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Weedy rice invasion in rice fields of India and management options

C. T. ABRAHAM AND N. JOSE

Kerala Agricultural University, Thrissur, India 680656

ABSTRACT

Weedy rice are complex of Oryza morphotypes widely distributed in the commercial rice fields in more than 50 countries of Asia, Africa and Latin America, especially in areas where farmers have switched to direct seeding due to labour shortage and high cost. Wild and weedy forms of different species coming under the genus Oryza are also known as wild rice, red rice, padi angin, windy rice, air rice, varinellu, wild rice etc. Southeast Asia has been identified as the centre of origin of rice and many wild and weedy relatives are present in different rice growing areas of this region. Indian weedy rice is identified as Oryza sativa f. spontanea which belongs to the indica group. They are major threat to irrigated rice production systems in Southeast Asian countries because of their great adaptability to emerge at low temperature and from deep soil or water depths. Weedy rice is problematic, especially in Asian rice bowls. The spread of wild rice takes place in West Bengal, Andhra Pradesh, Assam, Bihar, Karnataka, Madhya Pradesh, Orissa, Tamil Nadu and Uttar Pradesh. Wild and weedy forms are problematic in Eastern India (Eastern U. P., Bihar, Orissa, Manipur, and West Bengal) and Southern India (Kerala). In North Western states like Punjab and Haryana, weedy rice is rarely seen. Heavy infestation of weedy rice in rice fields during the recent years is forcing farmers to abandon the crop due to huge reduction in crop yield (around 40-70 per cent) depending on the severity of infestation (5-15 or even more mature weedy plants per square meter). Genetic and morphological similarity of weedy rice to the cultivated species makes it difficult to control and chemical methods alone are unlikely to be effective.Origin and spread of weedy riceCultivated rice is included in the genus Oryza of the grass family (Poaceae). This genus includes two cultivated species (Asian rice - Oryza s ativa, and African rice - O. glaberrima) and more than 20 wild species with ten different genome types, i.e., AA, BB, CC, BBCC, CCDD, EE, FF, GG, JJHH, and JJKK. The wild relatives of rice with different genome types usually have significant reproductive isolation, making them unlikely to hybridize under natural conditions. The AA genome weedy and wild relatives are highly compatible sexually with cultivated rice. Their interspecific F_1 hybrids could form complete chromosome pairing in meiosis and have relatively high pollen and seed fertility to produce viable offspring. It is widely hypothesized that weedy rice has a variety of origin.Weedy plants are adapted to a wide range of environmental conditions. The spread is generally favoured by the planting of commercial rice seeds that contain grains of the weed. The spread of weedy rice is likely to be accomplished by several means, including water, cattle, farm machinery, and as contaminants of new varieties. Disk cultivation also helped to move the seeds downward to the 3 - 15 cm soil layer resulting in serious infestations and difficulties in control.

Keywords**:** Genome, management, weedy rice, wild relatives.

Characters of weedy rice

Weedy plants showed wide variability of anatomical, biological and physiological features (Vaughan *et al.,* 2001). At seedling stage, it was difficult to distinguish weedy rice as they mimic the crop, while it was possible after tillering with many morphological differences with the rice varieties i.e., more numerous, longer and more slender tillers, leaves which were often hispid on both surfaces, tall plants, pigmentation of several plant parts, grains with awns and red pericarp and shattering of seeds (Kwon *et al.*, 1992 and Suh *et al.*, 1997). It was observed that the grains of weedy rice ripened earlier and less regularly than those of cultivated rice and were extremely prone to shattering. The stem of weedy rice was comparatively more brittle and round in cross section than that of cultivated rice; the surface of the leaf sheath of weedy rice was softer and spongier than that of cultivated rice; weedy rice plants flowered earlier than cultivated rice plants. Weedy morphotypes with anthocyanin in the apiculous occasionally showed pigmentation in the other plant structures, such as the first internode, ligule, margins of the first leaf and auricles. The red pigmentation is a dominant character and is controlled by more than one gene (Espinoza *et al*., 2005).

