BIOLOGY AND MANAGEMENT OF WEEDY RICE

(*Oryza sativa* f. *spontanea*)

by

NIMMY JOSE

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THESIS

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DECLARATION

I, hereby declare that the thesis entitled **"Biology and management of weedy rice (*Oryza sativa* f. *spontanea*)"** is a bonafide record of the research work done by me during the course of research and this thesis has not previously formed the basis for the award to me any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that the thesis entitled **"Biology and management of weedy rice (*Oryza sativa* f. *spontanea*)"** is a record of the research work done independently by Smt. Nimmy Jose under my guidance and supervision and that it has not previously formed the basis for award of any degree, fellowship or associateship to her.

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1. INTRODUCTION

Rice is the second most widely grown cereal crop and staple food for more than half the world's population. Global rice production of 730 M t is from an area of 163 M ha with an average productivity of 4480 kg ha^{-1}. Rice is the staple food of majority of the population in Asia and a way of life for millions of people all over the world. Rice production is closely related to social harmony and political stability in many countries. As rice consuming population continues to grow, and land and water resources required for rice production diminish, there is an urgent need to sustain the production. India has the largest rice growing area (44 M ha) in the world but contributes to less than a quarter of global production (103 M t). Rice accounts for more than 40 per cent of the food grain production of the country. Rice cultivation in India extends from 0.5 to 2.0 m below msl in Kuttanad to as high as 3000 m altitude in Assam and Arunachal Pradesh.

In Kerala, rice is grown in a gross area of 1.9 lakh ha producing 5.50 lakh tones with a productivity of 2671 kg ha^{-1}. The food production scene is turning gloomy in Kerala, with the gap between production and requirement of food grain widening every year. Rice farming in Kerala adds to environmental security and socio economic well-being. Rice based farming systems of Kerala are hub for biodiversity including aquatic and terrestrial organisms, wild life, livestock and other crop varieties. The scarcity of labour coupled with escalating production costs has changed the rice farming practices in the state. Inundation of river water, saline water intrusion in the below sea level rice fields of Kerala, highly acidic clayey soils in most of the rice fields and soil salinity restrict the possibility for crop rotation in rice fields. Shift in the crop establishment method from transplanting to direct sowing of pre germinated seeds and increased dependence on pesticides, especially herbicides and reduced tillage practices have given way for several biotic and abiotic stresses in rice. A perennial constraint in rice cultivation is the infestation by large number of weeds like *Echinochloa crusgalli*, *Echinochloa stagnina*, *Leptochloa chinensis* and *Sacciolepis interrupta* among grasses; *Cyperus iria*, *Cyperus difformis* and *Fimbristylis miliacea* among sedges;

Monochoria vaginalis and *Ludwigia perennis* among broad leaf weeds. Of late, weedy rice infestation has become a serious threat in all the rice belts of Kerala.

Weedy rice is the complex of morphotypes of *Oryza* species widely distributed in the commercial rice fields, especially in areas where farmers have switched to direct seeding due to labour shortage and high cost. Severe weedy rice infestations have been reported in the commercial rice fields in more than 50 countries of Asia, Africa and Latin America. Weedy rice is known by different names in different countries, 'Padi Angin' in Malaysia, 'Lua Lon' in Vietnam, 'Luta' in China, 'Akamai' in Japan, 'Sharea' in Korea, 'Khao Pa' in Laos, ' Khao' in Thailand and 'Jhor Dhan' in Bangladesh.

India has the earliest history of rice cultivation and introgression between perennial wild rice and cultivated rice has given rise to highly variable population of weedy/wild rice forms, including annuals and perennials. Indian weedy rice has been reported to be *Oryza sativa* f. *spontanea*, belonging to *indica* group (Vaughan, 1994). Weedy rice infestations are seen 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).

Weeds are a perennial problem in rice cultivation. Acute labour shortage leading to shift from transplanting to direct sowing, reduction in conventional land preparation operations, absence of hand weeding, increased dependence on selective and broad-spectrum herbicides have contributed to shifts in weed flora. During the recent years, heavy infestation of weedy rice and subsequent huge reduction in yield has forced many farmers to abandon the field even without harvesting (Plate 1).

Morphological similarity of weedy rice to cultivated rice, variable seed dormancy and early seed shattering nature, staggered germination and high competitiveness of weedy rice make hand weeding/rouging incomplete and ineffective. The spread of weedy rice as contaminants with seed material, its distribution through irrigation water, machinery and animals, and efficient

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പെരുന്ന കട്ടക്കുഴി പാടത്ത് വരിനെല്ല് വിളഞ്ഞനിലയിൽ

വിതച്ചത് 'ഉമ' നെൽവിത്ത്: വിളഞ്ഞത് വരിനെല്ല്

ചങ്ങനാശ്ശേരി: പെരുന്ന കട്ടക്കുഴി പാടശേഖരത്തിൽ 'ഉമ' ഡി-വൺ ഇനത്തിനുള്ള നെൽവിത്ത് വിതച്ച സ്ഥലത്ത് വിളഞ്ഞതിൽ ഭൂരിപക്ഷവും വരിനെല്ല്.

ഇവിടെ പാട്ടക്കൃഷി നടത്തുന്ന ചക്കരയിൽ ഗോപാലകൃഷ്ണൻ നായരുടെ അഞ്ചേക്കർ പാടത്താണിത്. 120 ദിവസം പ്രായമായ ഉമ നെൽവിത്തിന് ഇടയിലുള്ള വരിനെല്ലിന് 90 ദിവസമാണ് പ്രായം. ഇതോടെ ഇത്രയും കൃഷി നഷ്ടമായെന്ന് കർഷകർ പറഞ്ഞു.

ഇവിടെ കൃഷി നടത്താൻ 17,000 രൂപയോളം ചെലവു വന്നതായി കർഷകർ പറയുന്നു. വിള ഇൻഷുറൻസ് ലഭ്യമാക്കണമെന്ന് കർഷകരിൽ ഒരാളായ നിരണത്ത് കൃഷ്ണപ്രസാദ് ആവശ്യപ്പെട്ടു. ഉാപ്പാലം തോട്ടിൽ മുട്ട് ഇട്ടതുമൂലം പാടത്ത് ജലക്ഷാമവും ഉണ്ട്.

A. News item on weedy rice infestation in Kuttanad
Mathrubhomi daily, dated 21 March, 2010

B. Weedy rice infestation in Kuttanad

Plate 1. Weedy rice - A major threat to rice farming in Kerala

replenishment to the soil seed bank also add to the severity of infestation and invasion to newer areas. As the present recommendations of chemical weed control in rice are not effective for selective control of weedy rice, modifications in method, time and dose of herbicide application need to be tested. A suitable package for integrated management of weedy rice has to be evolved for effective and economical control of the weed.

In the above circumstances, the present research programme was undertaken with the following objectives:

1. to study habitat, distribution, biology and ecology of weedy rice and its competition with cultivated rice in the rice fields of Kerala,
2. to understand Indigenous Traditional Knowledge (ITK) and perception of farmers on weedy rice, its biology, problems and its management,
3. to study the effectiveness of different methods of weed control for the management of weedy rice,
4. to develop a suitable package for the integrated management of weedy rice and
5. to demonstrate viable technologies for management of weedy rice in a participatory mode in farmers' field.

2. REVIEW OF LITERATURE

Weedy rice is the complex of morphotypes of *Oryza* species 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 over to direct seeding due to shortage and high cost for labour. Weedy as well as wild forms of different species coming under the genus *Oryza* are also known as wild rice or red rice. Weedy rice is considered as a product of natural hybridization between cultivated and wild forms. Taxonomically, Indian weedy rice is *Oryza sativa* f. *spontanea* which belongs to the indica group (Vaughan, 1994). Infestation of weedy rice in paddy fields can reduce crop yield substantially to the tune of 50-70 per cent depending on the intensity and extent of infestation. Of late, infestation of weedy rice in rice fields of Kerala has increased to alarming rates, forcing many farmers to abandon rice farming due to unavailability of viable technology for its effective management.

The term weedy rice refers to the population of annual *Oryza* species that decreases the income of farmers both quantitatively through yield reduction and qualitatively through diminished commodity value at harvest. They are major threat to irrigated rice production systems in Southeast Asian countries like Malaysia, Indonesia, Thailand, Philippines, Vietnam, Bangladesh and Korea. Wild and weedy relatives are problematic in Eastern India (Eastern U.P., Bihar, Orissa, Manipur and West Bengal) and Southern India (Kerala, Tamil Nadu, Karnataka and Andhra Pradesh), whereas, in North Western states like Haryana and Punjab, they are not yet a problem. During recent years, there has been an increase in the population of weedy rice in rice fields of Kerala, Orissa, West Bengal and Madhya Pradesh which can be attributed mainly to the shift in the rice growing system from transplanting to direct sowing.

Weedy rice is known by different names in different countries, 'Padi Angin' in Malaysia, 'Lua Lon' in Vietnam, 'Luta' in China, 'Akamai' in Japan, 'Sharea' in Korea, 'Khao Pa' in Laos, ' Khao' in Thailand and 'Jhor Dhan' in Bangladesh.

In Kerala it is known as *Varinellu*. Weedy rice grains frequently have a red pigmented pericarp and it is for this reason that the term ‘red rice’ is commonly adopted in the international literature to identify these weedy forms. Variations in height, tillering, and colour and length of awns and grains are noticed among weedy rice morphotypes. Genetic and morphological similarity of weedy rice to cultivated species makes its control difficult even by hand weeding. Development of an effective strategy for management of weedy rice is possible only with an understanding of the origin and biology of the weed.

2.1. Wild rice and its species

The genus *Oryza* probably originated about 130 million years ago in Gondwana land and species were distributed in different continents when Gondwana land split up (Khush, 1997). The genus *Oryza* was classified under the tribe Oryzeae, subfamily Oryzoideae. This genus has two cultivated species (*O. sativa* L. and *O. glaberrima* Steud.) and more than 24 wild species (most of which are diploid) distributed throughout the tropics and subtropics. *O. sativa,* which is also known as Asian rice, comprises the ecogeographic races *indica, japonica* and *javanica*, and is grown worldwide. *O. glaberrima*, named as African rice, is mainly cultivated in West Africa.

Takeoka (1962) considered *Oryza rufipogon* to be a progenitor of *Oryza sativa*, and together with *O. longistaminata* and *O. sativa* forms the *O. sativa* complex. Before Takeoka's work, the Asiatic individuals were known as *O. fatua* (*O. sativa* var. *fatua*, *O. sativa* f. *spontanea*) or *O. rufipogon*. American wild rice was listed as *O. perennis* and African individuals as *O. longistaminata* or *O. perennis*. However, Takeoka (1962) redefined the complex and indicated that the Asiatic plants should be included in one species as indicated by Bor (1960) and the correct specific name for them was *O. rufipogon*. As the American plants had no clear distinction from the Asiatic plants in terms of awn length and rhizomes, he called them also *O. rufipogon*. However, African wild rice plants were separated from *O. rufipogon* as a different species, called *O. longistaminata*, on account of their different underground systems.

Later, Khush (1997) suggested that the name O. *nivara* should be retained for the annual forms of wild (shattering) rice in Asia. He reviewed the genus and defined *O. rufipogon* in narrowest sense as a perennial, restricted to Asia from Pakistan to China and Indonesia, and tropical Australia. He used the name *O. nivara* for the wild annual species, also of Asia, intermediate between *O. rufipogon* and *O. sativa*. All three species had the same AA genome and are not readily distinguished but for their annual/perennial character and deciduous/non-deciduous spikelets. He reported that many weedy forms shared most of the features of the two cultivated species *O. sativa* and *O. glaberrima*.

Based on morphological, physiological and biochemical features, and crossing relationship, eight different genomes were identified in the genus *Oryza* (Aggarval *et al.*, 1997). Wild species like *O. perennis, O. nivara*, *O. rufipogon* and *O. longistaminata* shared the same genome and could be easily crossed with the cultivated *O. sativa* species (Olofsdotter *et al*., 1999). The wild *O. barthii* species (*O. breviligulata*) was considered to be the progenitor, after mutation of African rice. *O. glumaepatula* is a wild endemic Central and South American species that was conventionally considered to be a subtype of *O. rufipogon*, but, according to recent genetic analysis, it has been determined to be closer to African forms. Olofsdotter *et al*. (2000) classified the 24 wild species into four species complexes *O. sativa, O. officinalis, O. ridleyi,* and *O. meyeriana* (Table 1). He made a comprehensive study of the group analysing awn length, life span and root type, and found that they were also divided geographically.

Table 1. Species complexes of the genus *Oryza*

Species	Genome	Chromosome no. (2n)	Distribution
***Oryza sativa* complex**			
O. sativa	AA	24	Worldwide, cultivated
O. nivara	AA	24	Tropical and subtropical

			Asia
O. rufipogon	AA	24	Tropical and subtropical Asia, tropical Australia
O. glaberrima	AA	24	West Africa, cultivated
O. barthii	AA	24	Africa
O. longistaminata	AA	24	Africa
***Oryza officinalis* complex**			
O. malamphuzhaensis	BBCC	48	India
O. eichingeri	BBCC	24, 48	South Asia and East Africa
O. officinalis	CC	24, 28	Tropical and subtropical Asia, tropical Australia
O. rhizomatis	CC	24	Srilanka
***Oryza meyeriana* complex**			
O. granulata	GG	24	South and Southeast Asia
O. meyeriana	GG	24	Southeast Asia
***Oryza ridleyi* complex**			
O. ridleyi	HHJJ	48	South Asia

Wild rice exhibited wide variation in life history traits and its annual type (designated as *O. nivara* or *O. sativa* f. *spontanea,* 2n=24, genome AA) was adapted to disturbed habitats and often exhibited substantial seed dormancy. A key for separating the complex was the spikelet characters. *O. sativa* had persistent spikelets, while *O.rufipogon* had deciduous spikelets. *O. longistaminata* *wa*s perennial with creeping and branched rhizomes (Bor, 1960). Second (1985), using isoenzyme analysis, described *O. rufipogon* complex with geographical forms separated from South Asia, China, Papua New Guinea, Australia and the Americas.

2.2. Weedy rice and its origin, spread and distribution

There are wild, weedy and domesticated races of most crop plants. The wild races survived without man, the weedy ones survived because of man and the domesticated races demanded care and cultivation for survival (Harlan, 1976). Wild rice exhibited wide variation in life history traits and its annual type (sometimes designated as *O. nivara* or *O. sativa* f. *spontanea,* 2n=24, genome AA) was adapted to disturbed habitats characterized by a prolonged dry season (Oka, 1988) and often exhibited substantial seed dormancy.

Oka and Chang (1961) observed bidirectional introgression between wild and cultivated rice. The phylogenetic origin of the weedy forms was found to be closely related to that of cultivated rice. According to Chang *et al.* (1982), *O. rufipogon* and *O. sativa* intercross and had a high rate of natural crossing resulting in numerous intergradations between the two species. Vaughan and Muralidharan (1988) reported that wild species/taxa under the genus *Oryza* were seen more prevalent in the evergreen to semi evergreen forests and water bodies of Kerala.

It is widely hypothesized that weedy rice has a variety of origin. One possibility is the introgression between wild and cultivated rice, and the second is through the segregation of off types from extensively planted cultivars, especially non-photosensitive varieties. Several research works have confirmed that red rice is a highly polymorphic population. Intra population genetic variation in red rice was suggested as the result of natural cross pollination of red rice and cultivated rice. This has led to the formation of innumerable ecotypes with increased compatibility to local environment and morphological characters resembling rice cultivar (Langevin *et al*., 1990; Noldin *et al*., 1999; Espinoza *et al*., 2005).

Khush (1997) reported that many weedy rice plants shared most of the features of the two cultivated species *O. sativa* (Asian) and *O. glaberrima* (African). The term 'weedy rice' refers to the population of annual species of *Oryza* that diminished farmers income both quantitatively through yield reduction and qualitatively through lowered commodity value at harvest (Mortimer *et al*., 2000). According to them, three factors that determined the population of weedy rice were (1) seed remaining dormant in the soil over crop seasons, (2) dissemination through crop seed contamination, and (3) seeds returning from plants of the previous crop.

In India, *O. sativa* f. *spontanea* is considered as the weedy rice species in cultivated rice (Vaughan, 1994). The weedy rice complex mainly included plants setting red pericarp seeds, known as red rice (Olofsdotter *et al*., 2000), although some morphotypes had white pericarps (Hernandez *et al*., 1979 and Espinoza *et al*., 2005). As *O. nivara* and *O. rufipogon* shared the same genome AA, they could easily cross with rice crop. Other wild species such as *O. malampuzhaensis* (BBCC)*, O. officinalis* (CC)*, and O. granulata* (GG), present in India, with genome different from AA, were difficult to cross with cultivated rice.

In contrast to wild plants, domesticated rice cultivars are characterized by a low rate of seed shedding at maturity, a low degree of seed dormancy, synchronous heading, self-pollination and high grain yield (Oka and Chang, 1961). Hybridization and backcrossing between perennial wild rice and cultivated rice created a highly variable range of weedy perennial wild rice types, including annual types. Sometimes hybrid swarms were produced and the hybrids showed no sterility. Abdullah *et al*. (1997) reported that close relationship between weedy rice and cultivated varieties give a strong indication that evolutionary forces were still present in rice ecosystems. The evolutionary response through ecotypic differentiation and hybridization with wild relatives was undoubtedly a primary source of weedy rice in Asia and Africa. Rice (*O. sativa* L.) in Asian countries was thought to be derived from common wild rice (*O. rufipogon* Griff. - Asian form of

O. perennis Moench) and hybrid progenies between cultivated rice and wild relatives were often weeds in lowland rice (Mortimer *et al*., 2000).

Distribution of wild and weedy relatives of rice

Weedy rice had become a problem in all tropical and subtropical rice growing regions of the world (Olofsdotter *et al*., 2000) especially in farms that utilized direct seeding and intensive rice production systems. Cao *et al*. (2007) also reported wide distribution of weedy rice in the rice planting regions all over the world, particularly in East, South and Southeast Asia, South and North America, and Southern Europe. They reported that weedy rice was present in countries like Brazil, Columbia, Costa Rica, Cuba, France, Ghana, Italy, Malaysia, Mexico, Portugal, Surinam, USA, Vietnam, and Venezuela. In China, weedy rice was commonly found in rice fields of many provinces. With the adoption of direct seeding and/or other no-till technologies, in addition to less input of labour for weed control, weedy rice re-occurred as a major weedy problem in Jiangsu, Hainan provinces and northeast parts of China (Wang and Chang, 2009).

Chang (1975) reported the spread of wild rice in West Bengal, Andhra Pradesh, Assam, Bihar, Karnataka, Madhya Pradesh, Orissa, Tamil Nadu and Uttar Pradesh. Wild and weedy forms are a problem in Eastern India (Eastern U. P., Bihar, Orissa, Manipur, and West Bengal) and Southern India. In North Western states like Punjab and Haryana, weedy rice is rarely seen (AICRIP, 2011).

