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EFFECT OF WEEDS AND THEIR MANAGEMENT IN TRANSPLANTED RICE – A REVIEW

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ABSTRACT

Rice is grown mainly as a wetland crop by transplanting seedlings into puddled fields. Conventional transplanting is the most common practice of rice cultivation in South and South East Asia. Weeds grow profusely in the rice fields and reduce crop yields drastically. Normally the loss in yield ranges between 15-20%, yet in severe cases the yield losses can be more than 50%, depending upon the species and intensity of weeds. Weed flora under transplanted condition is very much diverse and consists of grasses, sedges and broad-leaved weeds causing yield reduction of rice crop up to 76 %. In this paper, we will summarize and review possible effect of weeds on rice and cultural, mechanical and chemical weed management methods on growth, yield, labour saving and economics of rice for future research.

KEYWORDS: Chemical, Cultural, Mechanical, Rice, Weed Management

INTRODUCTION

Rice (*Oryza sativa* L.) production has pivotal role in our national economy. There is always a growing demand for rice in India due to burgeoning population. To sustain present food sufficiency and to meet future food requirements, India has to realize an annual growth rate of at least 3 % in productivity of rice. It is estimated that in Asia, yield loss due to uncontrolled weeds in transplanted paddy fields was 50 % (Johnson, 1996) and 12 % of the total loss of crop yields has been attributed to the weeds alone (Ananya, 1999). Weeds become detrimental to crops by changing the pH of soil, decreasing the nutrient availability, which inturn reduces straw yield by 13-38 % and grain yield by 25-47 % (Manandhar *et al.,* 2007). In this chapter an attempt has been made to review the salient research findings on crop-weed competition and weed management practices in transplanted rice cultivation on the relevant headings.

EFFECT OF WEEDS ON RICE

Rice grown under the lowland conditions are favourable for abundance growth and multiplication of weed species. Managing weeds in rice is tedious due its expensive nature coupled with labour scarcity.

Nature of Weed Spectrum

Weed menace is a common problem in rice cultivation. 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).

Srinivasan and Palaniappan (1994) reported that *Echinochloa spp.* was more competitive causing greater loss in growth and yield of rice as compared to *Marsilea quadrifolia*, *Cyperus difformis* and *Eclipta prostrata*. The weed spectrum and its density differ from the method of rice crop cultivation (Vinod Kumar *et al*., 1998). *Ammania baccifera* and *Cyperus spp*., as a whole constituted 83.8 and 87.4 % of the total weed flora respectively under direct sown puddled rice (Rana and Angiras, 2000).

According to Avudaithai and Veerabadran (2000), the grasses, sedges and broad-leaved weeds recorded 15, 16 and 29 % of the relative densities respectively. Within the grasses, *Echinochloa colona* was more dominant with 50 % relative density, *Cyperus iria* was the dominant sedge with 14 % relative density and *Marsilia quadrifolia* was the dominant broad-leaved weed with 15 % relative density.

In wet seeded rice, the weed flora consisting of grasses such as *Echinochloa colona* L., *E. crus-galli* L. and *Cynodon dactylon*; sedges such as *Cyperus rotundus* L., *C. difformis* L. and *C. iria* and broad-leaved weeds such as *Eclipta prostrata* L., *Ammania baccifera* L., *Phyllanthus niruri* L. and *Ludwigia parviflora* were found (Subramanian *et al*., 2006). In lowland transplanted rice field, *Echinochloa colona* and *E. crus-galli* among grasses, *Cyperus rotundus*, *Cyperus difformis* among sedges and *Eclipta prostrata*, *Ammania baccifera* among broad-leaved weeds were observed by Narayanaswamy *et al*. (2006).

Crop-Weed Competition

Weed competition is one of the major causes for yield loss in lowland rice in India. Weeds compete with the crop aggressively because of their high growth rate, high potential to acclimatize changing environment and more efficient seed production (Kim and Moody, 1989).

Grasses are usually the most dominant competitors during early season, while sedges and broad-leaved weeds dominate later in the season (Jiang, 1989). Most of the reports also agreed that grasses are vigorous competitors, exhausting greater portion of the fertilizer applied to the crop followed by sedges and broad-leaved weeds (Kim and Moody, 1989; Moorthy and Sanjoy Saha, 2005; Singh *et al*., 2006). Hence, weed competition studies are important, because these studies quantify the competition factors in terms of critical thresholds or duration of competition and the nature of competition mechanism.