Undesirable traits of weedy rice

Like the rice crop, the weedy rice seeds were unable to germinate in saturated soil. Unlike cultivated varieties, weedy rice seeds showed variable degree of dormancy and tendency for the seeds to shatter as soon as they are matured (Perreto *et al*., 1993). Seeds mature within a short period and shatter immediately facilitating the buildup of weed seed bank before the farmer gets a chance to remove the seeds and got along with the harvest of rice crop. Weedy rice harbored more major dormancy genes than cultivated rice. One or two genes for hull imposed dormancy was suggested in cultivars (Seshu and Sorrells, 1986; Das, 1995). Many researchers emphasized the influence of environmental factors during seed development,

Email:ctabraham@yahoo.com

storage, and germination on the trait (Nair *et al*., 1965; Rao, 1994 and Gu *et al*., 2006).

The breaking of weedy rice dormancy obtained with substances such as sodium nitrite, propionic acid, propionate-methyl, cytokinin, n-propanol resulted to be usually accompanied by a pH reduction of the embryo tissues (Footitt and Cohn, 1992). In a study conducted in Italy, the viability of weedy rice seeds taken at a depth by ploughing in loamy soil decreased to six percent after one year and to five percent after two years of burial (Ferrero and Vidotto, 1998). The non viable seeds appeared empty, without embryos, and reserve matter. Despite years of research on seed dormancy, mechanisms for the regulation of germinability are basically unknown (Foley, 2001; Koornneef *et al*., 2002). It was observed by Veasey *et al*. (2004) that the seeds of the dry region developed longer periods of seed dormancy, waiting for the wet period when environmental conditions again became favourable for germination and seedling survival.

Seed longevity in the soil was found to be ecotype dependent and also affected by burial depth, soil type and moisture, cultivation practices, the magnitude of seed production (fecundity) and dormancy intensity (Noldin, 1995). Emergence of weedy rice was greatly influenced by the soil texture, presence of water in the field and the depth of seed burial, which in turn was strictly related to the tillage adopted for seedbed preparation (Ferrero and Finassi, 1995). The minimum temperature for weedy rice germination was considered to be 10°C, same as that of cultivated rice.

Early seed shattering was a specific characteristic of weedy rice, controlled by the gene Sh which shows the shattering character in conditions of dominant homozygosys (Sh Sh) or heterozygosys (sh Sh) (Sastry and Seetharaman, 1973). Ferrero and Vidotto (1998) found that seed shattering in weedy rice started nine days after flowering and increased gradually for 30 days (65 per cent of the total grains). Ferrero (2010) reported that shattered and non shattered seeds became viable at about nine days from the beginning of flowering, with a germinability of about 20 percent, reaching about 85 percent at 12 days after flowering. Studies done at the at molecular level on the shattering ability found that the inactivation of the CTD phosphates like gene OsCPL1 enhances the development of abscission layer and seed shattering in rice (Abraham *et al*, 2012).

Competitive ability and yield in crop

Weedy rice is a superior competitor to crop cultivars due to its early vigour, greater tillering and height of plants. Yield losses largely depend on season, weed species, weed density, rice cultivar, growth rate and density of weeds and rice. Weedy rice at 35% infestation caused about a 60% yield loss and, under serious infestation, yield loss of 74% was recorded in direct seeded rice (Watanabe *et al*., 1996). Yield of weedy rice infested plots at the rate of 10, 100, and 1,000 weedy seeds per square meter were 4.05, 2.75, and 0.43t ha-1, respectively, compared to the check yield of 4.53 t ha-1 (Chin *et al.*, 2000). Short varieties are usually more susceptible to weedy rice competition than tall ones and interference duration is also a yield deciding factor (Kwon *et al.*, 1991). Weedy rice usually coexisted with cultivated rice and was highly competitive in rice fields of China (Xia *et al*., 2011). According to Chauhan (2013a), the important weedy traits of weedy rice are early shattering of seeds, variable seed dormancy, high seed persistence in soil and high nitrogen use efficiency.

Control of weedy rice

Controlling weedy rice is difficult as it mimics cultivated rice. Several methods are available for the control of wild and weedy rice, but none are highly effective on their own (Noldin, 1988). This weed had already caused a major damage to rice production by reducing rice grain yield and quality in China, the major rice producer (Xia *et al*., 2011). Therefore, effective control of weedy rice populations becomes very important for the sustainable production of rice crop in all growing regions worldwide.