Vaughan and Muralidharan (1988) reported O. *rufipogon* populations in the midlands along the fresh water streams of Kerala. *O. sativa* f. *spontanea* occurs throughout the Malabar region (North Kerala) as a weed of paddy fields. According to Thomas *et al*. (2001), the Western Ghats region of South India is rich in biodiversity of wild rice species including *O. rufipogon, O. nivara, O. granulata*, *O. malampuzhaensis,* and *O. officinalis*. Vaughan and Stich (1991) and Kumar *et al*. (2008) reported that the Bhoothathankettu, Parambikulam, and Kuralai forest reserves along the Western Ghats in Kerala had been identified for *in situ* conservation of these wild species by the International Rice Research Institute. More than 50 per cent of the major rice growing areas of Kerala Kuttanad, Palakkad and Kole lands, where rice is seeded directly had infestation of varying intensities (Abraham *et al*., 2012). Weedy rice has become a major problem in the recent past due to increased dependence on selective herbicides, mechanization, acute shortage and high cost for labour.

Spread of weedy rice

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. Heavy weedy rice infestations are observed in the summer-autumn rice crop than in other seasons of the year. The spread of weedy rice is likely to be accomplished by several means, including water, cattle, machinery, and as contaminants of new varieties (Chauhan, 2013a).

California Department of Food and Agriculture (2001) reported that the mature seeds of weedy rice with varying degrees of seed dormancy were shattered and buried in soil crevices at varying depths. While grazing, buffaloes trampled on the seeds and buried them deeper into the soil. Wild rice reproduces by seed and rhizomes. Seeds fell near the parent plant but were dispersed across greater distances as rice seed contaminants and with human activities, water and soil movement, and possibly by birds. Chen (2001) reported that the number of weedy rice seeds in a soil sample of 1 m x 1 m x 15 cm ranged from 10 to 30,000. After harvest and before disk harrowing, 84.4 per cent seeds remained in the top 0 - 3 cm surface layer of soil. Disk cultivation helped to move the seeds downward to the 3 - 15 cm soil layer resulting in serious infestations and difficulties in control.

2.3. Characters of weedy rice

Variability in weedy rice

Vaughan *et al*. (2001) reported wide variability in the anatomical, biological and physiological features of weedy plants. Azmi and Johnson (2001) also reported the highly variable characters of weedy rice. These plants may be shorter, taller than or as tall as cultivated rice. The flag leaf was either droopy or erect, panicles can be open or closed type, awns may be short, long or absent. Angiras and Singh (1985) observed that grains of wild rice ripened earlier and less regularly than those of cultivated rice and were extremely prone to shattering. The stem of wild rice was comparatively more brittle and round in cross section than that of cultivated rice; the surface of leaf sheath of wild rice was softer and spongier than that of cultivated rice; leaves were generally narrower, deep green and occur at short intervals on stem and wild rice plants generally had a spreading habit and flowered earlier than cultivated rice plants.

Kwon *et al.* (1992) and Suh *et al.* (1997) reported the difficulty in distinguishing weedy rice plants as it mimics the crop, while it was possible after tillering with many morphological differences with rice varieties i.e., more numerous, longer and more slender tillers, leaves often hispid on both surfaces, taller plants, pigmentation of several plant parts, grains with awns, red pericarp and shattering of seeds.

The term red rice is not very appropriate as red grains are also present in some cultivated varieties, but also absent in various weedy forms (FAO, 1999). Populations are highly variable, showing continuous independent variation in many characters, including heading and shattering time, tiller number and development, plant height, awn length, caryopsis pigmentation and seed dormancy (Rathore *et al*., 2013).

Gu *et al*. (2003) have revealed an association between morphological characteristics and seed or caryopsis germination in the weedy population. They observed that mean length of awns in a panicle varied from 1 to 8 cm and per cent of seeds with an awn in a panicle varied from a few to 100 per cent. It was reported that this range of variation suggested that more than one gene controlled morphological characteristics in weedy strains and linkage of some genes for dormancy and some genes for morphological characteristics. The works done by Espinoza *et al*. (2005) using multivariate analysis to identify morphometric similarities and differences between the weedy morphotypes and other *Oryza* species pointed out that morphological characters were more useful in the identification of morphotypes than seed characters.

Weedy morphotypes with anthocyanin in the apiculous occasionally showed pigmentation in other plant structures, such as the first internode, ligule, margins of the first leaf and auricles (Espinoza *et al*., 2005). The seeds of most weedy biotypes of *O. sativa* and *O. glaberrima* had pigmented pericarp due to the presence of variable content of different antocyanins, cathekins and cathekolic tannins. The red pigmentation, being dominant character, is controlled by more than one gene.

Scanning electron microscope studies conducted by Hamid *et al*. (2007) on weedy rice variants collected from Malaysia did not show any anatomical variations in seed and leaf characters. They have reported the presence of epicuticular waxes on the leaf surface and trichomes on the seed surface which favoured the spread and adaptation to competitive situations. They observed the presence of variable number of spikelets in the open (190-210 spikelets per panicle) and closed panicle (210-230 spikelets per panicle) types.

Undesirable traits of weedy rice

Undesirable morphological and physiological characters of weedy rice reported by Bakar *et al*. (2000) are detailed below (Tables 2 and 3).

Table 2. Morphological features of weedy rice

Trait	Characteristics	Impact
Plant mimicry	Mimics cultivated rice	Difficulty for manual weeding
Height	Taller (140 – 150 cm)	Cause lodging, competitive edge over rice
Grains	Awned/ awnless grains, red/straw coloured, short	Reduce rice quality

	grains	

Table 3. Physiological features of weedy rice

Trait	Characteristics	Impact
Dormancy	Variable period	Persistance
Seed longevity	Viable in soil for many months	Higher seed bank
Germination	Variable soil conditions	Adapt to wet seeding
Reproductive phase	Early flowering, maturity and spontaneous shattering	Increase seed bank in soil
Threshability	Presence of awns, tightly packed seed coat	Lack of uniformity in the milled product
Herbicide selectivity	Tolerance to rice herbicides	Chemical control less effective

According to Chauhan (2013 a), 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.

Dormancy of weedy rice

Seed dormancy is a physiological trait and contributes to the adaptability of plants in nature. According to Simpson (1990) dormancy is the temporary failure of a viable seed to germinate in a particular set of environmental conditions that allow germination after the restrictive state has been terminated by either natural or artificial conditions. Germinability is the capacity of seeds in a population with dormancy for immediate, intermediate, or much delayed germination due to the internal conditions (Foley, 2001).

O. rufipogon seeds were typically dormant at maturity. Dormancy was partly due to the presence of inhibitors in the seed coat and seeds may remain dormant and viable for up to three years or more under field conditions, depending on the biotype and environment. Many seeds decayed during long periods of flooded conditions. Viable weedy rice seeds with red pericarp remained dormant up to three years in Brazil (Leitao *et al*., 1972) and two years in the United States (Klosterboer, 1978). Tang and Morishima (1997) have also reported that there was variation in seed dormancy in weedy rice. Weedy rice harbored more major dormancy genes than cultivated rice. One or two genes for hull imposed dormancy were suggested in cultivars (Seshu and Sorrells, 1986; Das, 1995). Hull imposed dormancy in cultivated rice was reported to be a quantitative trait (Chang and Tagumpay, 1973).

Heritability for dormancy in cultivated rice ranged from 0.12 to 0.42 (Chang and Yen, 1969). Delatorre (1999) suggested that significant reduction of dormancy usually occurred two months after ripening. Dormancy regulation could most likely be attributed to factors present in glumella and in embryo. From inheritance studies of seed dormancy in weedy rice, Gu *et al*. (2003) concluded that seed dormancy at zero days after harvest was dominant, and that dominance for duration of seed dormancy was incomplete when judged by days to 50 per cent germination. They reported that weedy rice derived populations maintained a higher level of heritability for seed dormancy during a longer period after harvest. Thus, some strains of weedy rice should be good donors to impart resistance to pre harvest sprouting in cultivated rice.

It was observed by Veasey *et al*. (2004) that seeds of *O sativa and O. glaberrima* exhibited dormancy but at variable rates. The loss in seed dormancy was slower in *O. glaberrima* compared to *O. sativa*, which lost the dormancy soon after harvest. Wide variation in the mean dormancy period was observed in 35 cultures of *O. glaberrima*, showing that seed dormancy is not exclusive to the wild species. The seeds of dry regions developed longer periods of seed dormancy; wait for wet period when environmental conditions again became favourable for germination and seedling survival. They highlighted that ecotype differentiation within a species is due to the correlation between the degree of dormancy and habitat disturbance of the sites where the seeds matured. Germination response varied with latitude, elevation, soil moisture, soil nutrients, temperature, and nature and density of plant cover, where the seed matured.

Cohn *et al*. (1983) reported that sodium nitrite at 10 mM broke dormancy of dehulled red rice (*O. sativa*) especially in dry, after-ripened seeds. Cohn *et al*. (1989) reported that the relative activity of many dormancy-breaking chemicals is generally a function of their lipophilicity and further modulated by the nature of the functional group present or molecular size. Breaking of weedy rice dormancy obtained with substances such as sodium nitrite, propionic acid, propionate-methyl, cytokinin and n-propanol resulted to be usually accompanied by a pH reduction of the embryo tissues (Footitt and Cohn, 1992). The efficiency of commercial liquid smoke (LS) flavoring product (Reese Hickory brand) in aqueous dilutions of 4–5% (v/v) to break dormancy (40–100% germination) of both intact and dehulled red rice (*Oryza sativa*) has been reported by Doherty and Cohn (2000). Despite years of research on seed dormancy, mechanisms for the regulation of germinability are basically unknown (Foley, 2001; Koornneef *et al*., 2002).

Seed longevity

Seed longevity in the soil was 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). In a study conducted in Italy, the viability of weedy rice seeds taken deep by ploughing in loamy soil decreased to six per cent after one year and to five per cent after two years of burial (Ferrero and Vidotto, 1998). The non-viable seeds appeared empty, without embryos and reserve matter. The studies conducted at two locations in Texas showed that seed longevity in red rice was greater with deeper seed burial. Baek and Chung (2012) observed that seed viability of cultivated rice was 5 per cent in dry paddy and 0.5 per cent in flooded paddy, but weedy rice maintained a high viability of 90 per cent during winter in dry paddy and 61 per cent in the flooded paddy. Following freezing treatment of the imbibed seeds, the per cent seed viability was 78 for weedy rice and 16 for cultivated rice. In an accelerated ageing test at low temperature and soaking conditions, the seed viability of weedy rice was 40 per cent higher than cultivated rice at 90 days after treatment. During accelerated ageing of seeds, the protein content remained higher in weedy rice compared to the cultivated rice, and fat acidity remained lower in weedy rice compared to cultivated rice. Catalase and superoxide dismutase activity of weedy rice was four times higher than that of the cultivated rice, and DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging activity of weedy rice was also much higher than cultivated rice.

Emergence

Emergence of weedy rice was greatly influenced by the soil texture, presence of water in the field and 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. Typically germination occurred between 15 and 40°C. Seeds often germinated slightly sooner and at lower temperatures than commercial rice seeds. Some biotypes emerged from soil depths of up to 12 cm (California Department of Food and Agriculture, 2001). Chen (2001) reported that in pot experiment, 98 per cent of *O. rufipogon* seeds germinated within the top 4 cm and only 0.8 per cent seeds germinated in the 4 - 15 cm soil layer. The growth duration of *O. rufipogon* lasted about 130 days, 30 - 40 days shorter than rice cultivar IR8. The period from anthesis to seed maturation lasted only 14 - 15 days and the starch transport stage lasted only 10 days. Like the crop, the weedy rice seeds were unable to germinate in saturated soil. Unlike cultivated varieties, weedy rice seeds showed variable degree of dormancy and shattering tendency as soon as they are matured (Perreto *et al*., 1993).

Shattering of grains

Early seed shattering was identified as a specific characteristic of weedy rice, controlled by the gene Sh which shows the shattering character in dominant homozygosys (Sh Sh) or heterozygosys (sh Sh) conditions (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). The degree of shattering observed in wild and weedy rice is much higher than that exhibited by cultivated rice.

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 per cent, reaching about 85 per cent at 12 days after flowering. In general, the grains shattered up to 24 days after flowering showed lower germinability in comparison to that of non-shattered seeds. The germinability of the shattered seeds was very low during the first 15 days after flowering, with a maximum value of about five per cent. This behavior could most likely be explained by the incomplete development of the early shattered grains, which broke off mainly because of environmental causes like wind. The seeds that shattered after 15 days from flowering contained nearly filled and physiologically mature grains.

Abraham *et al*. (2012) in a review on shattering of grains in weedy rice grains, stated that shattering loci are present on chromosome 1, 3, 4, 7, 8 and 11. However, only two genes have been identified by map based quantitative trait loci (QTL) cloning: the qSH1 gene on chromosome1 and sh4 gene on chromosome 4. *qSH1e*ncodes for a homeobox gene and a single point mutation here has led to decline in seed shattering over the history of domestication. Shattering was generally estimated by breaking tensile strength (BTS), a value inversely proportional to shattering degree. Lesser the BTS, more easily was the shattering. They observed shattering levels for cultivated, wild and weedy individuals every five days from five days prior to flowering through 30 days. While BTS reduced in cultivated rice and wild rice between 10-15 days, weedy rice zeroed down its BTS starting from day 5. At 15 days, both wild and weedy individuals had BTS of zero. Weedy individuals maintained the BTS value throughout maturity thereafter.

Competitive ability of weedy rice and yield loss in the crop

Weedy rice was a superior competitor to crop cultivars due to its early vigour, greater tillering and height of plants. Yield losses largely depended on season, weed species, weed density, rice cultivar, growth rate and density of weeds and rice. Thirty five per cent infestation of weedy rice caused about 60 per cent yield loss and, under serious infestation, yield loss of 74 per cent was recorded in direct seeded rice (Watanabe *et al*., 1996).

Lee *et al*. (1987) reported that significant yield reduction of rice starts when rice competed with weedy rice for 20 days (or longer) after rice transplanting. Yield reduction was mainly attributed to the decrease in number of panicles per hill and number of grains per panicle. Fischer and Ramirez (1993) observed yield reduction of 50 per cent in Latin America when 24 weedy rice plants per square meter competed with the crop during the first 40 days after emergence. With the same initial density, the yield loss reached 75 per cent in the case of season long competition. Azmi and Johnson (2001) reported that when 30 per cent of the population was comprised of weedy rice, the grain yield losses reached 50-60 per cent and even complete crop failure under severe infestation. Eleftherohorinos *et al.* (2002) reported that weedy rice density of 40 plants per square meter resulted in 46 to 58 per cent reduction of yield. Short varieties are usually more susceptible to weedy rice competition than tall ones and interference duration was also identified as a yield deciding factor (Kwon *et al.,* 1991). Watanabe *et al*. (1996) pointed out that heavy grain losses were not only due to competition but also from increased lodging, leading to total grain loss.

Chauhan and Johnson (2010) observed considerable differences among Asian weedy rice variants and yet, competition from the rice crop greatly suppressed weedy rice growth. Hence, they suggested that measures to ensure a competitive crop should be an important component of control strategies. Weedy rice usually coexisted with cultivated rice and was highly competitive in rice fields of China (Xia *et al*., 2011).

Recently Ziska *et al.* (2012) reported that higher levels of atmospheric carbon dioxide (CO_2) facilitated the flow of genes between closely related wild or weedy rice plants and domesticated rice varieties. However, this gene flow was not the same in both directions. Increased temperatures due to CO_2 levels favoured double flowering in wild rice varieties. Moreover, weedy rice grew taller than domesticated rice. Flowering and plant height are important factors in pollen sharing and impact gene flow. Transfer of wild genetic material to domesticated rice resulted in the production of seed with weedy characteristics that would be undesirable in rice production. It was suggested that rising CO_2 may enhance the competition from weedy rice in rice production and reduce consumable rice production.

2.4. Management of weedy rice

Management of weedy rice in paddy fields 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). Its infestation in the rice fields of China, the major rice producer, had caused major damage to rice production by reducing rice grain yield and quality (Xia *et al.*, 2011). Hence, effective control of weedy rice population becomes very important for the sustainable production of rice crop in all growing regions worldwide. Ferrero (2010) outlined different strategies for the control of weedy rice as given in Table 4.

Table 4. Strategies and methods for the management of weedy rice

Control strategy	Method
Preventive	Certified seed
	Cleaning of machinery
Cultural	Crop rotation
	Soil tillage
	Stale seed bed preparation

	Water management
	Choice of rice variety
	Hand weeding
Mechanical	Before rice planting
	After rice planting
Chemical	Before rice planting
	After rice planting
Genetic	Herbicide tolerant rice varieties

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. Seed longevity was identified as a major characteristic of weedy rice population and management to reduce the size of the buried weed seed bank was suggested to be equally important (California Department of Food and Agriculture, 2001). The only possibility of obtaining weed free seeds was by inspecting seed production fields and rouging the ear heads of weedy plants before harvesting. Another preventative measure was cleaning the equipment used for rice harvesting to avoid spread of weeds to uninfested fields (Chauhan, 2013b).

Cultural methods of control

Non chemical means of weed control in rice should be centered on land preparation, varietal selection of crop, water management and fertilizer management. According to the California Department of Food and Agriculture (2001), in the absence of effective selective post emergence chemical control, techniques to minimize weedy rice infestations must focus 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 include 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 these practices reduce the chance of plant survival (as seed or seedling).

Minimum tillage

Puckridge *et al.* (1988) observed that minimum tillage resulted in high per cent germination of seeds that are present in the upper soil layer, compared to mould board ploughing. Minimum tillage systems were used in many areas with severe red rice problems (Menezes *et al*., 1994; Azmi and Johnson, 2001). In the practice they adopted, after seed bed preparation, the area was kept fallow to enable red rice and other weeds to grow and form a good mulching cover. Rice could either be drilled or water seeded after spraying the area with non-selective herbicides (glyphosate or paraquat dichloride). Using the minimum tillage system, farmers got good red rice control. The crop should be flooded soon after rice emergence; otherwise, the degree of weed control would decrease.

Selection of crop variety

Cultural strategy of weedy rice control also included the use of weed suppressing varieties and submergence tolerant varieties. Tall and long duration varieties usually showed a greater competitiveness than modern early and semi dwarf varieties. A new approach for chemical control of wild and red rice was the use of herbicide tolerant crop cultivars, which can be safely treated with otherwise non selective herbicides such as glufosinate (Sankula *et al*., 1997 and Chauhan, 2013 a).

According to Fischer and Gibson (2001), competition for light was a critical factor in the process of interference between rice and weeds. Leaf area and number of tillers were identified as characteristics directly correlated with the capacity of the crop to intercept light and suppress weed growth. They suggested the importance of combining phenological characteristics to maximize the level of competitiveness of rice with weeds. A strong crop root system also enabled the plant to compete at early stages with weeds when the leaf of the crop was yet to be developed.

Chauhan (2013 a) suggested that the use of cultivars with the traits of early vigour and quick canopy closure may help to suppress weedy rice growth. Short duration cultivars that mature earlier than weedy rice can help in reducing the weedy rice seed bank. The use of cultivars with purple coloured leaves also reduce weedy rice infestation and the weed seed bank.

Crop rotation

The best control of weedy rice could be obtained with crop rotation, but this practice cannot be applied in particular environmental conditions, such as saline and hydromorphic soils (Catala, 1995). Crops that are normally rotated with rice in temperate areas include soybean, maize, wheat, sunflower, sorghum and other crops. Introduction of mung bean cropping in Vietnam resulted in huge decrease of weedy rice plants and other species (Watanabe *et al*., 1998). In these conditions, many weeds emerged but did not complete their cycle because of the insufficient soil moisture during the mung bean season.