Critical Period of Crop-Weed Competition

Crop-weed competition plays an important role in the growth and yield of transplanted rice. Weeds are self grown, early emergent along with crop seedlings and their rapid growth and development resulted in a severe crop-weed competition for natural resources *viz.*, light, nutrients, moisture and space and ultimately resulted in low yield of rice. If weeds are not controlled before 50 days after transplanting, the farmers may lose one-third of their total expected yield. De Datta (1981) reported that weed must be controlled within 20-40 DAT to avoid reduction in grain yield. If weeding is delayed beyond 20 days after emergence, yield losses caused by weeds were irreparable.

During early establishment, the weeds make 20-30 % of their growth while the crop makes 2-3 % of its growth (Moody, 1990). Most research finding showed that competition period from 15 to 45 DAS had the greater impact on yield of wet seeded rice (Govindarasu *et al.*, 1998; Sathyamoorthy and Kandasamy, 1998).

Maintaining a weed free period upto 45 DAT was essential to augment the yield of medium duration rice as reported by Singh and Bhan (1989) and Chinnusamy *et al*. (2000). Bhan (1983) and Thapa and Jha (2002) also reported that upto 40 days after transplanting were critical for crop-weed competition in rice. In case of rainfed lowland rice, 30-60 days after sowing period considered critical period for crop weed competition (Moorthy and Sanjoy Saha, 2005).

Nature of Crop-Weed Competition

Crop yield losses from weeds usually proportional to the amount of nutrients, light and water used by the weeds at the expense of the crop. Other factors for which crops and weeds are said to compete are space, oxygen, carbon dioxide, air and heat energy. However, weed competes with crop plants mainly for nutrients, moisture, light and space (Singh *et al.,* 2004)

Competition for Nutrients

Weeds usually grow faster than the crop plants and then they adsorb the available nutrients earlier, resulting in reduced availability to crop plants. Weeds being more vigorous competitors remove a greater portion of the fertilizer applied to the rice crop (Thirumurugan *et al*., 1998). Weeds depleted higher amount of N to the tune of 35 kg ha^{-1} (Jitendra Pandey and Thakur, 1988). The N depletion increased with the age of the crop and weeds strive hard to take the nutrients present in limited amount. Further in transplanted rice, total N removal by crop and weeds together were significantly higher than in direct seeded rice culture (Subhas Chander and Jitendra Pandey, 2001).

Madhu and Nanjappa (1995) found that in direct seeded puddled rice, the weeds in weedy plots removed 48.79 kg N, 23.62 kg P and 67.37 kg K ha^{-1}. According to Rana and Angiras (2000), the removal of N, P and K by grasses, sedges and broad-leaved weeds were maximum in weedy check, because of higher crop-weed competition. On an average N, P and K removal in puddled transplanted rice due to weeds was to the tune of 2.87 kg N, 0.36 kg P and 4.90 kg K ha^{-1}, whereas it was 22.7 kg N, 2.99 kg P and 39.6 kg K ha^{-1} under direct seeded condition reported by Singh *et al*. (2006).

Competition for Water

Water is an essential factor in the growth and function of plants. Weed, which emerges with crop usually, requires more moisture than rice crop. Where water is plentiful, competition between rice and weeds is minimal, but during shortage the situation is quite different. If weeds consume significant portion of water then tillering, flowering, and grain filling are delayed or impeded (Islam *et al*., 1986).

Competition for Light

Competition for light occurs whenever plants are growing closely together and the ability to compete for light depends largely on the comparative growth stature of the competitors. Weeds that are shorter than rice crop throughout growth period compete a little or not at all with rice for light. However, weeds that are taller can reduce the light available to rice by as much as 50 %. Since sunlight provides the main source of energy utilized by plants for manufacturing food, shading by tall weeds can significantly stunt rice growth and reduce yields. Srinivasan (1989) noted that the nature of weed competition by major weeds revealed that the tall growing *Echinochloa spp*. eventually over tops the rice plant and competed for more light.

According to Fischer and Gibson (2001), competition for light is a critical factor in the process of interference between rice and weeds. Leaf area and number of tillers are characteristics directly correlated with the capacity of the crop to intercept light and suppress weed growth.

Competition for Space

Spacing also influences rice weed competition. Weed leaf area densities, leaf angles and maximum height to be the crucial determinants of weed interference in rice (Caton *et al.*, 2000).