Prevention

Prevention is the basic means of reducing weedy rice infestation and can be achieved mainly by sowing clean rice seeds that are free from weedy rice grains. Another preventative measure found effective was cleaning the equipments used for rice harvesting to avoid spread of weedy rice to uninfested fields (Chauhan, 2013 b).

Cultural methods

Non chemical means of weed control in rice should be centered on land preparation, varietal selection of crop, water management and fertilizer management. California Department of Food and Agriculture (2001) reported that in the absence of effective selective post emergence chemical control, techniques to minimize weedy rice infestations necessarily focused on (1) lowering the chance of emergence of weedy rice seedlings at crop establishment and (2) preventing subsequent seed return to the soil from surviving plants at maturity. The former included repeated (wet and dry) tillage to provide clean seed beds, rotation of crop establishment methods (transplanting, water seeding, wet direct seeding), and cultivar selection to enable water management during crop establishment. All of these practices reduced the chance of plant survival (as seed or seedling). Minimum tillage systems were used in many areas with severe red rice problems (Menezes *et al*., 1994; Azmi and Johnson, 2001). The practice they adopted was after seed bed preparation, the area was kept fallow to enable red rice and other weeds to grow and to form a good mulching cover. Rice could either be drilled or water seeded after spraying the area with non selective herbicides (glyphosate or paraquat). The crop should be flooded soon after rice emergence; otherwise, the degree of weed control will decrease. Studies conducted at Srilanka have revealed the reduction in weedy rice seed production in transplanting (96-98%) followed by seedling broadcasting (71-87%) compared to direct seeding method (farmers practice) of crop establishment (Chauhan, 2014).

Cultural strategy of weedy rice control also includes the use of weed suppressing varieties and submergence tolerant varieties. Tall and long cycle varieties usually showed a greater competitiveness than modern early and semi dwarf varieties. A new approach to chemical control of wild and red rice is the use of herbicide tolerant crop cultivars, which can be safely treated with otherwise non selective herbicides such as glufosinate (Sankula *et al*., 1997). Chauhan (2013a) has reported that the use of cultivars with the traits of early vigour and quick canopy closure may help suppress weedy rice growth. The use of cultivars with purple coloured leaves also reduce weedy rice infestation and the weed seed bank by assisting in mechanical control. He has suggested the use of herbicide resistant rice cultivars to be very effective in managing weedy rice in the short term; however, there was risk of their failure in the long term.

The best control of weedy rice could be obtained with crop rotation, and crops that were normally rotated with rice in temperate climate areas include soybean, maize, wheat, sunflower, sorghum etc. Introduction of mungbean cropping in Vietnam resulted in a huge decrease of the weedy rice plants and other species (Watanabe *et al*., 1998).

Stale seed bed technique

Stale seed bed, also named the false seeding technique, is a cultural method commonly applied in rice monoculture for weed management. Chen (2001) observed stale seed bed technique as an efficient means to manage weedy rice. After seed bed preparation the area is left idle, to allow weedy rice and other weeds to grow. The rice can then either be drilled or water seeded after the weeds are destroyed by either mechanical (harrows) or chemical (non-selective herbicides) means. This technique is aimed at reducing the weed infestation in the same season in which it is applied and gradually decreasing its seed bank. John and Mathew (2001) described stale seed bed as low cost, energy efficient and eco-friendly alternate technology for achieving total weed control in direct seeded lowland rice. Renu *et al.* (2000) and Sindhu *et al.* (2011) have also confirmed the effectiveness of stale seed bed technique in reducing the weed population and decreasing soil weed seed reserves in rice fields.

According to Azmi and Johnson (2001) the success of the stale seed bed method depended on the way the soil is prepared, the water management and its duration. Wet tillage after weed germination destroyed weedy rice seedlings and promoted new emergence. Puckridge *et al.*(1988) pointed out that soil flooding during the application of the stale seed bed reduced emergence from the soil in comparison to dry or moist soil, but favoured the evenness of the germination that in turn made the control easier. The duration of this technique in temperate climate conditions should be about 25-30 days.