Several studies carried out in Italy showed that weedy rice control in soybean was usually better than that in maize (Ferrero and Vidotto, 1997). This could be attributed to the lower emergence of the weeds in maize and the greater efficacy of the herbicides in soybean. The lower emergence in maize was likely a result of the burial of weed grains during soil tillage in deep soil layers, which prevented them from germinating. In these conditions seeds buried at more than 10 cm were not capable of emerging from the soil. One year of soybean cultivation led to a reduction of seed bank in the 0-10 cm soil layer by about 97 per cent. The reduction in the same layer was still higher (98.5 per cent) when soybean was planted at the end of May after the spring flush of weed emergence. In the United States, one or two year rotation with soybean is frequently adopted to control severe infestations of weedy rice plants (Noldin *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. 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. 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 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 an alternate low cost, energy efficient and eco-friendly weed control method for achieving total weed control in direct seeded lowland rice. Renu *et al.* (2000) and Sindhu *et al.* (2011) have confirmed the effectiveness of stale seed bed technique in reducing the weed population and decreasing soil seed reserves in rice fields. They have justified the merits of this technique in integrated weed management. Chauhan (2013b) has also emphasised the importance of stale seed bed preparation by repeated tillage for integrated weedy rice management. Stubble and straw burning, though reported to be effective for reducing weedy rice seeds present on the soil surface, cannot be largely adopted due to the adverse effect on organic matter content and pollution related problems.

According to Azmi and Johnson (2001) the success of stale seed bed method depended on the way soil is prepared, water management, and its duration. Wet tillage after weed germination destroyed weedy rice seedlings and promoted new emergence. It was observed that this could also help in land leveling and puddling which prevented further emergence from the soil. 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 in germination that in turn made the control easier. The duration of the stale seed bed must be a compromise between the necessity of obtaining the greatest number of seedlings at the 2-3 leaf stage and that of not delaying rice planting too long. The duration of this technique in temperate climate conditions should be about 25-30 days.

In Brazil, a new rice production system has been introduced, consisting of two early irrigation sessions during the rice cycle in order to promote red rice germination. Immediately after germination of weeds, glyphosate was applied in two sprayings: first, alone at a low rate of 0.384 kg ha^{-1} (or mixed with 2, 4 D [0.36 kg ai./ha] in the presence of broadleaf weeds); and second, at a reduced glyphosate rate of 0.240-0.288 kg ha^{-1} . This new system proved equal or superior to the traditional system of red rice control and reduced the soil seed bank considerably (Foloni, 1999).

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 4- 6 weeks duration using thin transparent polyethylene films of 19-25 µm. Studies conducted at Kerala Agricultural University have also indicated an increase in soil temperature by 8-10ºC on solarisation for two to six weeks during summer months, which was effective for the control of annual weeds but not the perennials (Sainudheen and Abraham, 2001). This technology was found effective for the control of soil borne pathogens also (Vilasini, 1996 and Singh *et al*., 2010). The efficiency of soil solarisation on the control of weed seed bank was reported by Kumar *et al*. (1993). This technique could control *Trianthema portulacastrum, Dactyloctenium aegyptium, Cyperus sp*., *Digera arvensis etc.* Khan *et al*. (2003) have also reported the efficacy of solarisation for weed control in rainfed upland rice ecosystem

Enhanced seed rate

According to Bakar *et al*. (2000) enhanced crop seeding rates above the optimum rate in infested fields suppressed weedy rice infestation. Azmi and

Johnson (2001) and Chauhan (2013 a) have reported that seed rate of more than 150 kg ha^{-1} could suppress weedy rice in infested areas.

Crop establishment methods

Row seeding was 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). Luat et al. (1998) at Central Rice Research Institute, Vietnam had introduced the technique of seedling broadcasting. Two to three rice seedlings were grown in plastic sheets with holes 2 cm diameter to a height of 10-15 cm and broadcasted in rows or randomly. 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. Studies conducted at Srilanka have revealed reduction in weedy rice seed production in transplanting (96-98 per cent) followed by seedling broadcasting (71-87 per cent) compared to direct seeding method (farmers practice) of crop establishment (Chauhan, 2013 c). The yield increase in row seeding was 31 per cent in seedling broadcasting compared to 0.6 - 2 t ha^{-1} in direct seeding.

Weedy rice was effectively managed and became negligible 15–20 years ago because of the extensive manual transplanting and intensive human labour for weed control in general in Heilongjiang, Jilin, and Jiangsu provinces of northeast and eastern parts of China (Zhang, 2000). However, with the adoption of direct seeding and/or other no-till technologies, in addition to less labour inputs for weed control, weedy rice reoccurred as a major weedy problem (Xia *et al*., 2011).

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). They suggested two management strategies for irrigation after seeding: (1) maintain water at a depth of 5-10 cm until drainage at harvest (continuous flooding), or (2) drain water, keep soil saturated for 3–5 days, and return to flooding gradually. Excessive drainage exposes the soil to air and increases oxygen concentration in the soil, thus stimulating weedy rice germination.

Azmi and Abdullah (1997) reported that farmers resorting to transplant 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 anaerobic conditions in the top soil and prevented weedy plants from becoming established (Fischer, 1999).Vidotto and Ferrero (2000) also found that flooding in well levelled soils limited weedy rice germination. They reported that combination of water seeding and use of weedy rice free seeds had led to virtual disappearance of the weed in California.

Hand weeding

The control of weedy rice plants is sometimes carried out manually, but this practice is costly and time consuming. Hand weeding is quite impractical up to 30-40 days after crop emergence as it was very difficult to distinguish cultivated varieties from weedy rice in the early stages (Chauhan, 2013b). Hand weeding of weedy rice plants was sometimes carried out for light infestations and frequently it is used together with other means of control (chemical) when the latter had given poor results, so as to avoid grain dispersal. The manual control method was also of great interest in fields where yields are intended for seed production in order to get a weed free seeds.

Mechanical control

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) suggested 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 machinery.

Weedy rice could also be controlled mechanically in line planted rice using tools. Mechanical control was applied after rice planting when weedy rice was taller than the crop. This practice was aimed at preventing the spread of the weed and was mainly carried out by cutting weed panicles before they set seeds. In Colombia, the panicle is cut by a machete, while in Europe this operation is usually performed with a combine harvester cutting device that is mounted onto the front of a tractor (Ferrero and Vidotto, 1999). Cutting equipment is usually fitted with a roll crusher made up from two contra-rotating rollers. The European experience showed that at least 94 per cent 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

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 is essentially the same biological species as cultivated rice. Close anatomical and physiological similarity of weedy rice to the crop makes selective post emergence herbicidal control of weedy rice very difficult. Most herbicides currently available in the market do not function selectively against weedy rice without affecting cultivated rice (Chen *et al*., 2004). However, there are a few reports on the selective control of weedy rice by altering the time and method of application, which are reviewed below.

Use of herbicides before sowing of crop

According to Noldin *et al*. (1998) use of antigerminative herbicides such as metolachlor at 3.5 kg ha^{-1}, alachlor at 3.5 kg ha^{-1} applied in soybean as pre emergence resulted in weedy rice control of about 90 per cent. Several anti germinative herbicides such as chloroacetamides, thiocarbamates and dinitroanilines applied alone or in mixtures with other herbicides proved to be effective on weedy rice before its emergence. Ferrero *et al*. (1999) could obtain good control of these weeds (often higher than 75 per cent) in European rice conditions with pretilachlor and dimethenamid used alone or in combination at 1.5 kg 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 molinate and butylate also controlled weedy rice (Fischer, 1999; Garcia de la Osa and Rivero, 1999). Sadohara *et al*. (2000) reported that molinate (6.5 kg ha^{-1}) gave 26–67 per cent control when applied six days before rice seeding.

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}. Severe rice injuries were observed with use of thiobencarb and oxadiazon under flooded conditions. A slight rice injury was noted when water was drained before herbicide application. Thiobencarb application as a pre-plant surface treatment at the rate of 4.4 kg ha^{1} in combination with reflooding within 3 to 5 days after drainage was recommended to control red rice in the United States (Sadohara *et al*., 2000).

Use of seed protectants

Studies conducted at Rice Research Station, Moncompu, Kerala by Nair *et al*. (1986) revealed that coating of dry seeds with 20 per cent calcium peroxide using four per cent PVA solution, and broadcasting them in field with 10-15 cm standing water for 10 days can help in establishing good crop stand of rice without weedy rice. Later, this technology was found not practicable due to increased *yeranda* (common teal) attack on coated seeds and lankiness of the crop plants due to continued submergence (Sasidharan, N. K., unpublished data, 2009; unreferenced). Based on the experiments carried out by CIAT in Central and South America, Smith (1992) suggested 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} as the best method for weedy rice control.

Use of herbicides during the crop season

In continuous flooded monoculture, an effective management of weedy rice is often achieved through the application of the stale seed bed technique followed by spraying of the graminicides or total herbicides, once the weeds have reached at least the 2-3-leaf stage (Vidotto *et al.,* 1998). The most frequently applied graminicides are dalapon (about 12 kg ha^{-1}), clethodim (0.2 kg ha^{-1}) and cycloxydim (0.6-0.8 kg ha^{-1}). Other broad spectrum herbicides used are glyphosate (1-1.5 kg ai ha^{-1}), glufosinate ammonium (0.5-0.7 kg ha^{-1}), paraquat (0.8 kg ha^{-1}) and oxyfluorfen (0.8 kg ha^{-1}). Graminicides were observed to be highly effective even at early stages of the weeds while total herbicides had to be applied on more developed plants. Shen *et al*. (2013) observed that weedy rice control efficiency was reduced by 98 to 100 per cent at 32 DAS, on application of pretilachlor with safener at two days after sowing (DAS) and reported that rice yield was increased by 26 per cent in the mechanical precise hill direct seeded rice relative to the manual seeding rice.

Post planting chemical control in crop 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, for example, glyphosate or cycloxydim, at 5 and 20 per cent concentration using wick/wiper applicators (Stroud and Kempen, 1989). These can be mounted on self-moving machines, the front of a tractor or hand-held equipment. The results of the treatments carried out with this equipment on semi-dwarf varieties at the beginning of the weedy rice flowering stage showed more than 90 per cent reduction in germinability of the weed rice seeds (Ferrero and Vidotto, 1999). This per cent concerned only the seeds of the weed panicle that come in contact with the wiping equipment. About one-third of the panicles in the experimental field escaped the treatment as they were equal to or lower in height than the crop. The seeds of the escaped panicles on one hand can feed the soil seed bank, but on the other can select short biotypes for the following years that can no longer be controlled with this equipment.

Maleic hydrazide, a plant growth regulator, had been used in Brazil to control seed production of red rice (Andres and Menezes, 1997). For this, the 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 reduced the production of red rice seed (Dunand *et al*., 1993). The number of red rice panicles decreased and red rice sterility increased with the use of maleic hydrazide. As maleic hydrazide reduced seed viability, 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, minimizes the problem in the following years.

Genetic and biotechnological approaches

The problem of weedy rice could be tackled by the introduction of herbicide tolerant varieties which allow selective post emergence control (Linscombe *et al.,* 1996; Wheeler *et al.,* 1997). Glufosinate can be safely applied to transgenic varieties at the 3-4 leaf or at the tillering stage. Glufosinate applied at the 3-4-leaf stage of the weedy rice (red rice) resulted in a better control (91 %) than at panicle initiation (74 %) or boot stage (77 %). Better weedy rice control was obtained by applying glufosinate to drained rice fields. Soil flooding reduced the herbicide activity proportionally to the water depth.

A non-transgenic rice variety ‘Clearfield’ tolerant to herbicide imazethapyr had been in use in red rice infested fields of the United States of America from 2002. 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). . However, the possibility of out crossing of resistant variety with wild rice was suspected to taint the advantage of this technology (Shivrain *et al*., 2009).

The transfer of resistance gene to weedy species is likely to occur as the incidence of natural hybridization ranges between 1-52 per cent in early to 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 per cent (Messeguer, 2002). These findings suggest that within a few generations the advantages of the herbicide resistance gene could partly disappear.

Continuous cultivation of transgenic or IMI rice (imidazolinone resistant) varieties could also lead to the selection of uncontrolled plants. This constraint could be overcome by turning to rotational crops (e.g., soybean) and using herbicides with different action mechanisms or with mechanical weed control means. Environmental and biological constraints were mainly associated with the risk of spreading the resistance gene from the crop to other *Oryza* species, the growth of volunteer resistant rice and of uncontrolled plants (Langevin *et al.,* 1990 and Oard *et al.,* 2000). Based on modeling studies, Madsen *et al*. (2002) have reported that herbicide resistance genes could become common in weedy rice populations within three to eight years of continuous rice cropping. In some countries, imidazolinone-resistant weedy rice outcrosses have been found abundant, thereby negating the utility of 'Clearfield' technology. The persistence of imidazolinone herbicide residues in the soil is a concern in regions where multiple crops are planted in a year or the following year (Sudianto *et al*., 2013).

Liu *et al.* (2012) made a major finding to prevent the spread of transgenes from 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. They reported that weedy rice plants containing transgenes from GM rice through gene flow could be selectively killed by the spray of bentazon when a non GM rice variety is cultivated alternately in a few year intervals. This built in control mechanism in combination of cropping management is likely to mitigate the spread of transgenes into weedy rice populations. Results from this study demonstrated that the insect resistant and herbicide tolerant GM rice with the built in control mechanism and its resultant crop-weedy rice hybrids can be selectively killed by the spray of bentazon at 5800 mg l^{-1}. The ideal scenario was that glyphosate can be regularly used to control weeds (including weedy rice) in rice fields when GM rice containing such herbicide tolerant transgenes is cultivated. If transgenes are accumulated in weedy rice populations to a certain threshold level through recurrent gene flow, they could cause considerable damage to rice production due to the increased tolerance of weedy rice plants to glyphosate. Non GM rice varieties can be cultivated in combination with the application of bentazon to control rice weeds, particularly weedy rice containing transgenes. Thus, the spread of transgenes tolerant to herbicides or other biotic stresses in weedy rice could easily be controlled by such a built-in mechanism and appropriate cropping in the agricultural environments.

Integrated weedy rice management

Pingali *et al*. (1997) and 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 Vidotto *et al*. (2001) 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 weed eco-biology. This is an important prerequisite for achieving the expected yield growth in rice production and obtaining necessary reduction in weed stand, including weed seed bank.

Multiple approaches need to be integrated to reduce weedy rice infestations in fields as farmers usually fail to reduce weedy rice populations using a single method of control (Watanabe, 1995). Effective control of weedy rice cannot be based on one single practice, but should rely on a complex management programme based on an appropriate combination of preventative, cultural, mechanical, chemical and genetic means (Chauhan, 2013b). Weedy rice infestation in farmers' fields requires management program aimed at local eradication at the field level followed by integrated management strategies.

2.5. Uses of weedy rice

Anderson (1976) has reported that wild rice, a grass belonging to genus *Zizania* (genus in the tribe Oryzeae) has more protein, lysine and methionine content compared to other cereals, and is a rich source of B vitamins, minerals etc. Antioxidant property of weedy rice has been reported by Asmaria *et al.* (1996). Zinc and iron content of red rices are two to three times higher than white rices (Ramaiah and Rao, 1953). Gaely and Bryant (2009) has reported the highly variable level of amylose in different accessions of rice. They have also reported that alkali spreading value of awned red rice is also higher.

The literature reviewed above indicates that weedy rice is the annual form of the crosses between cultivated and wild type of rice. It has become a problem in many rice cultivating countries in Asia, Africa and Latin America. The morphological and biochemical similarity between the cultivated and weedy rice makes hand weeding or chemical weed control ineffective. Some morphological characters like presence of awns, shattering of grains and hull induced dormancy of seeds are distinct to weedy rice. The dormancy of seeds can be broken by scrapping of seeds or by chemical treatments.

Weedy rice is more competitive than rice and its infestation leads to severe yield loss depending on the severity of infestation. Over the years, people have developed preventive, cultural and mechanical methods of weed control. Stale seed bed technique, soil solarisation, transplanting the crop etc. are some of the effective non chemical methods. Modifying the time and method of application of herbicide, and use of herbicide protectants have given positive response in chemical weed control. Use of resistant variety (transgenic or non-transgenic) is a comparatively new method of management. Integrating the various promising methods to suit the situation can lead to effective management of weedy rice.

3. MATERIALS AND METHODS

Research programme to study the biology and management of weedy rice (*Oryza sativa* f. *spontanea*) was carried out during 2010 to 2014. The whole programme was carried out under four major heads/parts, viz.,

Part I	:	Field survey on the infestation of weedy rice in the major rice growing tracts of Kerala
Part II	:	Biology and ecology of weedy rice
Part III	:	Control/management of weedy rice
Part IV	:	Farmer participatory demonstration of successful technologies

3.1. Details of the study area

3.1.1. Location

In Kerala, rice is cultivated under wide range of agro ecological conditions. The diversified rice growing situations of Kerala include uplands, lowlands, saline soils, alkaline soils, acid sulphate soils, sandy soils, iron toxic soils etc. The research works were conducted in the main three rice growing situations Palakkad (Palakkad district), Kuttanad (comprising panchayaths of Alleppey, Kottayam and Pathanamthitta districts) and Kole lands (panchayaths of Thrissur and Malappuram districts).

3.1.1.1. Kole lands

The Kole lands, which form the rice granary of Thrissur and Malappuram districts comprise of a unique system in Kerala extending over 13,000 ha. The Kole wetlands lies between 10° 20' and 10° 40' N latitudes and 75° 58' and between 76° 11' E longitudes and are located 0.5 to 1 meter below MSL. The soil is clayey in texture with pH 5.0 and belongs to the order Inceptisol. They are high in organic carbon, available phosphorous and medium in exchangeable potassium.

3.1.1.2. Kuttanad

Kuttanad is a unique low land ecosystem located at 9º 27' N latitude and 76º 25' E longitude, lying around 0.5 m to 2.0 m below msl. The land use pattern is very unique with garden or dry lands (31,000 ha), wetlands (11,000 ha), reclaimed lands situated below msl (55,000 ha), and water bodies including lakes, canals, etc. (13,000 ha). The soils are silty clay in texture with pH around 3.5 to 4.5 and belong to the soil order Entisol. They are medium to high in organic carbon, available phosphorous and exchangeable potassium.

3.1.1.3. Palakkad region

Palakkad is situated within the latitudes stretching from 10° 21' to11° 14' north and longitudes stretching from 76° 02' to 76° 45' east. The soil is lateritic with pH around 5.0 and belongs to the soil order Altisol. They are low in organic carbon and available phosphorous and exchangeable potassium. The gross paddy cropped area of Palakkad extends over 1.07 lakh ha. During *Kharif* season, rice is mainly grown under semi dry situation and in *Rabi* cultivation is done utilising the canal irrigation water from Mangalam, Pothundy and Malampuzha dams.

3.1.2. Climate and weather

The Kuttanad, Kole and Palakkad rice growing tracts enjoy tropical monsoon climate with more than 80 per cent rainfall distributed through South West and North East monsoon showers. Weather conditions, which prevailed during the experimental period were largely normal with slight variations in the onset of monsoon in the dry sown tracts of Palakkad and high temperature during *Rabi* 2010-11. The weekly averages of important meteorological parameters prevalent during the experimental period at three locations are presented in Appendices 1 to V and illustrated in Figure 1 to 5.

