kg/ha mixed with butachlor 0.938 kg/ha at three days after transplanting (DAT) was at par with hand weeding twice at 20 and 40 DAT in controlling weeds and higher grain yield. This application increased the grain yield by 45.1 per cent over the unweeded check. Sah *et al.,* (2012) observed that pre-emergence application of chlorimuron-ethyl + metsulfuron-methyl (0.025kg/ha) at 3 DAT *fb* sequential application of 2,4-DEE (0.5 kg/ha) at 20 DAT was found most effective in minimizing weed population and their dry matter accumulation and increasing weed control efficiency and grain yield next to two hand-weeding, both were at par. 80.1 per cent and 77.7 per cent increase in grain yield was recorded in two hand weeding and chlorimuron-ethyl + metsulfuron-methyl followed by 2, 4-DEE (0.025 + 0.5 kg/ha), respectively over weedy check.

Ethoxysulfuron : Ethoxysulfuron belongs to the Sulfonylureas group of herbicide and acts as Acetolactate synthase inhibitor (ALS). It acts by reducing the levels of three branched chain aliphatic amino acids. It is highly selective, post-emergence low mammalian toxic and low dose (10-40 g/ha) require herbicide so gaining popularity to control weed in transplanted rice. Shahbaz (2007) found there was lowest dry matter accumulation by *Alternanthara triandra* under the application of Ethoxysulfuron that might be due to better killing capacity of ethoxysulfuron against broad leaf weeds.

2, 4-D Sodium Salt (Fernaxone) : Sequential application of pretilachlor at 1.0 kg a.i./ha on 3 DAT and 2, 4-D at 0.5 kg a.i./ha on 40 DAT appeared to be the best treatment for weed management in transplanted rice (Duary *et al.,* 2009) and lowering the weed density of grassy and broad-leaved weeds and their dry weight and maximizing weed control efficiency (Mandhata Singh and Singh, 2010). Singh *et al.* (2005b) reported that combination of pre-emergence application of pendimethalin @ 1.0 kg a.i./ha and post emergence application of 2, 4-D @ 500 g a.i./ha recorded highest rice grain yield. Walia *et al.* (2008) observed that integration of pre-emergence application of pendimethalin at 1 kg a.i./ha followed by post-emergence application of 2, 4-D at 500 g a.i./ha enhanced the weed control and recorded higher grain yield. Pre-emergence application of butachlor + sequential application of 2, 4-D at 0.5 kg a.i./ha on 40 DAS recorded highest grain yield of 4.36 t /ha (Swapan Kumar Maity and Mukherjee, 2009). Post-emergence application of 2, 4-D with pre-emergence application of pretilachlor enhanced the yield attributes and yield of rice as reported by Mandhata Singh and Singh (2010).

Pre-emergence or early post emergence : Herbicide use offers best alternative method for selective and economical control of weeds right from the beginning, giving crop an advantage of good start and competitive superiority. However, no single herbicide is effective for broad-spectrum weed control in transplanted rice. Combination products consisting of two or more herbicides sprayed at different interval of time have greater activity on diverse weed flora due to differential mode of action and have become popular in recent years.

Pretilachlor : Pretilachlor belongs to Acetamides group of herbicides. It is selective systemic herbicide absorbed primarily by the germinating root with translocation throughout the plant. It is applied either as pre-emergence or early post emergence to control the annual grasses and broad leaf weeds but mainly used as a grass killer in transplanted rice.

It is selective broad spectrum pre- emergence herbicide for use in early season in transplanted rice with cell division inhibitor as its mode of action. It controls grassy and sedges weed species *viz., E. crus-galli, E. colona, Leptocholachinensie, C. rotundus, C. iria, C difformis and Fimbristylis millacea* in rice fields. Pretilachlor is supplied with a surfactant under the trade name sofit but the trade name rifit does not contain extra surfactant. Bhowmick *et al.,* (2000) found that pretilachlor at 0.8 kg/ha effectively controlled the weeds in transplanted rice and recorded the maximum grain and straw yields which were at par with hand weeding. Pretilachlor in combination with safener and hand weeding resulted in the lowest weed density and dry matter and highest weed control efficiency, grain yield and number of panicles in direct seeded puddled rice (Mahajan *et al.,* 2003).