Soil solarisation

Soil solarisation was reported as an advanced non chemical field technology for weed management (Yaduraju, 1993). The process significantly increased the soil temperature to 10-15ºC above the normal temperature. This technique was practiced in the warmest months for a duration of 4- 6 weeks using thin transparent polyethylene films of 19-25 micro meter. The efficiency of soil solarisation on the control of weed seed bank was reported by Kumar *et al*. (1993).

Enhanced seed rate

According to Bakar and co workers (2000) enhanced crop seeding rates of 80–100 kg ha–1, above the optimum rate of 60 kg ha–1 in infested fields, suppresed weedy rice infestations. Azmi and Johnson (2001) reported that seed rate of more than 150 kg ha^{-1} could suppress weedy rice in infested areas.

Row seeding

Row seeding was also reported as a better and easy method to differentiate cultivated rice plants in rows and weedy rice between rows. Row seeding was done by using the improved IRRI seeder (Luat, 1997).

Broadcasting of seedling

Studies undertaken by Luat and his co workers (1998) at Central Rice Research Institute, Vietnam observed that the technique of seedling broadcasting developed by Chinese as a suitable management strategy. Two to three rice seedlings (10–15 cm height) grown from seeds sown in plastic plates with holes of 2 cm diameter, were broadcasted randomly or in rows. This method allowed valuable rice seed to be saved, and gave comparable rice yield to that obtained with wet seeding. The water level at the time of broadcasting ranged from 5 to 10 cm and was sufficient to suppress weeds particularly grasses and weedy rice.

Water management

Water management can play an important role in weedy rice control. Early flooding 20-30 days before land preparation would help to control red rice (Noldin *et al*., 1997). After seeding of pre germinated seeds, water management was critical to successfully suppress weedy rice. There were two management strategies for irrigation after seeding: (1) water was maintained at a depth of 5–10 cm until drainage at harvest (continuous flooding); or (2) water was drained, soil is kept saturated for 3–5 days, and flooding is returned gradually. Excessive drainage exposed the soil to air and increased oxygen concentration in the soil, thus stimulating weedy rice germination.

Azmi and Abdullah (1997) reported that farmers resorting to transplanting rice culture in weedy rice infested areas had minimal or no recurrent problems with weeds. Puddling combined with the presence of a thin layer of water over the well levelled soil maintained the anaerobic conditions in the top soil and prevented weedy plants from becoming established (Fisher, 1999). Vidotto and Ferrero (2000) have also found that flooding in well levelled soils limited weedy rice germination. He reported that combination of water seeding and the use of weedy rice free seeds had led to the virtual disappearance of the weed in California.

Hand weeding

The control of weedy rice plants is sometimes carried out manually, but this practice was costly and time consuming. Hand weeding is quite impractical up to 30-40 days after crop emergence as it is very difficult to distinguish the cultivated varieties from the weedy rice in the early stages. Hand weeding of weedy rice plants can sometimes carried out for light infestations and frequently it is used together with other means of control (chemical) when the latter has given poor results, so as to avoid grain dispersal and also in seed production plots.

Mechanical control of weedy rice

Weed seedlings could be destroyed just before the planting of the rice by blade or rotary harrowing in both dried and flooded soils. The weed control obtained with this practice was satisfactory but more time consuming and usually lower than that achieved with chemical destruction (Ferrero *et al.*, 1999). Finassi *et al.* (1996) observed that mechanical control could also favour new flushes of weed emergence after the interventions because of the germination stimulation of the seeds brought to the soil surface by the machinery.

Weedy rice could also be controlled mechanically in line planted rice using tools. This practice was aimed at preventing the spread of the weed and is mainly carried out by cutting tall weed panicles before they set seeds. (Ferrero and Vidotto, 1999). Cutting equipment was usually fitted with a roll crusher made up from two contra-rotating rollers. The European experience showed that at least 94 percent of the panicles could be cut down using this equipment in two phases, the first at the beginning of the flowering and the second 15 days later.

Chemical control of weedy rice

Herbicide based weed management is generally the most popular method for weed control in the direct seeded rice fields. However, it is very difficult to control weedy rice by the use of selective herbicides because weedy rice was essentially the same biological species as cultivated rice. Close anatomical and physiological similarity of weedy rice to the crop made selective post emergence herbicidal control of weedy rice plants very difficult (Chen *et al*., 2004).