3.1.3. Cropping pattern

The experimental field at Kuttanad are double cropped wet lands, with two crop seasons *ie*., May - June to September- October and November - December to March- April. Broadcasting of sprouted seeds on receipt of monsoon has evolved as a viable technology for rice farming in Kuttanad, owing to availability of sufficient labourers in time. Chemical weed control has become almost an integral part of rice cultivation under wet seeded condition.

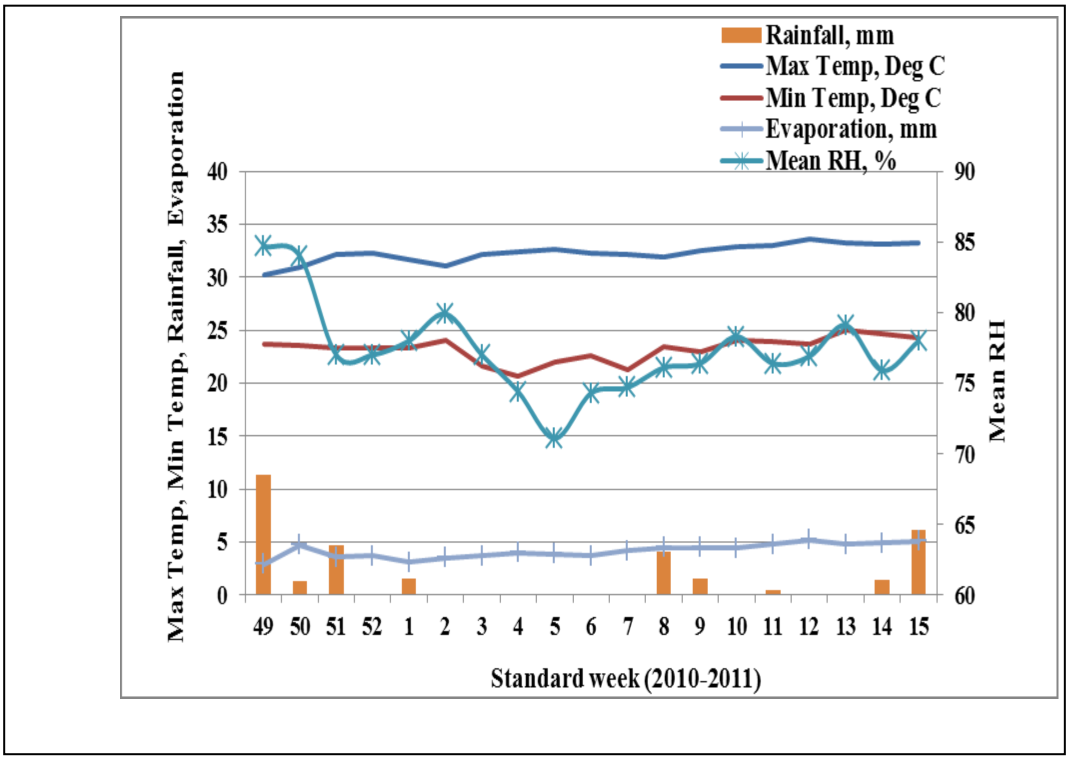


Fig. 1. Weather parameters during 2010-11 at Kuttanad (December -April)

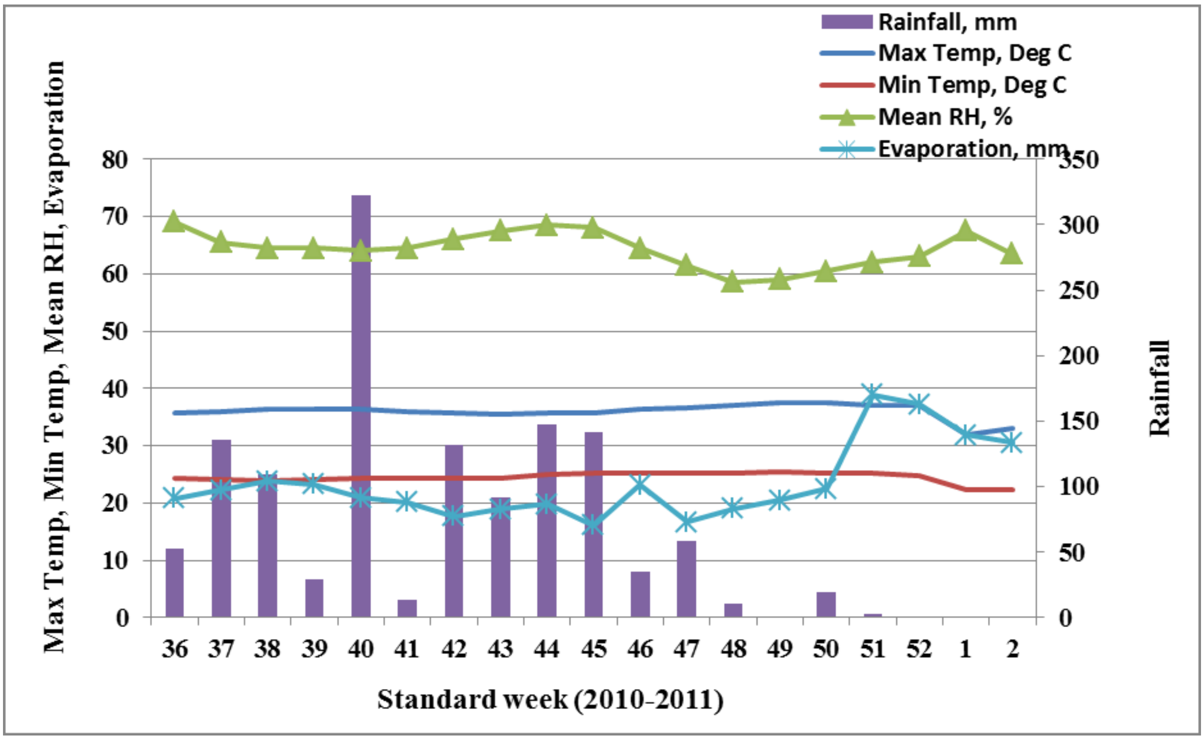


Fig. 2. Weather parameters during 2010-11 at Kole (September-January)

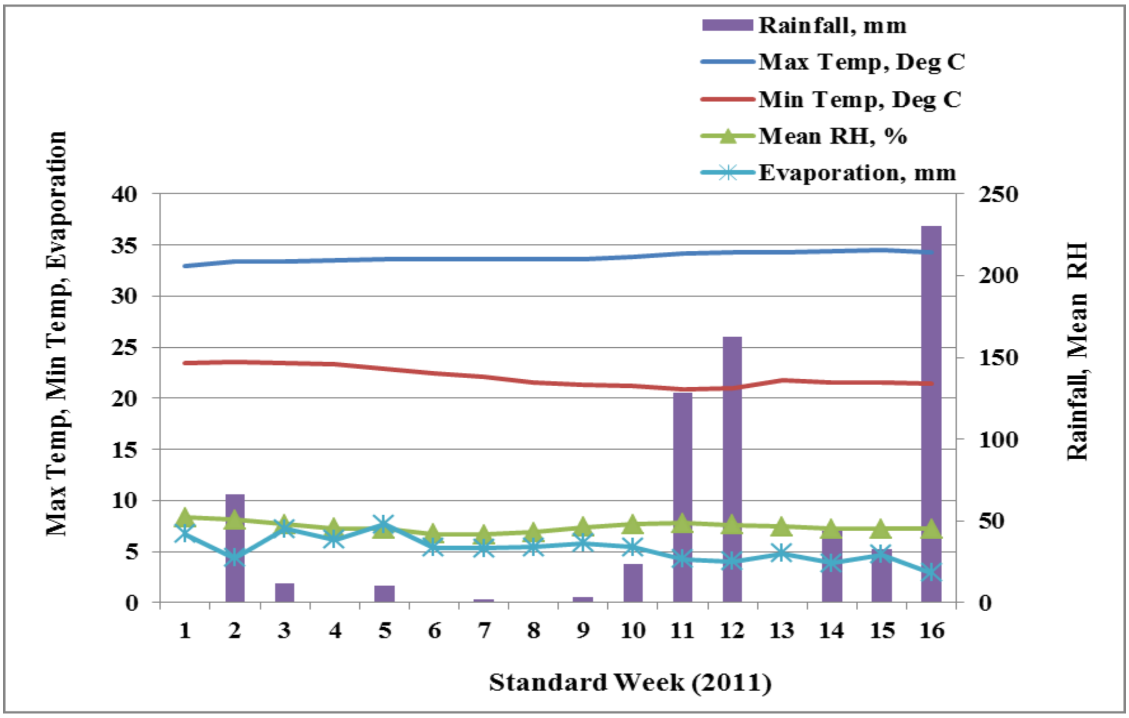


Fig. 3. Weather parameters during 2011 at Kole (January-May)

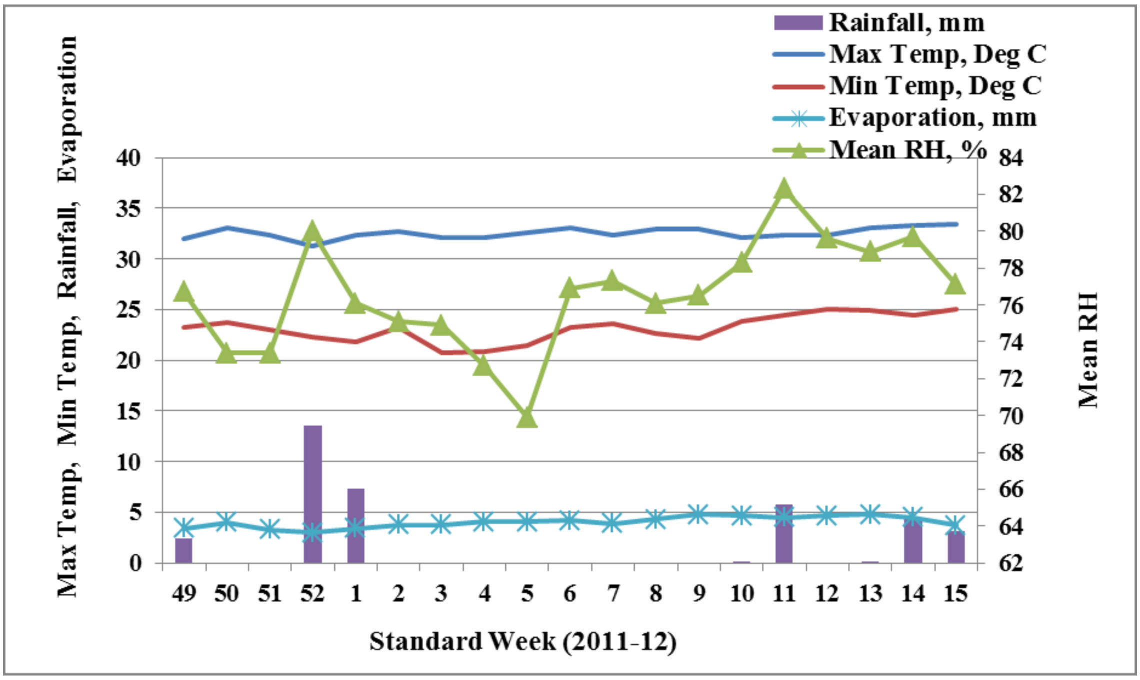


Fig. 4. Weather parameters during 2011-12 at Kuttanad (December-April)

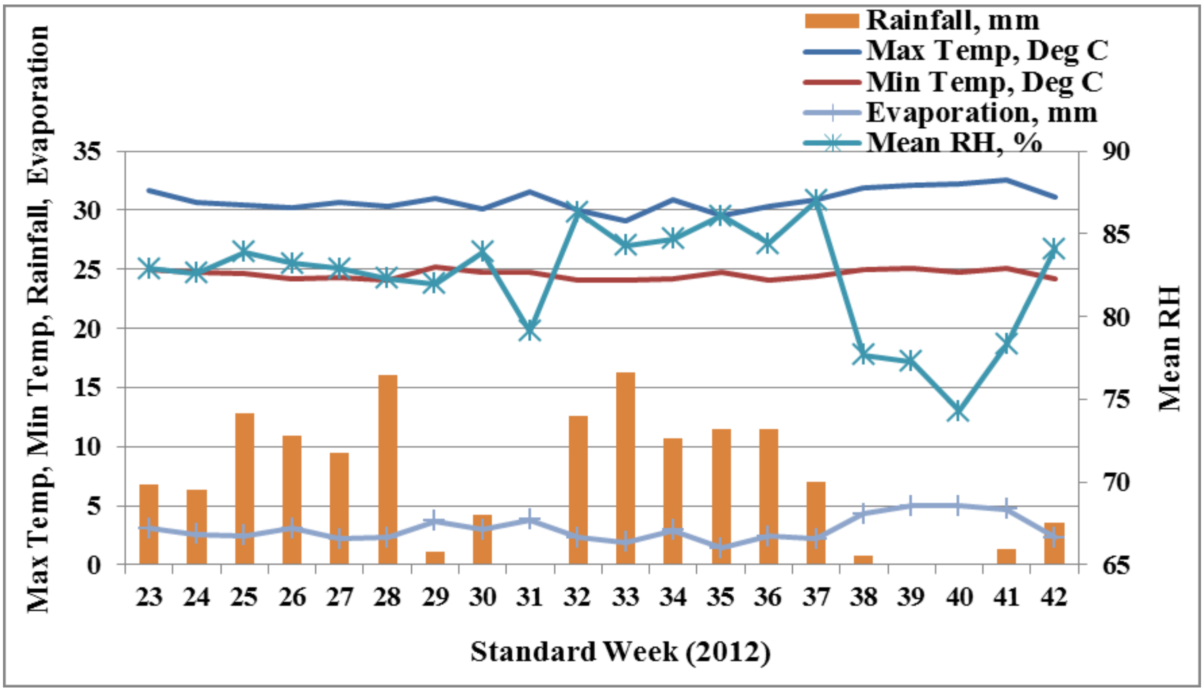


Fig. 5. Weather parameters during 2012 at Kuttanad (June-October)

In Kole lands, only one crop of rice is being cultivated during September - October to February - March and the area remains submerged during rest of the year. In certain Padasekharams where conditions are favourable, farmers go for a second crop during February- May, before the south west monsoon, using short duration varieties.

Palakkad is a semi dry tract with two rice cropping seasons, during May - June to August - September and September - October to December - January. The first crop is under semi dry system, where sowing is done in moist soil on receipt of pre monsoon showers, and the second is transplanted or irrigated rice under puddled condition.

3.2. Materials

3.2.1. Cultivar

Rice variety 'Uma' (MO 16) was used as the experimental variety. It is a medium duration, red, medium bold, non-lodging, high yielding rice cultivar with average yield around 7-8 t ha^{-1} in Kuttanad and 5-6 t ha^{-1} in Kole and Palakkad regions.

3.2.2. Manures and fertilisers

Fertilisers were applied @ 90: 45: 45 kg ha^{-1} N: P_2O_5: K_2O as per the recommendations for medium duration high yielding cultivar (Uma- MO 16). Full dose of phosphatic fertiliser was given as basal. One third dose each of nitrogen was given as top dressing at 15 DAS, active tillering and panicle initiation stage. Potassium was applied as equal doses at 15 DAS and panicle initiation stage.

3.2.3. Herbicides

The following table (Table 5) gives the list of herbicides used as per the technical programme. Details given as per the revised classification of herbicides based on the site of action (Smith and Reitzinger, 2003)

Table 5. Details of the herbicides used in the experiments

Common name	Trade name and formulation	Chemical family	Site of action	Recommended dose (kg ha^{-1})
Butachlor	Machete 50 EC	Chloroacetamide	Inhibit very long chain fatty acid synthesis	1.25
Pretilachlor	Rifit 50 EC	Chloroacetamide	Inhibit very long chain fatty acid synthesis	0.4
Pendimethalin	Stomp 30 EC	Dinitroaniline	Inhibit microtubule assembly	1.5
Oxyfluorfen	Goal 50 EC	Diphenyl ether	Inhibit protox enzyme	0.15
Paraquat dichloride	Gramoxone 24 SC	Bipyridiliums	Photosystem 1 electron diverters	0.4
Glyphosate	Round up 41 SC	None	Inhibit EPSP synthase	0.8
Glufosinate ammonium	Basta 15 SC	None	Inhibit glutamine synthetase	0.3-1

Experiments

3.1. Part I - Survey on weedy rice

Stratified survey was done in all panchayaths (covering representative padashekarams in a panchayath) in the major rice belts of Kerala, Kuttanad, Palakkad and Kole) during 2010, 2011 and 2013 to study the following aspects.

1. The extent of incidence of weedy rice in different agro ecological conditions of Kerala.
2. Traditional knowledge of the farmers on the biology and management practices of weedy rice.

3.1.1. Extent of occurrence of weedy rice

A sratified survey was undertaken in Kuttanad region in the first crop season during August- September, 2010 and in second crop season during January to February, 2011. In Palakkad region, the survey was conducted in the first crop season during August – September, 2010 and in the second crop season during December – January, 2010-11. The survey in the Kole lands was done during December – January, 2012-13. The survey sites were selected at 150-200 m on either side of jeepable road, at 7-10 km interval, covering at least four Padasekharams in a panchayath. The observations on the intensity of weedy rice infestation in rice fields were recorded from quadrats of size one square meter from three random spots and the average was worked out. Based on the average count in different Padashekarams, the panchayaths were rated as those with low, medium and high in weedy rice infestation and mapped in the geographical maps of the respective area utilizing the expertise of Greentouch Farm Media, Thiruvananthapuram.

Rating of weedy rice infestations in cropped fields:

Low	:	2-5 weedy rice plants per square metre
Medium	:	5-10 weedy rice plants per square metre
High	:	more than 10 weedy rice plants per square metre

3.1.2. Traditional knowledge of the farmers

A structured questionnaire was used as an instrument to collect data on farmers' cultivation practices, their knowledge on weedy rice distinguishing features, and their assumptions/opinions on the biology and management of weedy rice. Statements in the questionnaire were derived based on the perception about weedy rice expressed by the farmers in the focus group interviews. Farmer groups were randomly chosen for gathering data in a panchayat and questionnaire was circulated among 25 farmer groups each from Kole, Kuttanad and Palakkad. These assumptions were quantified and rated as detailed below.

Farmers' opinions were divided into two areas:

(1) Perception on weedy rice biology

(2) Perception on weedy rice management

Six statements, each related to the assumptions on weedy rice biology and management strategies were included in the questionnaire.

The statements used to study the knowledge of farmers on weed biology were:

1. Weedy rice seeds remain viable in the soil for more than one crop season
2. Weedy rice always shatters seeds
3. Weedy rice is always taller than rice
4. Weedy rice grains always have awns with red pericarp
5. Weedy rice flowers earlier than the cultivated rice
6. Weedy rice seedlings are difficult to be distinguished at 30 DAS

Statements used to study the indigenous traditional knowledge (ITK s) of the farmers on the management practice were:

1. Weedy rice problems are low in transplanted rice
2. Deep ploughing will reduce weedy rice problems
3. Use of certified seeds will decrease weedy rice problems

4. High seeding rate will reduce weedy rice
5. Herbicides can reduce the weedy rice problems
6. Cutting of panicles before harvest is the best way to reduce weedy rice

Each respondent was asked to express/indicate his or her opinion by choosing any one of the following options.

1. Strongly agree
2. Partly agree
3. Disagree

Responses from the farmers were classified based on their perception and expressed as per cent of respondents belonging to each category.