Pyrazosulfuron : Pyrazosulfuron is the member of the pyriimidinyl pyrazolesulfonyl ureas group of herbicide recently introduced in India (in rice belt) for weed control in rice nurseries as well as transplanted and direct seeded rice. It is a systematic type in nature and applied as pre-emergence and early post-emergence herbicide. It is highly selective to rice crop so also called as rice herbicide. It control grasses, sedges and broad leaf weed in rice. Grasses includes *Echinochloa colona, Panicum* spp., sedges includes *Fimbristylis millacea*, *Cyperus* spp., and broad leaf weeds includes *Ludwigia parviflora, Marsilea quadrifolium, Alternanthera sesselis* etc. Pyrazosulfuron is absorbed by roots or leaves and translocated to meristem which inhibits ALS/AHAS enzyme catalyzing the biosynthesis of three essential branched chain amino acid, namely leucine, valine and isoleucine they stops cell division of roots and check the plant growth. It has got very low persistence in soil and ground water with a half-life value of 7-10 days. Thus it is safe to ecosystem. Das (2008) found that the application of pyrazosulfuron in general increase vigor of rice plants in terms of more number of tillers and better grain filling resulting in higher yield. Revathi *et al.,* (2010) from Coimbatore (Tamil Nadu) found that the application of pyrazosulfuron ethyl 30 g/ha at 3DAT reduce the total weed density and dry weight.

Pretilachlor (6%) + Bensulfuron (0.69%) : Bensulfuron - methyl, a member of sulfonylurea herbicides, is a broad-spectrum herbicide for the control of broadleaf weeds and sedges in the rice fields. As a selective herbicide for direct seeding and mechanical transplanting rice fields, bensulfuron is active a rate as low as 30 - 70 g ai/ha and has a good herbicidal activity on most annual and perennial weeds in the rice fields. This is used as a mixture with pretilachlor, butachlor, mefenacet and other grass-killing herbicides for the effective control of grassy weeds. The mode of action by bensulfuron-methyl is similar to other sulfonylurea herbicides. The primary site of bensulfuron-methyl is the inhibition of ALS (acetolactate synthase) which is an important acid biosynthesis. Secondary effects of the cell division and retardation of plant growth (Ray, 1984 and Takeda *et al.,* 1985). This study was to examine and compare the physiological responses of differences in weeds showing different susceptibility to sulfonylurea herbicide which is known for representative herbicide in paddy fields. Singh *et al.,* (2005) from Pantnagar reported that Bensulfuro-methyl at 30 to 60 g /ha applied alone or as tank mixture with butachlor at 1.0 kg /ha reduced the density of all the sedges as well as *Caesulia axillaris* and *Commellina benghalensis.* At higher doses of bensulfuion methyl (50 and 60 g /ha), there was almost complete control of sedges and non-grassy weeds. The differences in grain yields due to various doses of bensulfuron-methyl were non-significant and yields were at par with weed free treatment. Shekhra*,* (2011) found that application of bensulfuron methyl + pretilachlor (6.6 %) at 0.06 + 0.60 kg a.i/ha + one intercultivation at 40 DAT recorded significantly lower weed population and weed dry weight and higher grain yield. This was at par with Bensulfuron methyl + pretilachlor (6.6 %) at 0.06 per cent+0.60 kg a.i/ha.

Therefore, to avert the economic losses a broad spectrum weed control should be affective during the life cycle especially during the critical stages of rice crop. Effective control of weeds in rice could be achieved with pre-emergence herbicide use of Butachlor, Pretilachlor, Penoxsulam and Pyrazosulfuron. Among the post emergence herbicides use of Chlorimuron-ethyl + Metsulfuron-methyl, Ethoxysulfuron, Bispyribac sodium gives promising results. But for the effective control of weeds combination of pre and post emergence herbicides is most effective method for broad spectrum weed control in transplanted rice. The higher broad spectrum weed control was observed with sequential application of pre emergent herbicide and Post emergent herbicides or manual weeding which is in conformity with Bhatt *et al*. (2017).

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. They are found to be cheaper, effective, available large quantities and more sustainably economical to the eco-friendly environment. It clearly defined by four strategies, *viz.,* classical, bioherbicidal, phytotoxins and integrated weed management approaches. Some of the examples have been given in table 2 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 2

List of biocontrol agents reported to be effective in weed management in rice (Phatak *et al*., 1987; Praveena & Naseema 2003; Luna *et al*., 2002 and Smith, 1991)

Weed species	Biocontrol agent
Cyperus esculentus	*Puccinia canaliculata*
Eichornia crassipes	*Fusarium pallidoroseum*
Cyperu sdifformis	*Curvularia tuberculata*
Aeschynomene virginica	*Colleto trichumgleosporoides*
Eichinochloa crus galli	*Cochliobo luslunatus*
Alternantheraphyloxeroides	*Fusarium* sp.

Integrated Weed Management

Weed management concentrates the reducing the weed population below the economic threshold level (ETL) which cannot affect the crop growth. In the different weed management practices any one of the weed management practice cannot reduce the weed population, effectively 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 (Sanyal, 2008). 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 (Singh *et al,* 2010). 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 reduces 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 per cent 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.

The study conducted by Jayadeva *et al* in 2010 revealed application of Azimsulfuron at 27.5 g a.i./ha + Metsulfuron methyl at 2 g a.i. / ha + 0.2 per cent surfactant was more effective in controlling weeds and recording higher mean grain and straw yield (6004 and 6734 kg/ha, respectively), which was on par with application of Azimsulfuron at 30 g a.i. / ha + Metsulfuron methyl at 2 g a.i. / ha + 0.2 per cent surfactant (6289 and 6923 kg / ha, respectively) compared to application of lower dose of Azimsulfuron (27.5 g a.i. / ha).