Use of herbicides before sowing

According to Noldin and his coworkers (1998) use of antigerminative herbicides, such as metolachlor at 3.5 kg ai ha^{-1}, alachlor at 3.5 kg ai ha^{-1}, applied in soybean as pre emergence resulted in weedy rice control of about 90 percent. Ferrero *et al*. (1999) could obtain good control of weedy rice (often higher than 75 percent) in European rice conditions with pretilachlor and dimethenamid used alone or in combination at 1.5 kg ai ha^{-1} and 0.48 kg ha^{-1}, respectively. To avoid any phytotoxicity risks, both herbicides need to be applied at least 25 days before rice planting. Pre-plant incorporation of thiocarbamate herbicides like molinate and butylate also controlled weedy plants (Fisher, 1999; Garcia and Rivero, 1999).

Kuk *et al.* (1997) found that weedy rice was completely controlled by thiobencarb at 2.1 kg ha–1 and oxadiazon at 0.24 kg ha–1. Molinate (6.5 kg ha–1), however, gave 26–67% control when applied 6 days before rice seeding. Thiobencarb application as a preplant surface treatment at the rate of 4.4 kg ha–1 in combination with reflooding within 3 to 5 d after drainage is recommended to control red rice in the United States (Sadohara *et al*., 2000).

Use of seed protectants

Studies conducted in Kerala by Nair and coworkers during 1984-86 have reported coating of dry seeds with 20% calcium peroxide using 4% PVA solution, and broadcasting them in field with 10-15 cm standing water for 10 days can control weedy rice. Later, this technology was found not practicable due to increased water fowl attack on coated seeds and lankiness of the crop plants due to continued submergence. According to the experiments carried out in Central and South America, the best weedy rice control could be achieved by applying molinate at 7.2 kg ha^{-1} and butylate at 4.2 kg ha^{-1} with seed protectants such as oxabetrinil at 1.5 g kg^{-1} and flurazole at 2.5 g kg^{-1} (Smith, 1992).

Use of herbicides during the crop season

Chemical control in crop post planting should only be considered as a salvage operation and it mainly relies on difference in size or growth stage between weedy rice and commercial rice. Weedy rice that had grown taller than rice could be treated with foliar systemic herbicides such as glyphosate or cycloxydim, at 20 and 5 percent concentrations, respectively, by using wick/wiper applicators (Stroud and Kempen, 1989). The equipment can be mounted on self moving machines, the front of a tractor or hand-held equipment.

A plant growth regulator, maleic hydrazide, had been used in Brazil to control seed production of red rice (Andres and Menezes, 1997). Rice cultivars must be earlier and head at least 10–15 days before red rice. Maleic hydrazide sprayed at the rice milk stage and prior to or during red rice heading stage reduces the production of red rice seed (Dunand, 1996). It was noticed that maleic hydrazide reduced seed viability and so it should not be used on rice seed production fields. The application of maleic hydrazide complements other methods for reducing seed production of red rice and, consequently, minimized this problem in the following years.

Genetic and biotechnological approach for weedy rice control

The problem of weedy rice could be tackled by the introduction of herbicide tolerant varieties which allowed the selective post emergence control (Linscombe *et al.*, 1996 and Wheeler *et al.*, 1997). Glufosinate applied at the 3-4-leaf stage of the weedy rice (red rice) resulted in a better control (91 per cent) than at panicle initiation (74 per cent) or boot stage (77 percent). Imazethapyr could be selectively applied to imidazolinone resistant varieties (IMI rice). This herbicide had proved to be effective against weedy rice and other rice weeds (Olofsdotter *et al.*, 1999). A non transgenic rice variety 'Clearfield' tolerant to herbicide imazethapyr had been in use in red rice infested fields of United States of America from 2002 onwards (Shivrain *et al*., 2009). However, possibility of out crossing of resistant variety with wild rice is suspected to taint the advantage of this technology.

The transfer of resistance gene to weedy species is likely to occur as the incidence of natural hybridization ranges between 1-52 percent in early and late flowering varieties (Langevin *et al.*, 1990). Field studies carried out in Spain have shown that the average gene flow from the transgenic 'Senia' variety (tolerant to glufosinate) to red weedy rice, considering all the wind directions, was 0.082 percent (Messeguer, 2002). These findings suggested that within a few generations the advantages of the herbicide resistance gene could partly disappear.