3.2. Part 11- Biology and ecology

3.2.1. Characterization of variants of weedy rice

Weedy rice variants were collected from the paddy fields of Kuttanad with severe infestation of weedy rice and observations were taken in the laboratory.

1. Morphological characters

Morphotypes were collected from eight locations of Kuttanad, which had severe infestation of weedy rice. Observation on morphometric characters both at vegetative and reproductive stages was recorded.

2. Methods of propagation

Different plant parts, seeds, culm cuttings with nodal roots, root clumps, plant stumps, etc., were grown in pots to assess the regeneration capacity.

3. Admixture of weedy rice in paddy harvested by machines

Random samples of paddy (200 g) were collected directly from the machine harvested heaps from rice fields to assess the contamination of rice seeds with weedy rice during machine harvesting. Three samples each were collected from rice fields from the panchayaths identified as severely infested with weedy rice, Kainakary, Ambalapuzha North and Ambalapuzha South; moderately infested, Edathua, Thannermukkam, and Mannanchery; and less infested, Neelamperoor, Karuvatta and Veliyanadu. These samples were analysed at the State Seed Testing Lab, Alleppey. These grains were spread on the purity board and viewed through magnifying lens to identify weedy rice seeds. The weedy rice seeds were counted and expressed as number per 40 g of working sample.

3.2.2. Dormancy studies

Laboratory studies were conducted to evaluate the extent of dormancy in the seeds of weedy rice. For this, half matured (straw coloured) and fully matured (black coloured) seeds were collected from the tagged weedy rice plants during March 2011, the *Punja* season in Kuttanad. This was done to maintain uniformity among the seeds collected for germination studies and to avoid environmental variation during seed maturation. The fully matured as well as half matured grains of weedy rice were allowed to germinate under laboratory conditions to assess the extent of dormancy.

Seed dormancy was determined by testing the germination of intact seeds as well as seeds with scraped hull (both fully matured and half matured grains) in petri plates lined with Whatman No.1 filter paper and moistened with 10 ml of distilled water. The observations on germination of both mature and half matured grains as well as intact and scraped grains were recorded by counting the number of germination in every week.

The influence of various pre-soaking/dormancy breaking treatments on the germination and growth of weedy rice seed/seedlings were also studied. Various pre-soaking treatments were imposed and germination was scored as the emergence of the radicle and was monitored daily for 12 days. The experiment included seven treatments with four replications. The treatments were

1. Acid scarification with 0.6% nitric acid for six hours
2. Exposing imbibed seeds to 20^{o}C air temperature for 48 hours and soaked in water
3. Exposing seeds to 40^{o}C air temperature for 6 hours and soaked in water

4. Soaking seeds in salt water (EC at 5 dSm^{-1})
5. Soaking seeds in salt water (EC at 15 dSm^{-1})
6. Mechanical scarification by scraping the hull with a razor blade, soaked in water
7. Germinating weedy rice without seed treatment (control)

Design : CRD

Replication : 4

The observations on the germination of seeds as well as root and shoot length of the seedlings were recorded on three, six and twelve days after soaking.

3.2.3. Scanning electron microscope studies

The leaves and grains (both fully matured and half matured grains) of both rice and weedy rice were viewed under Scanning Electron Microscope (SEM-facility of TNAU, Coimbatore) to understand the topographical and anatomical differences. The grains of rice and weedy rice were fractured using a razor blade and mounted on aluminium stubs for viewing under SEM.

3.2.3. Germination studies under simulated field conditions

The study was conducted by sowing seeds of weedy rice in shallow pots (30 cm diameter and 15 cm height) filled with soil collected from rice fields (the soil was solarised to destroy soil seed bank). Fifteen seeds of weedy rice (scraped to break hull induced dormancy) along with 15 seeds of rice were placed at different soil depths (0, 2, 4 and 8 cm). For this, the seeds of both rice and weedy rice were kept in plastic net bags at desired depths from the top of the pot and then filled with soil. Another set of pots were maintained as above without rice seeds in association with weedy rice seeds. The moisture in the pots was maintained at saturation level. The number of seeds germinated was counted on 7, 14 and 30 days after sowing and germination was expressed on per cent basis.

Treatments : 8 (Factorial combinations of four sowing depths and presence or absence of rice).

Design : CRD; Replication : 3

3.3. Part 111- Control methods

3.3.1. Physical methods

3.3.1.1. Effect of stale seed bed technique on the incidence of weedy rice

Location 1

Following treatments were imposed and pre germinated rice seeds were sown on draining water at 10 days of flooding.

Location : Kuruvapadam of Nedumudy Panchayath in Kuttanad

Season : *Punja* 2011-12 (November - March)

Treatments

1. Drain the field and sow pre germinated seeds in the plot (control)
2. Drain the field where hand weeding was done during the previous year
3. Drain the field and allow the weed seeds to germinate for 15 days, followed by application of glyphosate @ 0.8 kg ha^{-1} and re- flooding after one week
4. Drain the field and allow the weed seeds to germinate for 15 days followed by shallow wet tillage. Allow further germination from soil seed bank for 10 days and re-flood
5. Drain the field and allow the weed seeds to germinate for 15 days followed by shallow wet tillage. Allow further germination from the soil seed bank for 10 days and apply glyphosate @ 0.8 kg ha^{-1} followed by flooding after one week

Design : CRD

Replication : 4

Plot size : 240 m^2

Taking in to account the practical difficulties for allotting treatments in small plots with randomisation, the staling operations were carried out for different treatments individually in larger plots of 1200 m^2. Observations were recorded from four replications in the succeeding crop and the data were analysed in CRD.

Location 2

Based on the results of the experiment conducted during *Punja* 2011-12 at Kuruvapadam of Nedumudy panchayath in Kuttanad, a second experiment with modification in the treatments was conducted during the additional crop season 2012-13 (June - October) in Manimalakkadu Padasekharam of Champakulam panchayath in Kuttanad. As in the previous trial, treatments were imposed in larger plots of 1200 m^2. Observations were recorded from four replications and data were analysed in CRD. In treatments 2 to 5, the plots were drained after 10 days of flooding and pre germinated seeds were sown.

Treatments

1. Drain the field and sow pre germinated seeds in the plot without staling operations
2. Drain the field and allow the weed seeds to germinate for 15 days followed by application of glyphosate @ 0.8 kg ha^{-1} and re-flood after one week.
3. Drain the field and allow the weed seeds to germinate for 15 days followed by shallow dry tillage. Allow further germination from soil seed bank for 10 days and apply glyphosate @ 0.8 kg ha^{-1} and re-flood after one week
4. Drain the field and allow the weed seeds to germinate for 15 days followed by wet tillage. Drain and allow further germination from soil seed bank for 10 days and apply glyphosate @ 0.8 kg ha^{-1} and re-flood after one week
5. Drain the field and allow the weed seeds to germinate for 15 days. Give shallow dry tillage followed by wet tillage. Drain and allow further germination from the soil seed bank for 10 days and apply glyphosate @ 0.8 kg ha^{-1} followed by flooding after one week

Location : Manimalakkadu Padam of Champakulam Panchayat in Kuttanad

Season : *Kharif* 2012-13 (June - October)

Design : CRD

Replication : 4

Plot size : 240 m^2

Observations on weedy rice population crop yield were recorded in the succeeding crop for comparing different treatments.

3.3.1.2. Effect of burning straw

The experiment was done during March, 2011 after the harvest of the *Punja* crop in Purathoor Padavu in Alappad Kole.

Treatments

1. Spread the straw of the previous crop uniformly @ 2.5 t/ha and burn. Experimental crop was sown with land preparation.
2. Spread the straw of the previous crop uniformly @ 2.5 t/ha and burn. Experimental crop was sown without land preparation.
3. Sprayed kerosene on the stubbles, spread straw @ 2.5 t/ha and burn. Experimental crop was sown with land preparation.
4. Spray kerosene on the stubbles, spread straw @ 2.5 t/ha and burn. Experimental crop was sown without land preparation.
5. Control

Design : RBD

Replication : 4

Plot size : 80 m^2

From each treatment, observations on the weedy rice population and crop yield were recorded from four quadrats of 1x1 m size.

3.3.1.3. Effect of soil solarisation

The experiment to evaluate the efficiency of soil solarisation on the management of weedy rice was conducted in the direct seeded rice fields of RRS, Moncompu in Alleppey district during the summer season of Feb-March, 2012. These fields were severely infested with weedy rice during the previous years (≥10 weedy rice ear heads per square metre of crop). The soil seed bank was analysed by collecting soil from 7 cm depth, from the experimental location, using core samplers of radius 2.5 cm and height 7 cm. The soil was mixed with one litre of distilled water and seeds were separated using sieves for counting.

The soil surface of the infested experimental field was ploughed and the clods were crushed. Prepared a good seed bed and six treatment plots each of 10 x 2 cm size were laid out. The soil was moistened to field capacity. The plots were covered with transparent poly ethylene sheets with 100 micron thickness and the free edges of the sheets were tucked in to the furrows, and sealed to maintain an air tight condition. Holes made in the polythene sheets for inserting the probe of the sensor to record soil temperature were sealed immediately after taking observation.

The treatments are given below.

1. Solarization for 20 days
2. Solarization for 25 days
3. Solarization for 30 days
4. Solarization for 35 days
5. Solarization for 40 days
6. Control

Depending on the treatments, the sheets were removed on respective days without disturbing the remaining plots. Observation on soil temperature at 3, 5 and 10 cm depth from soil surface was recorded using portable sensors by inserting the probe through holes and temporarily sealed with cellophane tapes. Germination from these treatment plots was recorded for 30 days after removal of all solarisation sheets (on receipt of pre monsoon showers during April) and also during the next crop season when these plots were maintained fallow.

3.3.2. Chemical control

3.3.2.1. Effect of pre emergence herbicides on weedy rice infestation

The pre emergence herbicides were either surface applied (S.A.) or soil incorporated (S. I.) at different doses either three days before sowing (DBS) or six days after sowing (DAS) of crop seeds, to evaluate the efficacy of the herbicides on controlling weedy rice in wet seeded rice. The net plot size at all the location was 20 m^2. The treatment was replicated thrice and field was laid out in Randomised complete block design.

Location 1 : Kole lands (Purathoor Padavu, Alappad Kole)

Season : First crop of 2010-11 (September -January)

Treatments

1. S.I. of pretilachlor @ 1.0 kg ha^{-1} 3 DBS
2. S.I. of pretilachlor @ 1.5 kg ha^{-1} 3 DBS
3. S.A. of pretilachlor @ 0.5 kg ha^{-1} 3 DBS
4. S.A. of pretilachlor @ 1.0 kg ha^{-1} 3 DBS
5. S.I. of oxyfluorfen @ 0.2 kg ha^{-1} 3 DBS
6. S.I. of oxyfluorfen @ 0.3 kg ha^{-1} 3 DBS
7. S.A. of oxyfluorfen @ 0.1 kg ha^{-1} 3 DBS
8. S.A. of oxyfluorfen @ 0.2 kg ha^{-1} 3 DBS
9. S.I. of butachlor @ 2.5 kg ha^{-1} 3 DBS
10. S.I. of butachlor @ 3.75 kg ha^{-1} 3 DBS
11. S.A. of butachlor @ 1.25 kg ha^{-1} 3 DBS
12. S.A. of butachlor @ 2.5 kg ha^{-1} 3 DBS
13. S.A. of pretilachlor @ 0.5 kg ha^{-1} 6 DAS
14. S.A. of oxyfluorfen @ 0.1 kg ha^{-1} 6 DAS
15. S.A. of butachlor @ 2.5 kg ha^{-1} 6 DAS
16. Hand weeding at 20 and 40 DAS
17. Un weeded control

Location 11

Based on the results of the first trial in wet sown rice, the herbicides were tried at higher concentrations both by surface application and incorporation in soil at three BDS. The pre emergence application of herbicides (6 DAS) was not included in trials 2 and 3 as it was not found effective in the trial 1.

Treatments

1. S.I. of butachlor @ 2.5 kg ha^{-1}
2. S.I. of butachlor @ 3.0 kg ha^{-1}
3. S.A. of butachlor @ 2.5 kg ha^{-1}
4. S.A. of butachlor @ 3.0 kg ha^{-1}
5. S.I. of pretilachlor @ 1.5 kg ha^{-1}
6. S.I. of pretilachlor @ 2.0 kg ha^{-1}
7. S.A. of pretilachlor @ 1.5 kg ha^{-1}
8. S.A. of pretilachlor @ 2.0 kg ha^{-1}
9. S.I. of oxyfluorfen @ 0.2 kg ha^{-1}
10. S.I. of oxyfluorfen @ 0.3 kg ha^{-1}
11. S.A. of oxyfluorfen @ 0.2 kg ha^{-1}
12. S.A. of oxyfluorfen @ 0.3 kg ha^{-1}
13. Hand weeding at 20 and 40 DAS
14. Un weeded control

All the herbicides were applied three DBS as surface application (S. A.) or soil incorporation (S. I.)

Location : Kuttanad (Devasomkari Padam)

Season : *Punja* 2010-11 (December to April)

In the herbicide applied as well as unweeded control plots, broad-spectrum selective herbicide bispyribac sodium was sprayed @ 30 g ha^{-1} at 15 DAS to avoid competition from other weeds.

Location 111

Based on the results of the previous trials done at different doses and by different methods of application it was found that surface application was more effective and practically feasible than incorporation. Therefore, an experiment was designed using the three herbicides at different doses to standardise the management strategy.

Treatments

1. Butachlor @ 2.5 kg ha^{-1}
2. Butachlor @ 2.0 kg ha^{-1}
3. Pretilachlor @ 2.0 kg ha^{-1}
4. Pretilachlor @ 1.5 kg ha^{-1}
5. Oxyfluorfen @ 0.4 kg ha^{-1}
6. Oxyfluorfen @ 0.3 kg ha^{-1}
7. Oxyfluorfen @ 0.2 kg ha^{-1}
8. Oxyfluorfen @ 0.1 kg ha^{-1}
9. Hand weeding at 20 and 40 DAS
10. Un weeded control

All the herbicides were applied at three DBS as surface application (S. A.)

Location : Kuttanad (Manimalakkadu Padam of Champakulam panchayath)

Season : *Punja* of 2011-12 (December - April)

In the herbicide applied as well as unweeded control plots, broadspectrum selective herbicide bispyribac sodium was sprayed @ 30 g ha^{-1} at 20 DAS to avoid competition from other weeds on the growth and performance of rice and weedy rice.

3.3.2.2. Development of prototype of a device for direct contact application of herbicides

Direct contact application (DCA) of herbicides is an effective way of controlling tall growing weeds in a crop stand without destroying the crop. Morphological as well as genotypic similarity of weedy rice to cultivated rice makes hand weeding and herbicidal control of weedy rice ineffective. In many fields, it was noticed that weedy rice comes to flowering around 65 days, about 15 days ahead of the flowering in rice. At this stage, there is a quick growth for weedy rice resulting in production of the panicles about 15-30 cm above the canopy of rice. Therefore, it was felt that it may be possible to kill the weedy rice earheads by DCA, using a wick applicator. A wick applicator imported from Taiwan was tested. However, it was heavy to carry and had difficulties for operation. Therefore, it was decided to develop a wick applicator suitable for use in rice fields. The details of the prototype developed are given in the results (section 4.3.2.2.1.)

3.3.2.3. Effect of direct contact application of herbicides on weedy rice infestation

Weedy rice panicles were selectively dried by direct contact application (DCA) with wick applicator using broad spectrum herbicides at 60 to 65 DAS. At flowering, weedy rice ear heads which were 15- 20 cm taller than the rice canopy are selectively dried by swabbing herbicide on the ear heads of weedy rice using the device, without touching the rice canopy beneath when the operator moves forward by the horizontal swinging of the lance to smear the panicles.

Treatments

1. Paraquat dichloride at 10% concentration
2. Paraquat dichloride at 15% concentration
3. Glyphosate at 10% concentration
4. Glyphosate at 15% concentration
5. Glufosinate ammonium at 5% concentration
6. Glufosinate ammonium at 10% concentration
7. Glufosinate ammonium at 15% concentration
8. Control

Design : RBD

Replication : 3

Plot size : 5 x 4 m^2

Location 1 : Puravathoor Padavu - Alappad Kole (*Punja* 2009-10)

Location 11 : Devasomkari Padam - Kuttanad (*Kharif* 2011-12)

3.4. Part 1V- Farmer participatory demonstration of successful technologies

Field testing of the technologies developed was done in larger areas in farmers' field in participatory mode. Different technologies individually as well as integrated mode were demonstrated in farmers' field with severe infestation. The technologies demonstrated were, stale seed bed technique, pre-sowing surface application of herbicides and direct contact application of broad-spectrum herbicides. Observations on the incidence of weedy rice as well as yield in the previous season and current season were taken.

3.5. Cultural operations in the experimental plots

All the intercultural operations were done as per Package of practice recommendations (KAU, 2011)

3.6. Observations from the field experiments

3.6.1. Growth and biometric characters

a. Number of hills per square meter

Number of hills per 0.25 m^2 quadrat was counted from three locations in each plot and computed as number per square meter.

b. Plant height

Height of five plants from each plot was measured from the base of the plant to the tip of the topmost leaf at seedling, active tillering and panicle initiation stages. At harvest it was measured form the base of the plant to the tip of the longest panicle. The mean height was computed and expressed in centimetre.

c. Number of panicles

Total number of panicles in a quadrat of 0.25 m^2 was counted from three locations in each plot and the mean expressed as number per square meter.

d. Grain yield

The grain yield from each net plot, after winnowing and cleaning, was weighed and recorded fresh weight. Moisture per cent of the sample of the grains was worked out and grain yield was computed at 13 per cent moisture and expressed in kg ha^{-1}.

e. Straw yield

The straw from each net plot was sun dried uniformly, weighed and expressed in kg ha^{-1}.

3.6.2. Observations on weed incidence

a. Weed density

Observations on weed density were recorded from three spots using quadrat of size 0.25 m^2 and expressed as number of weedy rice per square meter.

b. Weed dry weight

Weedy rice plants from the observational areas in each plot were uprooted, cleaned, dried and weight expressed as g m^{-2}.

3.6.3. Observations from pot culture studies

Morphotypes collected were evaluated based on morphological characters.

1. ***Plant height***: At flowering stage, the culm length was measured in centimetre from ground level to base of the panicle.
2. ***Tiller number***: Ttiller number was recorded after full heading as the total number of grain bearing tillers.
3. ***Panicle length***: The length of the panicle was measured in centimetre from the base to the tip of the panicle.
4. ***Panicle type***: Panicles were classified according to the branching, angle of primary branches and spikelets

   1. Compact

2. Intermediate

3. Open

5. Presence of awns recorded as

1. Absent

2. Present

6. Grain length: The length of the grains in millimetre was taken from the base of lowermost sterile lemma to the tip of the grain.

7. Grain width: The distance across the fertile lemma and palea at the widest point of the grain was measured in millimetre.

8. Awn length: The length of the awns in millimetre was taken from the tip of the grain to the tip of the awn.

4. RESULTS

4.1. Part 1- Survey on weedy rice in major rice growing tracts of Kerala

4.1.1. Extent of infestation in the major rice belts of Kerala

A survey was conducted during 2010-11 in Kuttanad and Palakkad regions. The Kole lands which spread in the districts of Thrissur and Malappuram were surveyed during 2013 (Plate 2).