Effect of Crop-Weed Competition on Rice

Under a given set of environmental conditions, a unit area of land can produce a certain amount of total vegetative dry matter. In order to maximize crop yield, all of this growth should be in the form of the crop. Any weed growing in association with the crop will reduce vegetative potential of the crop and ultimately resulted in loss of yield (Moody, 1978). Many workers reported the effects of weed competition on rice growth and yield. Severe infestation of weeds suppressed the plant height (Bhargavi and Yellamanda Reddy, 1994) increased tiller mortality, decreased shoot and grain production (Srinivasan and Palaniappan, 1994).

Moorthy and Manna (1984) reported that in direct sown rice under puddled condition, weeds caused 24 to 32 % yield reduction. In direct seeded rice, the competition of grasses, sedges and broad-leaved weeds prevailed throughout the season resulted in yield reduction of 46 % as reported by Chin and Sadohara (1994). Due to higher weed competition, grain yields in unweeded control remained significantly lowest (9.27 q ha^{-1}) as compared to grain yield of 21.48 q ha^{-1} recorded in weed free check (Masthana Reddy *et al.*, 1995). Weeds compete severely with rice and cause drastic reduction in grain yield and lower the productivity level of rice (Muthukrishnan *et al.*, 1996).

In India, due to uncontrolled weed growth, yield of lowland rice was reduced by 17 to 73 % (Choudhury and Thakuria, 1998). According to Tamil Selvan and Budhar (2001), weeds alone have been reported to reduce the yield by 50 to 60 % in direct sown rice. Singh *et al*. (2002) reported a reduction in grain yield in weedy check to the tune of 50.1 %. They also observed that maintaining weed free condition till maturity significantly reduced the density and dry weight of weeds and enhanced the grain yield due to more number of panicles m^{-2}. Moorthy and Sanjoy Saha (2005) reported that losses in grain yield due to weed free condition upto 30, 60 and 90 DAT were 17.7, 11.8 and 5.0 % respectively. The overall effect of crop weed competition is the reduction in the economic as well as biological yield of rice.

METHODS OF WEED CONTROL

A sound weed management system involved all feasible methods of prevention and control to keep weed population below threshold level. The system aims at maintaining crop-weed density and development balance in favour of the crop, which can be done by adopting integrated method of weed management.

Cultural Methods

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).

Subbulakshmi and Pandian (2001) 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. Subramanyam *et al.* (2006) found that intensive puddling with continuous submergence recorded lower weed dry weight. 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).

Hand Weeding

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 % 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.

Higher weed control efficiency of 93.1 % was recorded in hand weeding treatments (Moorthy and Sanjoy Saha, 2002). Hand weeding twice at 20 and 40 DAT resulted in significantly lower weed density and dry weight (Bhanu Rekha *et al.*, 2003), and recorded highest weed control efficiency (Kathirvelan and Vaiyapuri, 2003; Patra *et al.*, 2006). Among various weed management practices, hand weeding twice at 20 and 40 DAT recorded lower weed density and biomass of weeds than the rest of weed management practices (Pal et *al*., 2009; Jayadeva *et al*., 2009).

Prasad *et al*. (2001) reported that manual weeding in transplanted rice recorded more number of tillers, panicles, filled grains, 1000 grain weight, grain yield and straw yield in comparison to chemical methods. The maximum values of yield attributing characters like tillers, panicle length, grains panicle^{-1}, grain weight plant^{-1}, test weight as well as grain yield recorded under manual weeding twice was also reported by Suresh and Singh (2003) and Dave and Sahu (2006). Jayadeva *et al*. (2009) and Subha Lakshmi and Venkata Ramana (2009) found that hand weeding at 20 and 40 DAT recorded highest plant height, dry matter production, tillers m^{-2}, nutrient uptake by crop and highest grain and straw yield of rice crop.

Mechanical Weeding

In the recent past, weed control is effected more by chemical means supplemented by hand weeding. Increasing demand for labour and escalating cost of agrochemicals together with phytotoxicity pose the farming community to think of mechanical measures, which will help the rice production to free itself from the scourge of weed menace with limited labour. 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). Mechanical weed control through the use of rotary weeder or other implements helped in minimizing weed competition, besides improving soil aeration (Mishra and Sahoo, 1971; Shad, 1986). Uphoff (2001) emphasized that early and frequent weeding is essential in rice, when fields were not covered with standing water. 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.