Liu *et al.* (2012) made a major finding to prevent the spread of transgenes form GM rice to weedy rice which in due course would taint the advantage of GM herbicide resistant crop. They developed an insect-resistant and glyphosate-herbicide tolerant GM rice line that is sensitive to bentazon, a commonly used herbicide. He reported that weedy rice plants containing transgenes from GM rice through gene flow can be selectively killed by the spray of bentazon when a non GM rice variety is cultivated alternately in a few year interval. The built in control mechanism in combination of cropping management is likely to mitigate the spread of transgenes into weedy rice populations.

Integrated weedy rice management

Pingali *et al.* (1997) cited by Luat (2000) stated that the trend towards increased herbicide use and the likely environmental concerns and health consequences of such a trend, always call for integrated weedy rice management. According to Abraham (2012) the only way to avoid the problem associated with weed control is the implementation of improved weed control within the context of integrated weed management, with particular emphasis on the ecobiology of the species. This is an important prerequisite for achieving the expected yield in rice production and obtaining the necessary reduction in weed stand, including weed seed bank. Effective control of weedy rice cannot be based on one single practice, but should rely on complex management program based on an appropriate combination of preventative, cultural, mechanical, chemical and genetic means (Chauhan, 2013b).

Research on the biology and management of weedy rice in Kerala Agricultural University

Heavy infestation of weedy rice in rice fields of Kerala during recent years had forced the farmers to abandon the crop due to huge reduction in crop yield (around 30-60 per cent) depending on the severity of infestation (3-10 mature weedy plants per square meter). Acute labour shortage and high wages added to the severity of the infestation. Infestation became serious from 2005 when farmers started relying more on chemical weeding and mechanized harvesting. During 2008-09 many farmers had to abandon the crop without harvesting, due to the severe incidence of weedy rice in the cropped field.

Survey undertaken in the major rice growing tracts of Kerala during 2009-12 identified the infestation of weedy rice to the tune of 3- 12 plants per square meter. Infested polders have been categorized as those with mild, moderate and severe occurrence. Variations in plant height, tiller production, pigmentation, length of awn and grain were noticed in the weedy rice types of Kerala. Major reason for the spread was the non-recognition of the weedy rice biotypes or hybrids in the crop field during the early stage of infestation due to its close similarity to the cultivated rice with short awns and straw coloured grains, gradually turning black or deep brown on maturity. At seedling stage, it is difficult to distinguish weedy plants as it mimics the crop, while it was possible after tillering with many morphological differences with the rice varieties i.e., more numerous, longer and more slender tillers, leaves which were often hispid on both surfaces, light green, tall plants, pigmentation of several plant parts, grains with awns and red pericarp and shattering of seeds. The weedy plants have more brittle culm and are round in cross section than that of cultivated rice. The plants generally have a spreading habit and flower earlier than cultivated rice plants. Weedy morphotypes with and without auricles, either straw or red colour, are noticed in Kerala (Jose *et al*., 2012 a).

It was observed that the variable dormancy and staggered germination in weedy rice favoured the survival and spread in cultivated fields. Lab studies have confirmed the hull induced dormancy in weedy rice of Kerala. Among the various treatments evaluated for breaking hull induced seed dormancy of weedy rice, treatments in the descending order of efficiency were: (i) subjecting seeds to low temperature of 22ºC for 48 hours, (ii) scraping of seed hull, (iii) salt water treatment for six hours (EC–5 dS $m^{-1}$and 15 dS m^{-1}) and (iv) 0.6% nitric acid soaking for six hours. These treatments can be effectively opted alone or in combination during different seasons in stale seed bed preparation for weedy rice management under different field situations (Jose *et al*., 2013).

Scanning electron microscope studies of weedy rice seeds (Jose *et al*., 2013) revealed the presence of indentations on the exterior surface with silica in the mid region. The seed surface had parallel rows of trichomes which help in dispersal of seeds, give better grip for seeds in soil facilitating germination and prevent wash out during heavy rains. Observations confirmed the delayed germinability of matured weedy rice seeds compared to immature ones. The weedy rice leaves had more micro hairs and epicuticular wax which can reduce transpiration and enhance water use efficiency.