Kole lands

Direct seeding of pre germinated seeds is the common practice of the area. The main crop is taken during September - January and some farmers take a second crop during February - May. Among the 22 panchayaths surveyed in Thrissur Kole (Table 6), six had severe, ten had moderate and five had low infestation. Pavaratty panchayath had relatively lesser area under paddy and no infestation was noticed. Severe infestation was seen in Adat, Ayyanthole, Arimpoor, Anthikkad and Manaloor panchayaths. Porathussery, Avanissery and Paralam panchayaths were rated as having moderate and Elavally, Muriad and Kattoor panchayaths as low as regards the infestation of weedy rice.

Among the six panchayaths surveyed in Malappuram Kole, only Nannamukku panchayath had severe infestation and others had only low infestation. Some of the padasekharams were lying fallow. Most of the farmers in Malappuram Kole and certain areas of Thrissur Kole was practising transplanting (both manual and mechanical) to manage weedy rice infestation, which was problematic during 2009-12 (Fig. 6).

Kuttanad area

The Kuttanad area includes all panchayaths of Alleppey district and certain panchayaths of Kottayam and Pathanamthitta districts. Direct sowing of pre germinated seeds is the crop establishment practice of the area. Among the 30 panchayaths surveyed (Table 7) in Alleppey district, the number of severe,

A. Kuttanad area

B. Malappuram Kole

C. Thrissur Kole

D. Palakkad region

Plate 2. Scenes from the survey in the major rice belts of Kerala

Table 6. Extent of infestation of weedy rice in Kole lands

Thrissur district			Thrissur district		
Sl. No.	Panchayath	Extent of infestation	Sl. No.	Panchayath	Extent of infestation
1	Pavaratty	Nil	17	Adat	Severe
2	Karalam	Low	18	Anthikkad	Severe
3	Muriyad	Low	19	Chazhur	Severe
4	Kattur	Low	20	Manalur	Severe
5	Parapukkara	Low	21	Arimpur	Severe
6	Elavally	Low	22	Ayyanthole	Severe
7	Venkitangu	Moderate	**Malappuram district**		
8	Thanniyam	Moderate	1	Vattamkulam	Low
9	Avinissery	Moderate	2	Alangode	Low
10	Vallachira	Moderate	3	Veliyamkode	Low
11	Paralam	Moderate	4	Marancheri	Low
12	Avanur	Moderate	5	Perumpadappu	Low
13	Porathissery	Moderate	Low : 2-5 weedy rice plants per square metre Moderate : 5-10 weedy rice plants per square metre Severe : more than 10 weedy rice plants per square metre		
14	Kaiparamba	Moderate			
15	Tholur	Moderate			
16	Mullassery	Moderate			

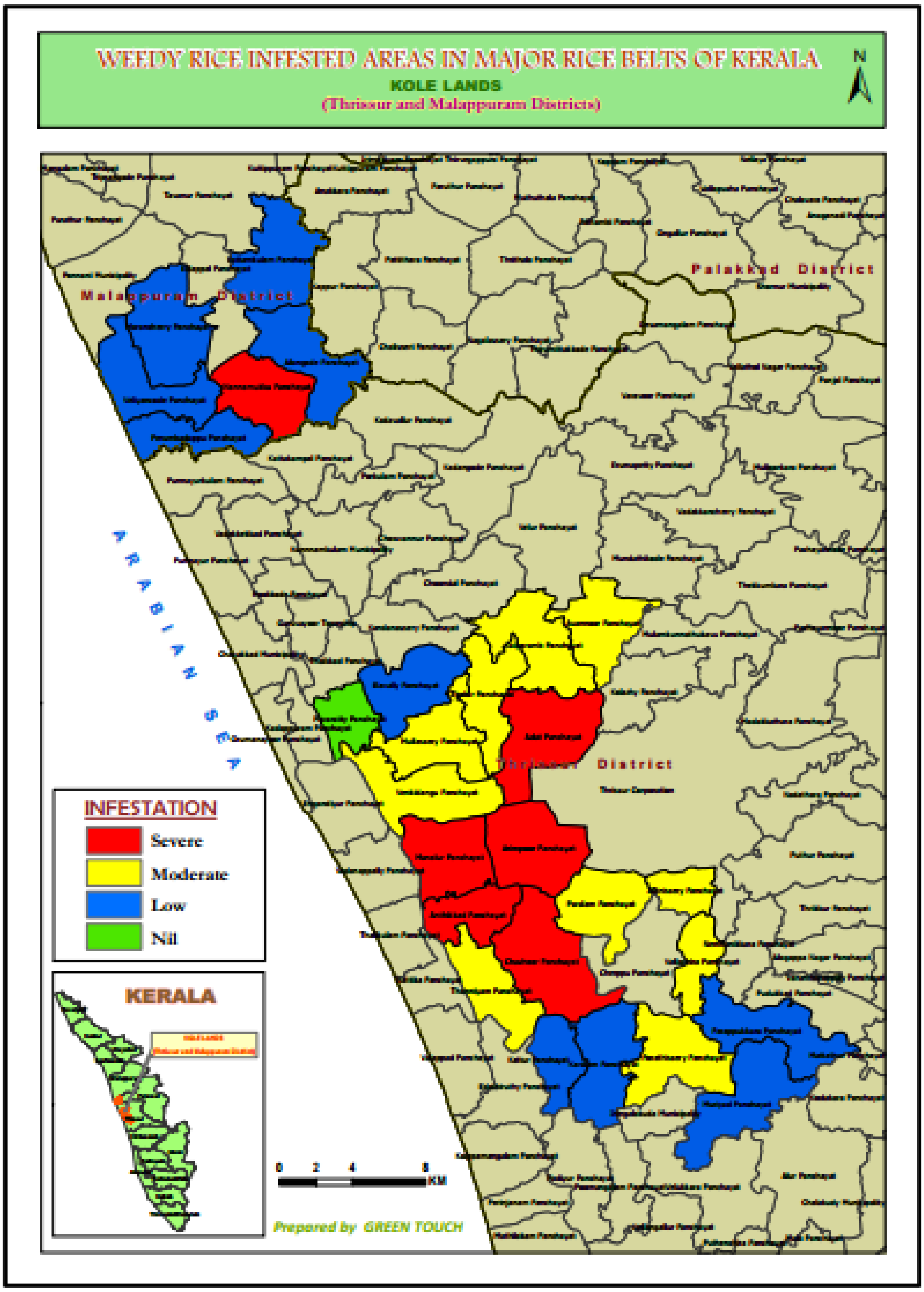


Fig.6. Extent of infestation of weedy rice in the panchayaths of Kole lands

Table 7. Extent of infestation of weedy rice in Kuttanad region

Alleppey district						
Sl. No.	Panchayath	Infestation	Sl. No.	Panchayath	Infestation	
1	Arukutty	Nil	19	Kavalam	Moderate	
2	Aryad	Nil	20	Mannar	Moderate	
3	Marari south	Nil	21	Thanneermukkam	Moderate	
4	Kanjikuzhi	Nil	22	Mannancherry	Moderate	
5	Thakazhi	Low	23	Kainakary	Severe	
6	Thalavady	Low	24	Alleppey muncipality	Severe	
7	Ramankary	Low	25	Champakulam	Severe	
8	Purakkad	Low	26	Nedumudy	Severe	
9	Kruvatta	Low	27	Ambalapuzha north	Severe	
10	Pulinkunnu	Low	28	Ambalapuzha south	Severe	
11	Veliyanadu	Low	29	Punnapra south	Severe	
12	Neelamperror	Low	30	Muttar	Severe	
13	Muhamma	Low				
14	Panavally	Low	**Pathanamthitta District**			
15	Thaikattussery	Low	1	Kuttoor	Low	
16	Perumbalam	Low	2	Peringara	Medium	
17	Edathua	Moderate	3	Niranam	Medium	
18	North Punnapra	Moderate	4	Thiruvalla Municipality	Nil	

Kottayam district					
1	Chempu	Nil	14	Kurichi	Low
2	Velloor	Nil	15	Payippadu	Low
3	Mulakkulam	Nil	16	Vazhappally	Low
4	Manjoor	Nil	17	Udayanapuram	Moderate
5	Kanakkary	Nil	18	Thalayolaparampu	Moderate
6	Kumaranelloor	Nil	19	Maravanthuruthu	Moderate
7	Thrikkodithanam	Nil	20	Vechoor	Severe
8	Kaduthuruthy	Low	21	Thalayazham	Severe
9	Kallara	Low	22	T V Puram	Severe
10	Neendoor	Low	23	Arppookara	Severe
11	Athirampuzha	Low	24	Kumarakom	Severe
12	Nattakom	Low	25	Aimanam	Severe
13	Panachikkad	Low	26	Thiruvarppu	Severe

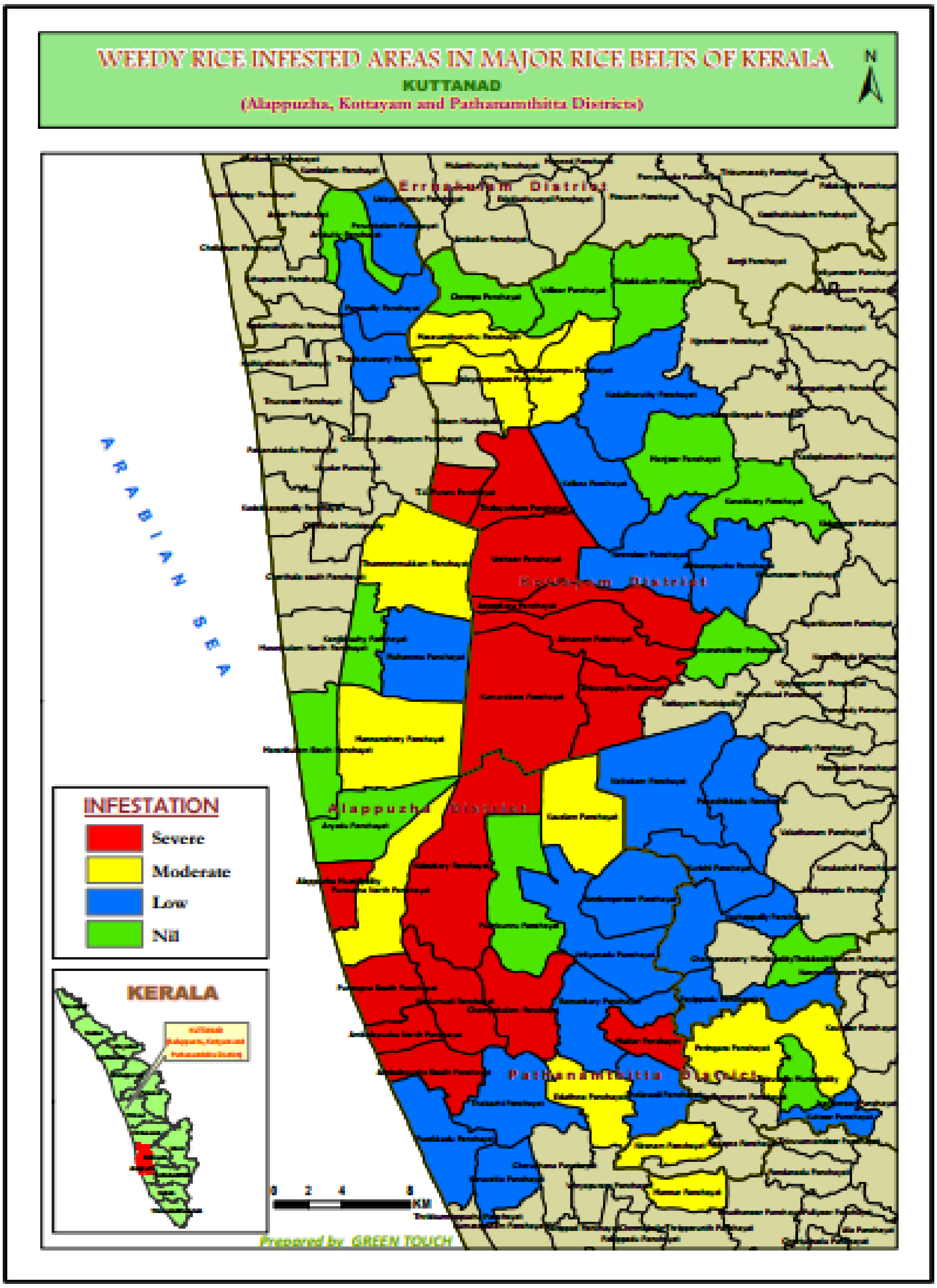


Fig. 7. Extent of infestation of weedy rice in the panchayaths of Kuttanad

moderate and low weedy rice infested panchayaths was eight, six and twelve, respectively. Four panchayaths, where rice was not the main crop, were ranked as low. The panchayaths, Kainakary, Ambalapuzha North and South, Punnapra South, Nedumudy, Champakulam and Muttar had severe infestation, while, Edathua, Punnapra North, Kavalam, Thannermukkam and Mannar had moderate infestation. The single cropped lands of Neelamperror, Karuvatta, Purakkad, Veliyanad and Pulincunnoo had low infestation (Fig. 7).

The Kuttanad rice fields of Kottayam district had severe infestation of weedy rice in Vechoor, Thalayazham, Aimanam, Thiruvarppu, Kumarakom and Arppookkara panchayaths. There was moderate infestation in Udayanapuram, Thalayolaparambu and Maravanthuruthu panchayaths. The rice fields in the panchayaths of upper Kuttanad region Vazhappally, Kurichi, Nattakom and Kaduthuruthy had low infestation. Seven panchayaths of Kottayam district coming under Kuttanad belt had less paddy cultivation with no infestation of weedy rice.

In Patahnamthitta district, four panchayaths of the Kuttanad belt, Kuttor, Peringara, Niranam and Thiruvalla municipality had low to moderate infestation even though these areas had only single crop in a year.

Palakkad region

Out of the total 85 panchayaths surveyed, the number of panchayaths ranked severe, moderate and low were four, fifteen and seventeen, respectively. Six two panchayaths had no infestation of weedy rice. Severe weedy rice infestation was noticed in Pallassana (Nenmara block), Alathur (Alathur block) and Polpully (Malampuzha block) panchayaths. Moderate infestation was noticed in Palakkad, Pattambi and Kuzhalmannam blocks (Table 8). Low infestation was recorded in the panchayaths of Thrithala and Kollengode blocks. In Palakkad district, a vast majority of the area like Ottappalam, Sreekrishnapuram, Mannarkad and Attappady block had less rice cultivation and hence ranked as zero (Fig. 8).

Table 8. Extent of infestation of weedy rice in Palakkad district

Sl. No.	Panchayath	Infestation	Sl. No.	Panchayath	Infestation
1	Nagallassery	Nil	25	Thachampara	Nil
2	Thirumittacode	Nil	26	Karakurussi	Nil
3	Muthuthala	Nil	27	Kottopadam	Nil
4	Paruthur	Nil	28	Kanjirapuzha	Nil
5	Kulukkallur	Nil	29	Thachanatkara	Nil
6	Nellaya	Nil	30	Thenkara	Nil
7	Thiruvegapura	Nil	31	Agali	Nil
8	Vilayur	Nil	32	Sholayur	Nil
9	Ambalappara	Nil	33	Puthur	Nil
10	Chalavara	Nil	34	Mannur	Nil
11	Vaniyamkulam	Nil	35	Keralassery	Nil
12	Ananganadi	Nil	36	Mundur	Nil
13	Lakkidi-Perur	Nil	37	Pirayiri	Nil
14	Cherplassery	Nil	38	Eruthenpathy	Nil
15	Karimpuzha	Nil	39	Nalleppilly	Nil
16	Sreekrishnapuram	Nil	40	Perumatty	Nil
17	Vellinezhi	Nil	41	Kozinjampara	Nil
18	Kadampazhipuram	Nil	42	Pattanchery	Nil
19	Pookottukavu	Nil	43	Vadakarapathy	Nil
20	Thrikkaderi	Nil	44	Muthalamada	Nil
21	Alanallur	Nil	45	Nelliyampathy	Nil
22	Karimba	Nil	46	Erimayur	Nil
23	Kumaramputhur	Nil	47	Kizhakanchery	Nil
24	Mannarkkad	Nil	48	Tharur	Nil

Sl. No.	Panchayath	Infestation	Sl. No.	Panchayath	Infestation
49	Anakkara	Low	73	Mathur	Moderate
50	Kappur	Low	74	Thenkurissi	Moderate
51	Pattithara	Low	75	Nenmara	Moderate
52	Thrithala	Low	76	Melarcode	Moderate
53	Chalissery	Low	77	Elavanchery	Moderate
54	Koppam	Low	78	Kavassery	Moderate
55	Ongallur	Low	79	Puthukode	Moderate
56	Vallappuzha	Low	80	Kollengode	Moderate
57	Manakkara	Low	78	Kavassery	Moderate
58	Koottayi	Low	81	Kannambra	Moderate
59	Peringottukurussi	Low	82	Pallassena	Severe
60	Vadavannur	Low	83	Alathur	Severe
61	Koduvayur	Low	84	Vadakanchery	Severe
62	Puthunagaram	Low	85	Polpully	Severe
63	Ayllur	Low			
64	Vandazhi	Low			
65	Elapully	Low			
66	Pattambi	Moderate			
67	Kodumbu	Moderate			
68	Kongad	Moderate			
69	Parali	Moderate	Low : 2-5 weedy rice plants per square metre Moderate : 5-10 weedy rice plants per square metre Severe : > 10 weedy rice plants per square metre		
70	Kuzhalmannam	Moderate			
71	Kannadi	Moderate			
72	Kuthannur	Moderate			

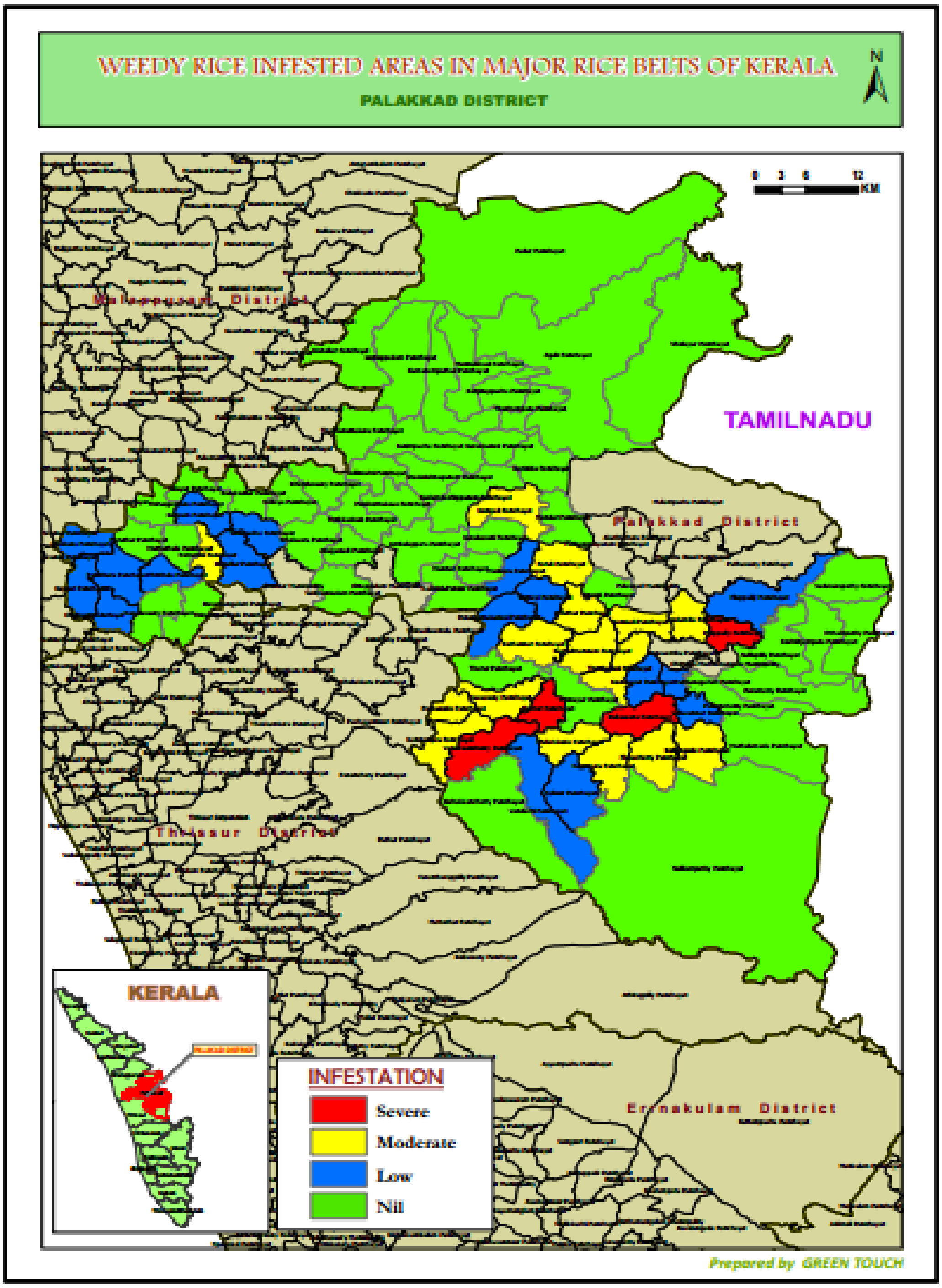


Fig. 8. Extent of infestation of weedy rice in the panchayaths of Palakkad

Table 9.Extent of infestation of weedy rice in various panchayaths of major rice belts of Kerala

Rating of weedy rice infestation	No. of panchayaths					
	Kole		Kuttanad			Palakkad
	Thrissur	Malappuram	Alleppey	Kottayam	Pathanamthitta	Palakkad
Nil	1	0	4	7	1	49
Low	5	5	12	9	1	17
Moderate	10	0	6	3	2	15
Severe	6	1	8	7	0	4
Total	22	6	30	26	4	85

Low : 2-5 weedy rice plants per square meter

Moderate : 5-10 weedy rice plants per square meter

Severe : > 10 weedy rice plants per square meter

The survey revealed that almost all the major rice growing areas in Kole, Kuttanad and Palakkad rice bowls have low to severe infestation (Table 9).