Abhijit Sarma and Gogoi (1996) reported that increased plant height was recorded, when weeders were operated twice at 20 and 30 days after emergence which was attributed to better control of weeds in particular, broad-leaved weeds and sedges, which emerged during later growth stages.

Dinesh Chandra and Manna (1990) studied the effect of different weed management practices in transplanted rice grown during summer under shallow condition and found suppression of weeds by hoeing with the use of Japanese rotary weeder two times effectively controlled the weeds and increased the grain yield by 29.7 % over control. The rotary weeding three times at 15, 30 and 45 DAT recorded better weed control and higher grain yield in rice (Makarim *et al*., 2002; Bhatta and Tripathi, 2005; Vijayakumar *et al*., 2005). Nadeem Akbar *et al.* (2011) reported higher weed suppression and increase in rice yield by 25 % over control under mechanical hoeing and it was statistically on par with hand weeding treatment.

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 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, atleast 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.

Pre-Emergence Herbicide

Butachlor (Machete)

Govindra Singh *et al*. (2004) observed that application of butachlor alone @ 1.25 kg a.i. ha^{-1} was effective against annual grasses. According to Rajkhowa and Gogoi (2004) application of butachlor @ 1.5 kg a.i. ha^{-1} as pre-emergence herbicide recorded significantly lower weed density and dry matter accumulation over weedy check.

The higher grain yield was recorded with the pre-emergence application of butachlor followed by one hand weeding treatment and it was on par with butachlor followed by two hand weeding treatments (Madhavi and Reddy, 2002). Application of butachlor @ 1.5 kg a.i. ha^{-1} as pre-emergence + 2, 4-D @ 0.5 kg ha^{-1} as post-emergence herbicide produced grain yield similar to hand weeding twice at 30 and 50 DAT (Singh *et al*., 2004). Among the herbicidal treatments, the lowest dry weight of weeds was recorded with butachlor @ 1.5 kg a.i. ha^{-1} + one hand weeding, which was statistically similar to two hand weeding (Ramphoolpuniya *et al.*, 2007). Application of butachlor at 1.25 kg a.i. ha^{-1} gave the efficient weed control and ultimately gave the maximum number of effective tillers ha^{-1} (Mirza Hasanuzzaman *et al.*, 2008).

Singh and Govindra Singh (2001) revealed that higher gross income recorded with butachlor 1.0 kg ha^{-1} + one hand weeding and on was at par with two hand weeding. Singh *et al*. (2006) found that pre-emergence application of butachlor along with 2, 4–D (1.5 + 0.5 kg ha^{-1}) followed by one hand weeding were effective ways to minimize weed competition and enhance grain yield of rainfed lowland rice. Nasimulbari (2010) reported that butachlor provided better weed control efficiency and contributed to better crop growth and grain yield compared to other treatments. Pre-emergence application of butachlor at 1.25 kg a.i. ha^{-1} recorded significantly higher grain and straw yield of 6084 and 6835 kg ha^{-1} respectively in transplanted rice (Jayadeva *et al.*, 2011).

Oxadiargyl (Topstar)

According to Sharma *et al.* (2004), weed density and dry weight significantly less under pre-emergence applicaton of oxadiargyl. Rohitashav Singh *et al*. (2004) observed that oxadiargyl @ 80 g a.i. ha^{-1} effectively controlled *Echinochloa colona* and reduced the density, whereas reduced dry weight of *Echinochloa crus-galli* observed with pre-emergence applicaton of oxadiargyl @ 70 g a.i. ha^{-1} (Kumar *et al*., 2004). Among various weed management practices, oxidiargyl at 75 g a.i. ha^{-1} 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.*, 2006).

Among the herbicidal treatments, application of oxadiargyl @ 70 g a.i. ha^{-1} recorded higher number of panicles, 1000 grain weight and grain yield of rice (Kumar et *al.*, 2004). Ramana *et al.* (2008) noticed that pre-emergence application of oxadiargyl at 80 g a.i. ha^{-1} + 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^{-1}, 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.