Studies in severely infested rice fields of Kerala by Jose and co-workers (2012 b) revealed that stale seed bed preparation by ploughing the field in between two germinations at 25-30 days interval prior to sowing provided conditions for germination of majority of weed seeds in the soil seed bank. Ploughing (wet ploughing was more effective than dry ploughing) in between two stale seed bed operations took the buried seeds to the top soil for promoting germination, as weedy rice seeds do not germinate under continuous submergence and emerged only from top 4cm of soil. In double cropped fields, where farmers do not get ample time for doing the staling operations twice, burning of straw before first stale broke seed dormancy and ensured uniform germination of weeds from the soil surface. Participatory technology demonstration revealed that in severely infested double cropped areas it is better to skip one crop and repeat staling operations twice to prepare a weed free field, giving maximum time for exhausting soil seed bank.

Table 1: Effect of stale seed bed technique in managing weedy rice

Treatment	Plant density at 45 DAS (No. m $^{-2}$)		Tiller count at 45 DAS (No. m $^{-2}$)		Grain yield (kg ha^{-1})	WCE (%)
	Weedy rice	Rice	Weedy rice	Rice		
One SSB	6	75	16	201	5688	49.8
Two SSB	3	75	8	241	6562	75.2
SSB with skip crop	1	74	4	323	7500	89.6
Control	12	73	29	195	2420	0
LSD (0.05)	**2**	**NS**	**3.2**	**48**	**587**	**-**

Studies at KAU revealed the effectiveness of soil solarisation by using 100 micron transparent polyethylene sheets for 30 to 45 days during the summer months for getting more than 90 percent control of weedy rice. This technique will be useful for the rice nurseries to produce seedlings free of weedy rice seedlings. Surface application of oxyfluorfen @ 0.2 to 0.3 kg ha^{-1} in 2cm standing water three days before sowing effectively controlled weeds (84% reduction in weedy rice dry weight) during the initial critical period (Jose *et al*., 2012 c).The research activities undertaken at AICRP on Weed Control have standardized a new prototype of Wiper Device for selective drying of weedy rice earheads for which patent is awaited. It was proved that better WCE can be obtained by selective killing of weedy panicles by direct contact application using a specially designed wiper device at 60-65 DAS, with broad spectrum herbicides viz., glufosinate ammonium, paraquat or glyphosate @ 15-20% concentration, taking advantage of 15-20 cm height difference between rice and weedy rice plants (Abraham *et al*., 2012).

Integrated management strategies like stale seed bed technique to exhaust soil seed bank, pre plant application of herbicides to prevent the early emergence, and use of wiper device to selectively dry the panicles of weedy rice in standing crop to prevent buildup of soil seed bank are viable technologies for managing this difficult to control weed in rice. Effective management of weedy rice is possible by following other management options like higher seed rate, use of pigmented rice varieties, straw burning, appropriate tillage practices, adoption of mechanized transplanting or dibbling, scientific water management, and hand weeding in an integrated approach (Abraham *et al*., 2012). Participatory technology demonstration have confirmed that weedy rice infestation in farmers' fields required a management program aimed at local eradication at the field level followed by integrated management strategies.

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Table 2: Effect of direct contact application of herbicides on the control of weedy rice panicles

Herbicides	Dose (%)	Plant height at 65 DAS (cm)		Panicles before drying (No. m^{-2})	Skipped panicles (%)	Dried panicles (%)
		Weedy rice	**Rice**			
Paraquat 24 SL	10	93.3	73.3	38	25	75
Paraquat 24 SL	15	89	74.3	29	33	67
Glyphosate 41 SL	10	93.3	77.0	36	30	70
Glyphosate 41 SL	15	89	71.0	40	28	72
Glufosinate Ammonium 14 SL	5	94.3	81.7	33	52	48
Glufosinate Ammonium 14 SL	10	91.7	75.0	36	37	63
Glufosinate Ammonium 14 SL	15	91.3	79.0	27	37	63
Glufosinate Ammonium 14 SL	20	87.7	72.7	45	38	62
Glufosinate Ammonium 14 SL	25	96.3	79.7	44	23	77
Control		89	75.3	57	100	0
LSD (0.05)		**NS**	**NS**	**NS**	**18.7**	**18.7**

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