4.1.2. Survey on Indigenous Traditional Knowledge of the farmers on weedy rice biology and management

The survey among the farmers in the major rice belts of Kerala indicated that farmers are well aware of the problems from weedy rice (Table 10). More than 80 per cent of the farmers had noticed that weedy rice mimics rice crop during early stages and flowers earlier than rice with high seed shattering. Seventy per cent of the farmers have noticed that grains have red pericarp and awns. The high longevity of weedy rice seeds in the soil was noticed by 60 per cent of the farmers. There was difference in opinion among the farmers on the height of weedy rice plants. Twenty per cent of the farmers were of the opinion that weedy rice is not always taller than cultivated rice (sometimes weedy rice is lesser in height than cultivated rice).

Assessment of indigenous traditional knowledge (ITK) of the farmers on the technologies for management of weedy rice revealed that more than 80 per cent of the farmers are well aware of the utility of transplanting as a strategy for managing weedy rice (Table 11). Deep ploughing, use of certified seeds and removing the ear heads of weedy rice are the other management options known to 30 to 40 per cent of the farmers. Farmers are not aware of any herbicides for the selective control of weedy rice, even though many of them are hopeful of such an option. Majority of the farmers do not feel that increase in seed rate will reduce the menace of weedy rice.

4.2. Part 11-Biology and ecology of weedy rice

4.2.1. Morphometric studies of vegetative and reproductive descriptors of weedy rice morphotypes

The weedy rice plants collected from different panchayaths having severe infestation of weedy rice in Kuttanad were characterised based on morphometric

Table 10. Perception of the farmers on the biological characters of weedy rice

Sl. No.	Perception of the farmers	Farmers in each knowledge group, %		
		Strongly agree	Partly agree	Disagree
1	Seeds remain viable in the soil for more than one crop season	60	40	0
2	Seeds shatter usually	87	13	0
3	Plants are always taller than rice	55	25	20
4	Grains always have awns with red pericarp	70	30	0
5	Flowers earlier than the cultivated rice	87	13	0
6	Plants are difficult to be distinguished at 30 DAS	80	20	0

Table 11. Perception of the farmers on the technologies for management of weedy rice

Sl. No.	Perception of the farmers	Farmers in each knowledge group, %		
		Strongly agree	Partly agree	Disagree
1	Weedy rice problems are low in transplanted rice	87	13	0
2	Deep ploughing will reduce weedy rice problems	47	27	26
3	Use of certified seeds will decrease weedy rice problems	40	40	20
4	High seeding rate will reduce weedy rice	7	66	27
5	Herbicides can reduce the weedy rice problem	0	87	13
6	Cutting of the panicles before harvest is the best way to reduce weedy rice	33	47	20

descriptors. The vegetative descriptors included in the study were number of tillers per plant, maximum length and width of leaf, length of culm, ligule and internode, and height of the plant. The data indicated high variability between the weedy rice morphotypes (Table 12). Among the vegetative characters analysed, there was significant difference between the morphotypes in the number of tillers per plant (2.5 - 10.8), length of leaves (28.5 - 48.0 cm) and height of plants (81.3 - 140.5 cm). There was no significant difference between the morphotypes in the length of ligule (1.3 - 2.1 cm), length of culm (54.5 - 87.7 cm) and width of leaves (Plate 3).

Among the reproductive characters observed (Table 13), there was significant difference between the morphotypes in the length of panicle (18.4 - 29.5 cm) and smallest length of awns in a panicle (1.1 - 4.5 cm), while, there was no significant difference between morphotypes in the length (0.7- 0.9 cm), width (0.3 - 0.4 cm) of grains and the number of grains per panicle (41 - 112). Synchronous flowering and proximity of cultivated rice and weedy rice favour introgression (Plate 4 and 5).

A comparison of the morphometric characters of weedy rice with that of cultivated rice (Uma- MO 16) revealed that (Table 12 and 13), rice plants are shorter in plant height (98- 110 cm), number of tillers (5-6 per plant) and length of internodes (15.6-21.0 cm). The number of grains per panicle was much higher in rice (140-158) than in weedy rice (63-112). High per cent of chaffing to the tune of 50 per cent or more was observed in weedy rice.

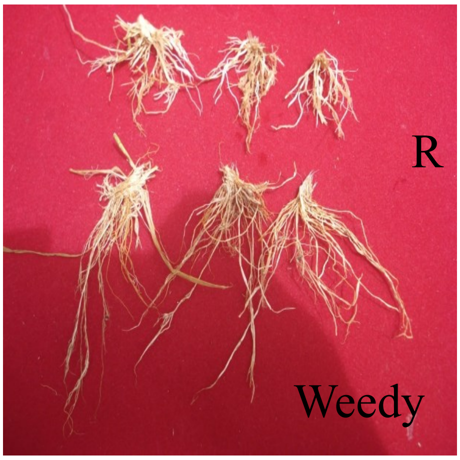
4.2.2. Morphological characterisation of weedy rice using scanning electron microscope

Scanning electron microscope studies (SEM) were done to identify the topographical and morphological differences between rice and weedy rice grains and the leaves (Plates 6, 7 and 8). Observation on weedy rice seeds using SEM revealed the presence of indentations on the exterior surface of weedy rice seeds with silica in the mid region. Weedy rice seed surface had parallel rows of

A. Plant height

B. Colour variation in culm

C. Root length and tiller production



D. Rooting pattern of rice and weedy rice

Plate 3. Variability in the vegetative characters of weedy rice

A. Colour of grains and awns

B. Panicle type (open and closed)

C. Length of grains and awns

D. Chaffiness and shattering

Plate 4. Variability in the reproductive characters of weedy rice

Plate 5. Synchronous flowering and proximity of cultivated rice and weedy rice favouring introgression

Table 12. Characterisation of weedy rice morphotypes using morphometric descriptors and comparison with the cultivated variety

Morphotypes	Tillers/ plant, No./ pt	Leaf length, cm	Leaf width, cm	Ligule length,cm	Culm length, (cm)	Plant height, (cm)	Internode length, (cm)
Kainakri	5.6	48	1.3	2.1	87.7	119.1	16.3
Champakulam	7.4	39.0	1.2	1.6	69.9	101.4	14.7
Nedumudy	10.8	28.5	1.2	1.3	65.8	81.3	16.6
Ambalapuzha North	4.0	33.0	1.5	1.5	68.0	107.0	18.0
Ramankary	7.0	46.5	1.6	1.5	87.5	140.5	23.0
Ambalapuzha South	5.5	43.5	1.1	1.6	85.0	119.5	16.8
Punnapra	2.5	36.5	1.2	1.9	80.0	113.0	23.0
Alapuzha	6.0	35.5	1.3	1.5	54.5	82.5	13.2
CD (P=0.05)	4.7	10.7	NS	NS	NS	33.5	NS
Cultivar (MO 16) - 1	5	39.5	1.0	1.0	83.5	100	20.3
Cultivar (MO 16) - 2	4	40.6	1.2	0.5	76.0	98	15.6
Cultivar (MO 16) - 3	4	34.2	1.1	1.8	82	110	21.0

Table 13. Characterisation of weedy rice morphotypes using reproductive descriptors and comparison with the cultivated variety

Morphotypes	Panicle length, cm	Min. awn length, cm	Max.awn length, cm	Grain length, cm	Grain width, cm	Grains/panicle, No.
Kainakari	24.9	2.4	6.0	0.9	0.3	76
Champakulam	22.2	3.7	6.7	0.7	0.3	58
Nedumudy	18.4	4.5	6.4	0.8	0.3	60
Ambalapuzha North	29.0	3.5	6.1	0.8	0.3	112
Ramankary	25.5	3.5	6.1	0.9	0.3	63
Ambalapuzha South	29.0	1.1	5.5	0.8	0.4	69
Punnapra	29.5	2.8	6.0	0.9	0.3	74
Alapuzha	20.0	2.0	7.0	0.8	0.3	41
CD (P=0.05)	6.4	1.7	NS	NS	NS	NS
Cultivar (MO 16) - 1	19.3	-	-	0.8	0.3	160
Cultivar (MO 16) - 2	18.7	-	-	0.9	0.4	148
Cultivar (MO 16) - 3	19.1	-	-	0.8	0.3	150

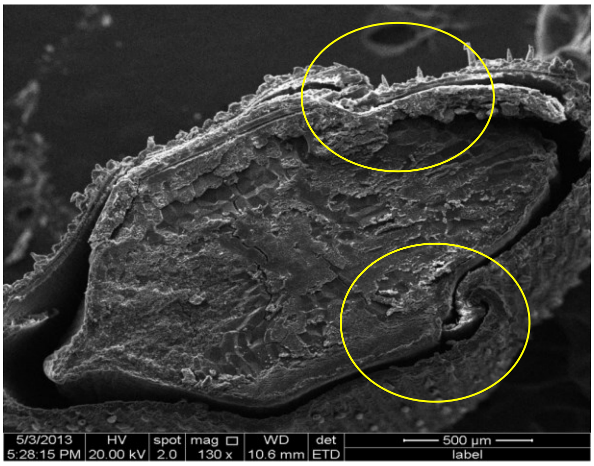
trichomes. Matured weedy rice seeds (moisture content - 15 per cent) had tight packing of the glumes (lemma and palea) and the overlapping region of the glumes extended up to 319.8 to 354.3 µm, whereas, in half matured seeds, it was only 210.0 to 267.5 µm. The thickness of lemma and palea was 87.4 µm and 73.6 µm in matured weedy rice grains and that for half matured grains was 63.24 µm and 55.73 µm, respectively (Plates 6 and 7). The maximum angular distance between the rudimentary glumes was higher in half matured grains (2.675 mm) compared to the matured ones (2.140 mm).

Matured rice grains (moisture content - 12 per cent) had tight packing of glumes and the overlapping region of the glumes extended up to 459 to 529 µm, whereas, in half matured rice grains, it was only 342.7 to 354.8 µm. The thickness of lemma and palea was 99.1µm and 80.8 µm, respectively, in matured rice grains while, it was 54.7 µm and 58.01µm, respectively, in half matured rice grains. The maximum angular distance between the rudimentary glumes was higher in half matured rice grains (2.765 mm) compared to the matured grains (2.140 mm).

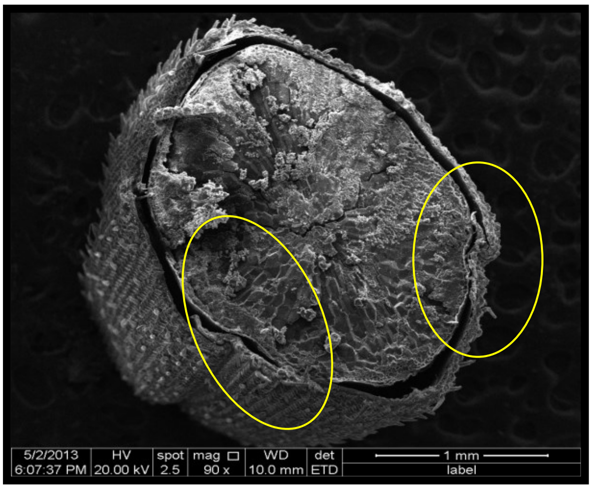
Weedy rice leaves had more micro hairs and epicuticular wax on the adaxial surface compared to the abaxial surface (Plate 8). Stomatal studies have also shown the presence of more stomata on the adaxial surface compared to the abaxial surface. The stomatal count on the adaxial and abaxial surface of rice leaves was 1.85/mm^2 and 0.5/mm^2 and that of weedy rice was 7.5/mm^2 and 3.8/mm^2 respectively.

4.2.3. Mode of propagation

The main mode of propagation in weedy rice is through seeds. As seeds of weedy rice possess variable dormancy, the spread and invasion to newer location is through seeds. The germination studies showed variability in the germination per cent of weedy rice seeds within a panicle. Pot culture studies have shown that weedy rice is highly efficient in regeneration of growth even from almost dried and rotted nodal cuttings, root clumps and plant stumps (Plate 9).

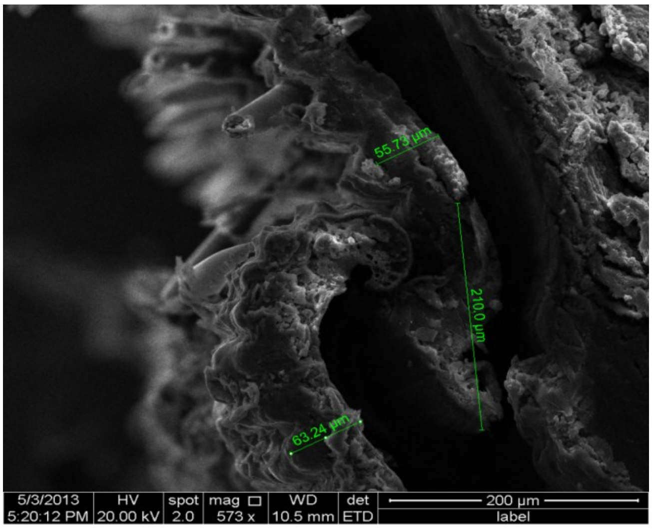


A. Half mature weedy rice grains - less overlapping of glumes

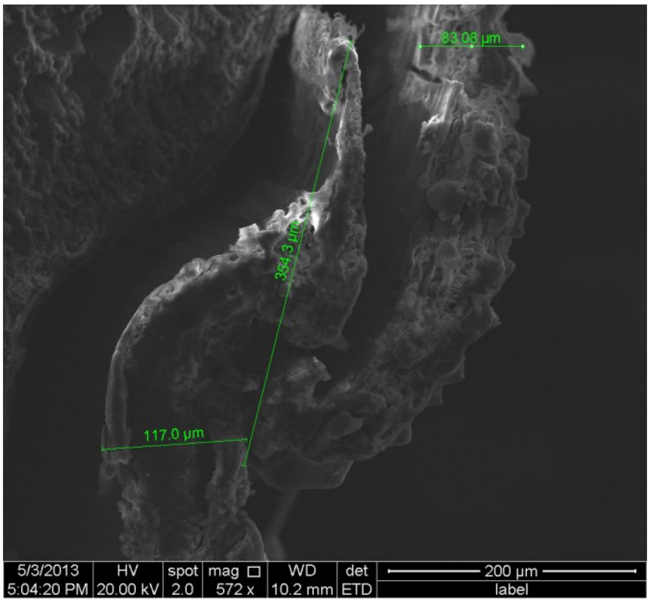


B. Fully mature weedy rice grains - more overlapping of glumes

Plate 6. Scanning Electron Microscope view of weedy rice grains showing the overlapping of glumes

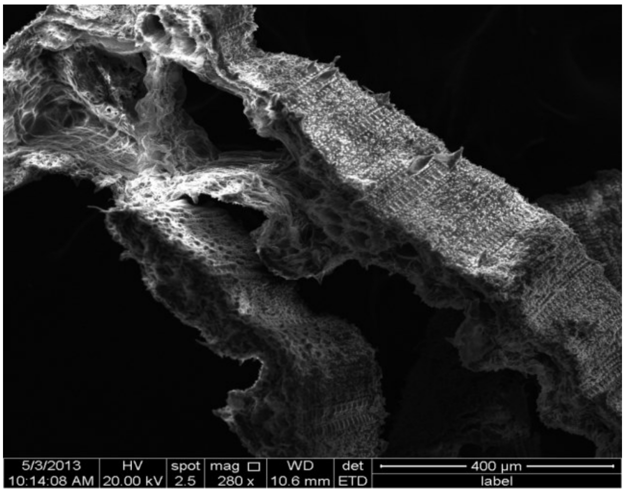


C. Half mature weedy rice grains – less overlapping of glumes

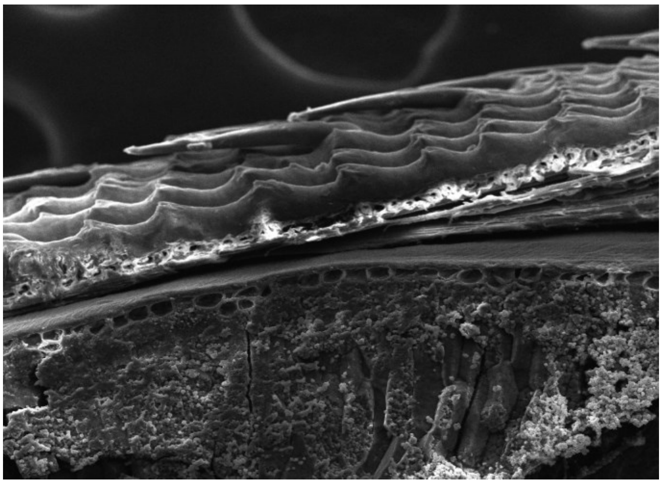


D. Fully mature weedy rice grains- more overlapping of glumes

Plate 7. SEM view on extent of overlapping of glumes in weedy rice grain

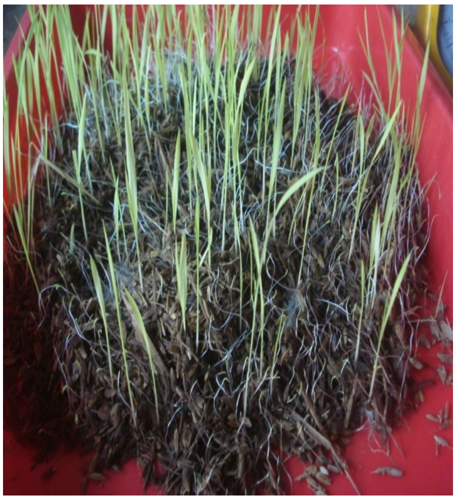


A. Epidermal hairs and waxy cuticle on leaf surface of weedy rice



B. Trichomes and indendations on grain surface of weedy rice

Plate 8. SEM view of leaf and grain surface of weedy rice



A. Seeds and seelings

B. Nodal cuttings C. Stumps

Plate 9. Mode of propagation

4.2.4. Admixture of weedy rice in paddy harvested by machines

The average number of weedy rice grains in the machine harvested paddy form severely infested area was 8-10 per 40 g of working standard, while that in moderately infested fields was four to five, and in low infested fields was zero to one number per 40 g working sample used for purity analysis of the seed lot.