Metsulfuron Methyl + Chlorimuron Ethyl (Almix)

Metsulfuron methyl + Chlorimuron ethyl was effective against control of broad-leaved weeds and sedges (Samar Singh *et al.*, 2003). Pre-emergence application of mixture of almix + 2, 4-D (15 + 500 g ha^{-1}) was most effective against grasses and sedges, when applied at 8 DAT and reduced total weed density and total dry matter with higher weed control efficiency (Mukherjee and Singh, 2005). The performance of metsulfuron methyl + chlorimuron ethyl @ 4 g a.i. ha^{-1} was found superior in controlling *Eclipta prostrata* and provided excellent control of broad-leaved weeds and sedges (Singh and Tewari, 2005). Almix @ 8 g a.i. ha^{-1} was found significantly superior in reducing the population of all type of weeds with higher weed control efficiency of 97.2 % for broad-leaved weeds, 60.0 % for sedges and 21.6 % for grasses (Purshotam Singh *et al.*, 2007). Ramana *et al.* (2008) reported that pre-emergence application of metsulfuron methyl + chlorimuron ethyl at 8 g a.i. ha^{-1} resulted in effective weed control as compared to other weed control treatments. Govindra Singh *et al*. (2008) reported that the density of sedges and broad-leaved weeds in almix treated plots were less as compared to application of butachlor, anilofos and pretilachlor alone.

Application of almix @ 4 g ha^{-1} mixed with butachlor @ 938 g ha^{-1} at 3 DAT was at par with hand weeding twice at 20 and 40 DAT in controlling weeds and achieving higher grain yield (Patra *et al*., 2006).

Bensulfuron Methyl + Pretilachlor (Londax Power)

Singh *et al.* (2005a) observed that bensulfuron methyl (Londax) at different doses (40 g a.i. ha^{-1} and 50 g a.i. ha^{-1}) applied alone or as tank mixture with butachlor @ 1000 g a.i. ha^{-1} reduced the density of all the sedges and broad-leaved weeds and increased the grain yield.

Mirza Hasanuzzaman *et al.* (2007) reported that pre-emergence application of pretilachlor (Rifit) at 30 DAT recorded highest grain yield of 5.2 t ha^{-1} and weed intensity and dry matter were most effectively reduced. Among the weed control treatments, pre-emergence application of pretilachlor @ 0.75 kg a.i. ha^{-1} + safener recorded highest weed control efficiency and grain yield of 2.13 t ha^{-1} (Rajkhowa and Barua, 2007). Application of pretilachor followed by 2, 4- D (0.75 - 0.5 kg a.i. ha^{-1}) was most effective in lowering the weed density of grassy, broad-leaved weeds and their dry weight and thus enhancing yield attributes and yield of rice and maximizing weed control efficiency (Mandhata Singh and Singh, 2010).

Sunil *et al*. (2010) found that pre-emergence application of bensulfuron methyl + pretilachlor at 0.06 + 0.60 kg a.i. ha^{-1} followed by one hand weeding at 40 DAS recorded significantly higher grain yield (4425 kg ha^{-1}) and straw yield (5020 kg ha^{-1}) with lower weed population and their dry weight resulted in higher profit in aerobic rice cultivation. Bensulfuron methyl at 60 g a.i. ha^{-1} tank mix with pretilachlor 450 g a.i. ha^{-1} applied at 20 DAS were found to be effective in controlling weeds with weed control efficiency of 92.2 % and produced 5.53 t ha^{-1} of grain yield and this herbicide treatment was at par with hand weeding twice at 20 and 40 DAS (Sanjoy Saha and Rao, 2010).

Post-Emergence Herbicide

2, 4-D Sodium Salt (Fernaxone)

According to Gupta (1997), pre-emergence application of butachlor @ 1.0 kg a.i. ha^{-1} + post-emergence application of 2, 4-D Na salt @ 0.4 kg a.i. ha^{-1} resulted in the greatest reduction of weed biomass. Balyan and Malik (2000) observed that application of 2, 4-D Na salt at 1000 g ha^{-1} effectively controlled weeds and gave similar yield as that of weed free treatment. Pre-emergence application of anilofos at 0.4 kg a.i. ha^{-1} followed by 2, 4-D at 0.5 kg a.i. ha^{-1} as post-emergence proved it's superiority in controlling weeds and was on par with two manual weeding (Singh *et al*., 2004). Jacob and Syria (2005) noticed that post-emergence application of 2, 4-D Na salt @ 1.0 kg a.i. ha^{-1} at 20 DAT suppressed all the weeds and it had the highest weed control efficiency of 80 %. Sequential application of pretilachlor @ 1.0 kg a.i. ha^{-1} on 3 DAT and 2, 4-D at 0.5 kg a.i. ha^{-1} 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^{-1} and post emergence application of 2, 4-D @ 500 g a.i. ha^{-1} recorded highest rice grain yield. Jacob and Syria (2005) noticed that post-emergence application of 2, 4-D Na salt @ 1.0 kg a.i. ha^{-1} at 20 DAT combined with pre-emergence application of anilofos @ 0.4 kg a.i. ha^{-1} generally favoured with increased yield and net income. Walia *et al*. (2008) observed that integration of pre-emergence application of pendimethalin @ 1 kg a.i. ha^{-1} followed by post-emergence application of 2, 4-D @ 500 g a.i. ha^{-1} enhanced the weed control and recorded higher grain yield. Pre-emergence application of butachlor + sequential application of 2, 4-D @ 0.5 kg a.i. ha^{-1} on 40 DAS recorded highest grain yield of 4.36 t ha^{-1} (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).