Recent studies reported that criss cross sowing plus 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.

The field experiment was conducted during summer, 2013 and 2014 in transplanted rice at University of Agricultural Sciences, Bangalore, among weed management practices, pyrazosulfuron ethyl 20 g ai/ ha - 3 DAP *fb* manual weeding (45 DAP) was better in controlling weed complex, gave paddy yields better than hand weeding, besides saving cost of weed management to the extent of (Rs.2775 to 4700/ha) compared to manual weeding under present conditions of labour scarcity (Anon, 2014). Dhanapal *et al*., 2018 reported that significant the lowest weed density (18.3 - 22.0 no./m^2) and weed biomass (5.4 - 6.3 g/m^2) was noticed with hand weeding at 25 and 45 DAS, which was at par with pre-emergence application (PE) of bensulfuron-methyl + pretilachlor *fb* triafamone + ethoxysulfuron applied at 30 days after transplanting (DAT) (Anon 2014.Pre-emergence application of metsulfuronmethyl+chlorimuron ethyl supplemented with one hand weeding at 40 DAT provided a broad spectrum weed control (Dhimna Mukherjee, 2015)

Economics of Weed Management

Weed management should be practiced by least expensive available technology that does not interfere with other phases of crop production or human activities. Any weed control measure should be used only when its results are expected to be more economically beneficial then the results of not using any control measures (Moody, 1993). Marginal benefit cost ratio and net returns are the best ways to assess the economic viability of a particular weed control treatment. Hand weeding is the predominant method of weed control. However low cost chemicals are being effectively used (De Dutta, 1974) often in combination with limited hand weeding, this appears to be economical in many situation. Pretilachlor 625 g/ha was reported more economical as compared to butachlor 1250 g/ha getting good yield as well as cost benefit ratio (Sharma and Upadhyay, 2002). Chlorimuron-ethyl + metsulfuron-methyl *fb* 2, 4-DEE (0.025 *fb* 0.5 kg/ha) recorded highest net returns (Rs.18070/ha) and benefit: cost ratio (1.99). Veeraputhiran and Balasubramanian (2012) recorded higher economic benefits like net income and benefit cost ratio with the post-emergence application of bispyribac-Na at 25g/ha than all the other weed management treatments under Madurai situations. The highest net return (Rs.15,990/ha) and B:C ratio (2.00) was recorded in metsulfuron methyl at 8 g /ha (SanjoySaha and Rao, 2010). In transplanted rice, butachlor at 1.0 kg /ha on 3 DAT and almix at 4.0 g / ha on 20 DAT registered maximum monetary returns of Rs.14, 843 and 17,728 /ha as well as B: C ratio of 1.09 and 1.31 during 2006 and 2007, respectively (Swapan Kumar Maity and Mukherjee, 2009).

Weed management with bensulfuron-methyl + pretilachlor (60 + 600 g/ha) PE *fb* triafamone + ethoxysulfuron (60 g/ha) applied at 25 DAT recorded significantly higher paddy grain and straw yields and higher economic returns (Dhanapal *et al*., 2018). The field experiment was conducted during summer, 2013 and 2014 in transplanted rice. Among weed management practices, pyrazosulfuron ethyl 20 g ai/ ha - 3 DAP *fb* manual weeding (45 DAP), pretilachlor 750 g - 3 DAP *fb* chlorimuron ethyl + metsulfuron methyl 20 WP 4 g ai/ha - 25 DAP, pretilachlor 750 g - 3 DAP *fb* ethoxysulfuron 18.75 g ai/ha - 25 DAP were better in controlling weed complex besides saving cost of weed management to the extent of (Rs.2775 to 4700 / ha) compared to manual weeding under present conditions of labour scarcity (Anon, 2014).

Maximum net returns were obtained with bensulfuron methyl 0.6 per cent G at 60 g a.i. ha^{-1} + pretilachlor 6 per cent G at 600 g a.i. ha^{-1}. Higher benefit cost ratio was also recorded in bensulfuron methyl 0.6 per cent G at 60 g a.i. ha^{-1} + pretilachlor 6 per cent G at 600 g a.i. ha^{-1}. The unweeded control recorded lower net returns and B:C ratio (Manjunath *et al*., 2013).

In developing countries like India, shortage/less availability of labour for agricultural work is the major prominent issue. 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 cultural, chemical and prevention measures would control weeds more effectively than with the use of only one weed control strategy. In future, mitigation on climate change specifically rice production more strategies need to be worked out. Adopting integrated different weed management strategies offers the opportunity for reducing the weed infestation in crops effectively and sustainably. 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 to develop integrated weed management systems under organic farming system that are innovative, effective, economic 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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