Integrated Weed Management

Heavy infestation of weeds is one of the major constraints for the successful cultivation of rice. No single weed control method can combat the multitude of weed problems in a given area and so it is necessary to use a combination of physical, chemical and cultural management techniques to achieve higher benefits in rice cultivation. The only effective method to control weeds in the early stage is the pre-emergence application of herbicides.

Pre-emergence application of pretilachlor + safener (@ 0.4 kg a.i. ha^{-1}) followed by one hand weeding recorded lesser weed density, dry weight and higher weed control efficiency (Subramanian *et al.*, 2006). Among the herbicidal treatments, the lowest dry weight of weeds was recorded with butachlor @ 1.5 kg ha^{-1} + one hand weeding which was statistically similar to two hand weeding (Ramphoolpuniya *et al.*, 2007).

Bayan and Kandasamy (2002) found that pre-emergence application of pretilachlor + safener at 0.45 kg a.i.ha^{-1} followed by one mechanical weeding at 35 DAS reduced weed dry matter production, increased weed control efficiency and growth attributes in direct seeded rice. Ramana *et al.* (2008) noticed that pre-emergence application of oxadiargyl @ 80 g ha^{-1} + mechanical weeding with star weeder resulted in improved weed control and higher grain and straw yield. Sunil *et al*. (2010) found that pre-emergence application of bensulfuron methyl + pretilachlor @ 0.06 + 0.60 kg a.i. ha^{-1} followed by one hand weeding at 40 days after sowing recorded significantly higher grain yield of 4425 kg ha^{-1} and straw yield of 5020 kg ha^{-1} with lower weed population and their dry weight resulted in higher profit in aerobic rice cultivation.

ECONOMICS OF WEED MANAGEMENT

Sankaran *et al.* (1990) observed that integrated weed management with chemical and manual weeding registered higher B: C ratio than chemical methods alone. Manual weed control is practised in upland rice to minimize weed competition which is tedious, time consuming, labour intensive and costly (Pandey and Swarnkar, 1997).

Singh and Singh (1998) reported that mechanical weeding at 15 and 30 days after sowing recorded higher B:C ratio of 1.50 next to thiobencarb with 2, 4-D combination. The highest net returns of ₹ 25,340 ha^{-1} and B:C ratio of 3.15 was recorded with application of almix at 4 g a.i. ha^{-1} followed by one hand weeding on 30 DAT (Yogalakshmi, 2001). The highest B: C ratio of 2.47 was recorded with 2, 4-D Na salt at 1.5 kg ha^{-1} applied at 10 DAS (Dani Tabin and Singh, 2008). The lower net return (₹ 15,993) and B:C ratio (0.68) were obtained in farmers practice of hand weeding thrice because of more man days employed for hand weeding at 15, 30 and 50 DAS resulting in considerable increased cost of cultivation (Swapan Kumar Maity and Mukherjee, 2009).

The highest net return (₹ 15,990 ha^{-1}) and B:C ratio (2.00) was recorded in metsulfuron methyl at 8 g ha^{-1} (Sanjoy Saha and Rao, 2010). In transplanted rice, butachlor @ 1.0 kg ha^{-1} on 3 DAT and almix @ 4.0 g ha^{-1} on 20 DAT registered maximum monetary returns of ₹ 14,843 and ₹ 17,728 ha^{-1} as well as B:C ratio of 1.09 and 1.31 during 2006 and 2007 respectively (Mukherjee and Swapan Kumar Maity, 2011).

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