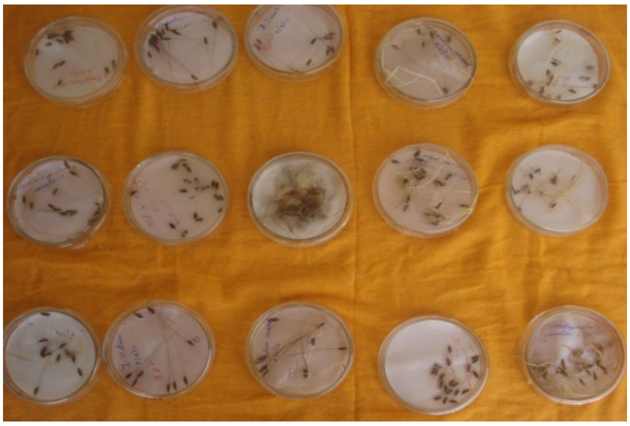
4.2.5. Influence of dormancy breaking treatments on germination of weedy rice

Laboratory studies were conducted to evaluate the efficiency of germination of mature and half matured seeds. The half matured seeds recorded quick and high germination compared to fully mature dried seeds. Half matured seeds had 60 per cent germination after 10 days of soaking compared to zero germination observed in mature weedy rice seeds. It was also observed that scraping of the hull could induce germination compared to the intact seeds of weedy rice (Plate 10).

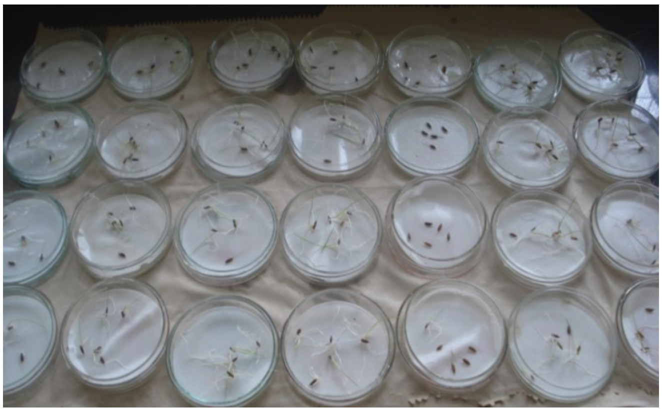
The response of weedy rice seeds to various dormancy breaking treatments were quantified by counting the number of seeds germinated and measuring the length of root and shoot after three, six and twelve days of soaking. The data are presented in Table 14.

Germination

At three days after soaking, hull scraping (T6) recorded the highest germination of 90 per cent followed by T4 and T5 (salt water treatment at EC 5 dS m^{-2} and 15 dS m^{-2}), and T2 (low temperature treatment). The lowest germination was 10 per cent in T3, where seeds were exposed to high temperature of 40 for six hours. The control treatment showed 40 per cent. germination. More number of seeds germinated by 6 and 12 days in all the treatments and the hull scraping and low temperature treatment resulted in 90 and 100 per cent germination by 12 days after soaking. However, even at this stage, the high temperature treatment continued to record very low germination (20 per cent). The control treatment recorded 75 per cent germination on 12^{th} day of soaking. However, it was significantly lower than T2, T4, and T6.



A. Germination studies on fully mature and half mature grains of weedy rice



B. Germination under different dormancy breaking treatments

Plate 10. Laboratory studies on dormancy of weedy rice seeds

Root and shoot length

In root length also, the treatments with 0.6 per cent nitric acid and low temperature exposure of 20 ºC for 48 hours showed higher values. The lowest root length was recorded by the high temperature treatment followed by control (Table 15). The shoot length of seedlings that emerged from nitric acid treated seeds (T1) was the highest, which was on par with low temperature treatment (T2). The lowest value was recorded by the high temperature treatment (T3). All other treatments including control recorded intermediary values in shoot length (Table 16)

Among the various treatments evaluated for breaking hull induced seed dormancy of weedy rice, good results were obtained in (i) scraping of seed hull (ii) subjecting seeds to low temperature of 20ºC for 48 hours (iii) soaking seeds in 0.6% nitric acid for six hours and (iv) salt water treatment for six hours (EC - 5 dS $m^{-1}$and 15 dS m^{-1}).

4.2.6. Effect of depth of seed burial and presence of rice seeds on the germination of weedy rice

The effect of depth of seed burial and presence of rice seeds on the germination of weedy rice was studied by conducting pot culture experiment. The results revealed that germination of weedy rice seeds (scraped to break hull induced dormancy) was higher at the surface and at 2 cm depth of the soil (Table 17). When weedy rice seeds were placed at 4 cm depth, there was significant reduction in the germination which further got reduced when the depth was increased to 8 cm.

It was also noticed that there was no additional germination after seven days when the seeds were at the surface. However, when they were in deeper layers (4-8 cm), additional germination was obtained during 7 to 14 days. There was no significant difference between the germination of weedy rice when it was in association with or without rice seeds.

Table 14. Germination of weedy rice seeds as influenced by dormancy breaking treatments

Sl. No.	Treatment	Cumulative germination, %		
		3 DAT	6 DAT	12 DAT
1	Nitric acid	35 [cd]	90 [a]	90 [ab]
2	Low temperature	55 [abc]	95 [a]	100[a]
3	High temperature	10 [d]	20 [c]	20 [c]
4	EC 5 d S m^{-1}	80 [ab]	95 [a]	95 [a]
5	EC 15 d S m^{-1}	80 [a]	85 [a]	90 [ab]
6	Hull scraping	90 [a]	95 [a]	95 [a]
7	Control	40 [cd]	55 [b]	75 [b]
	CD (0.05)	36	23	23

In a column, figures followed by the same alphabets do not vary significantly in DMRT

DAT: Days after treatment – soaking in water for germination in petriplates

Table 15. Root length of weedy rice seedlings as influenced by dormancy breaking treatments

Sl. No.	Treatment	Root length, cm		
		3 DAT	6 DAT	12 DAT
1	Nitric acid	3.09 [a]	6.51 [a]	9.55 [a]
2	Low temperature	3.95 [a]	6.71 [a]	9.20 [a]
3	High temperature	0.81 [b]	1.05 [d]	1.35 [d]
4	EC 5 d S m^{-1}	3.88 [a]	5.70 [ab]	7.43 [b]
5	EC 15 d S m^{-1}	3.58 [a]	5.88 [ab]	7.03 [b]
6	Hull scraping	3.20 [a]	4.38 [bc]	5.70 [bc]
7	Control	2.38 [a]	3.28 [c]	4.45 [c]
	CD (p=0.05)	1.5	1.8	2.0

In a column figures followed by the same alphabets do not vary significantly in DMRT

DAT: Days after treatment - soaking in water for germination in petriplates

Table 16. Shoot length of weedy rice seedlings as influenced by dormancy breaking treatments

Sl. No.	Treatment	Shoot length, cm		
		3 DAT	6 DAT	12 DAT
1	Nitric acid	2.77 [a]	4.13 [a]	5.55 [a]
2	Low temperature	1.38 [bc]	3.45 [ab]	5.10 [ab]
3	High temperature	0.50 [d]	0.63 [c]	1.13 [c]
4	EC 5 d S m^{-1}	1.83 [b]	2.88 [b]	4.75 [b]
5	EC 15 d S m^{-1}	1.80 [b]	2.83 [b]	4.35 [b]
6	Hull scraping	1.78 [b]	2.65 [b]	3.95 [b]
7	Control	0.88 [b]	2.53 [b]	3.84 [b]
CD (P=0.05)		0.86	1.2	1.6

In a column, figures followed by the same alphabets do not vary significantly in DMRT

DAT: Days after treatment – soaking in water for germination in petriplates

Table 17. Effect of depth of weedy rice seed burial and presence of rice seeds on the germination of weedy rice

Sl. No.	Treatment	Germination of weedy rice, %			Germination of rice, %		
		7 DAS	14 DAS	30 DAS	7 DAS	14 DAS	30 DAS
	Main effect (Depth of sowing)						
1	Surface	*1.1 (78)	1.6 (87)	1.4 (87)	9.4 (89)	9.6 (93)	9.7 (93)
2	2 cm	1.0 (71)	1.2 (84)	1.2 (86)	9.5 (89)	9.6 (91)	9.6 (91)
3	4 cm	0.7 (46)	0.9 (58)	0.9 (58)	7.9 (62)	8.9 (80)	8.9 (80)
4	8 cm	0.6 (40)	0.8 (47)	0.8 (47)	7.8 (62)	7.8 (62)	7.8 (62)
	CD (P=0.05)	0.56 (22)	0.4 (20.2)	0.44 (18.8)	1.1 (17.2)	0.94 (15.3)	0.94 (15.3)
	Main effect (Association)						
1	Weedy rice + Rice	0.85 (56)	0.95 (65)	0.96 (66)	-	-	-
2	Weedy rice alone	0.89 (59)	0.97 (67)	0.97 (67)	-	-	-
	CD (P=0.05)	NS	NS	NS	-	-	-
	Interaction effect CD (P=0.05)	NS	NS	NS	-	-	-

*Arc sine transformed values, figures in the parenthesis are original values   DAS : Days after sowing

4.3. Part 111- Control strategies

4.3.1. Physical methods

4.3.1.1. Management of weedy rice by stale seed bed technique (SSB)

Location 1

Management of weedy rice by stale seed bed technique was conducted in Kuruvapadam of Nedumudy panchayath in Kuttanad. Weedy rice infestation was severe in the experimental field during the previous crop season. The results of the experiment showed that there was significant difference between treatments in the population of weedy rice. The infestation of weedy rice was significantly higher in plots where no staling was done before the crop season (T1) and in plots where hand weeding alone was resorted to (T2) during the previous crop with severe weedy rice infestation. In all the treatments where staling operations were done either once or twice prior to the sowing of the crop (T3, T4 and T5), there was significant reduction in the infestation of weedy rice and corresponding effect on yield in the succeeding crop (Table 18).

Plant population (rice and weedy rice)

The number of weedy rice plants at 30 and 60 DAS was significantly higher in the control plots (T1) and in plots which was hand weeded during the previous season (T2) and they were on par. The treatment, single stale tilled plots without herbicide application (T4) was the next in terms of higher weedy rice population. The number of weedy rice plants per square at 30 and 60 DAS in T4 was 27 and 22, respectively. Corresponding values was 13 and 12 in T3 and, two and three in T5. Comparison of single (T3) and double stale operation (T5) revealed that double stale reduced the weedy rice plant population by 85 and 75 per cent over single stale at 30 and 60 DAS, respectively. It was observed that single stale operation followed by herbicide application (T3) recorded 52 and 41 per cent reduction in weedy rice population at 30 and 60 DAS than T4 with single stale followed by tillage.

There was significant reduction in rice plant population in the experimental field depending on the intensity of infestation of weedy rice. The number of rice plants per square metre at 30 and 60 DAS was 47 and 45, respectively, in treatment T5 (the best treatment with two stale followed by herbicide application). It was observed that rice plant population increased by 121 and 95 per cent in double stale (T5) compared to control (T1) at 30 and 60 DAS. The rice plant population was 37 and 32 per cent higher in single staled herbicide applied plots (T3) than that in single staled tilled plot (T4). Among different treatments, crop stand at 60 DAS was significantly higher and on par in T3 and T5 and significantly lower in T1 and T 2, which were on par.

Biomass of weedy rice

There was significant difference among treatments on the biomass of weedy rice at 30 and 60 DAS. The dry weight of weedy rice was the lowest in T5 at 30 and 60 DAS (3.5 g m^{-2} and 17.8 g m^{-2}). The study revealed that the dry weight of weedy rice was significantly higher in the untreated plots (TI and T2) compared to staled fields at 30 and 60 DAS. The dry weight of weedy rice in T2 was on par with T 4 at 30 DAS, while, T2 and T1 were on par at 60 DAS. Single stale followed by herbicide application (T3) resulted in 70 and 74 per cent reduction in the dry weight of weedy rice at 30 and 60 DAS while that in T4 was 19 and 36 per cent (single stale followed by tillage) compared to control. It was observed that staling twice (T5) reduced the dry weight of weedy rice by 73 and 61 per cent, respectively, at 30 and 60 DAS compared to single stale (T3). Reduction in the dry weight of weedy rice was 92 and 90 per cent, respectively at 30 and 60 DAS in T5 compared to control (T1).

Productive tiller count of rice and weedy rice

There was significant reduction in the productive tillers of the crop due to severe infestation by weedy rice (Table 18) as evidenced by 50 per cent reduction in the control compared to T5. The treatments T5 (double stale followed by herbicide application) and T3 (single stale followed by herbicide application) were on par and had significantly higher productive tillers than other treatments

(367 and 351 productive tillers per square metre). The tiller count of rice was 51 per cent lesser in control than that in the best treatment T5 (two stales with wet tillage in between, followed by herbicide application). Single stale followed by dry tillage (T4) had 47 per cent more tillers than control.

The treatments varied significantly in the number of productive tillers of weedy rice also. It was significantly higher in the untreated plots (T1 and T 2) and in plots where tillage was resorted to destroy the germinated weedy rice seedlings during the staling operation (T4). There was 57 and 87 per cent reduction in the weedy rice productive tillers in single staling followed by herbicide application (T3) and double staling followed by herbicide application (T5), respectively.

Crop yield

There was significant difference among treatments in grain and straw yield of the crop. In both treatments where stale operations were not done prior to sowing (T1 and T 2), grain yield was lesser by 72 and 65 per cent and straw yield by 62 and 51 per cent, respectively, compared to the best treatment (T5). Treatment T5 with double stale produced 7800 kg ha^{-1} of grain yield compared to 2200 kg ha^{-1} in the control plot. It was found that double stale could increase the grain yield by 22 per cent than single stale. Single stale followed by herbicide application (T3) gave 61 per cent increase in yield compared to single stale followed by tillage (T4). Grain yield in the single stale followed by herbicide application was 6110 kg ha^{-1} and that in single stale followed by tillage was 3800 kg ha^{-1}(Plate 11)

. Straw yield in the best treatment (T5) was 8548 kg ha^{-1} and was on par with T3 (7225 kg ha^{-1}) and superior to all other treatments. Straw yield in T1 (control) was 61 per cent lower than the best treatment (T5).The straw yield of treatments T1 and T2 was 3275 kg ha^{-1} and 4150 kg ha^{-1}, respectively and was significantly lower than that in all treatments where staling operations were done.

A. Germination from soil seed bank

B. Destroying germinated seedlings using herbicide

C. Drying of seedlings

D. Flooding the field after 10 days

Plate 11. Different operations in stale seed bed technique

Table 18. Effect of stale seed bed on the management of weedy rice in succeeding crop (Location - 1 - Kuruvappadam)

Treat ment	Plant population, hills m^{-2}		Plant population, hills m^{-2}		Dry weight, gm^{-2}		Plant height, cm		Productive tillers, No. m^{-2}		Plant height, cm	Crop yield, kg ha^{-1}	
	30 DAS		60 DAS		30 DAS	60 DAS	45 DAS		100 DAS		100 DAS		
	WR	R	WR	R	WR	WR	WR	R	WR	R	R	Grain	Straw
T1	*6.6 (50)	7.0 (47)	6.1 (47)	6.6 (45)	5.1 (43.8)	13.3 (182.3)	57.5	48.3	7.4 (57.0)	11.7 (182)	96.8	2200	3275
T2	7.1(43)	6.9 (48)	6.9 (37)	6.7 (44)	6.6 (25.7)	13.5 (178.6)	59.3	48	7.5 (55.0)	11.1(178)	95.8	2720	4150
T3	3.6 (13)	9.8 (95)	3.6 (12)	9.3 (86)	3.7 (13.0)	6.8 (46)	50	51	4.9(24.0)	20.2 (351)	103.3	6110	7225
T4	5.2 (27)	8.3 (69)	4.7 (22)	8.1 (65)	6.0 (35.5)	10.7 (115.8)	51.3	47.3	7.0 (50.0)	18.4 (261)	100.0	3800	5195
T5	1.3 (2)	10.2 (104)	1.9 (3.0)	9.3 (86)	2 (3.5)	4.2 (17.8)	49.5	55.8	2.7 (7.0)	20.5 (367)	108.0	7800	8548
CD (P=0.05)	0.7 (6.9)	0.5 (8.9)	0.7 (6.9)	0.6 (10.4)	0.7 (6.7)	1.4 (29.9)	6.5	3.7	0.8 (8.9)	0.9 (43.9)	7.6	757	636

- Square root transformed values, figures in the parenthesis are original values
  f.b. - followed by

T 1- Control
T 2- Hand weeded during previous season
T 3- Single stale f. b. glyphosate application
T 4- Single stale f. b. shallow wet tillage
T 5- First stale f. b. shallow wet tillage + second stale f.b. glyphosate application

R - Rice
WR- Weedy rice


A.


B.


C.


D.


E.


F.

Plate 12. Different operations in double stale seed bed technique
(A) Flooding after harvest [3-4 days] (B) Germination of weeds [2 wks]
(C) Dry tillage (D) Wet tillage (E) Second flush of germination [10 days]
f.b. herbicide application (F) Flooding till sowing (10 days)

Location 2

The treatments for the second trial (Manimalakkadu padam of Champakulam panchayath in Kuttanad) were modified based on the results of the first trial. This experiment was conducted to evaluate the efficiency of single stale over double stale and the response of wet and dry tillage on weedy rice infestation in the succeeding crop (Plate 12). The data showing the influence of stale seed bed treatments on weedy rice and rice are given below.

Plant population (rice and weedy rice)

There was significant difference among treatments on the weedy rice population in the succeeding crop at 30 and 60 DAS (Table 19). The number of weedy rice plants per square metre in the control plot (T1) was 49 and 45 at 30 and 60 DAS. In the treatment with double stale operations with two tillage operations in between (both dry and wet tillage) followed by herbicide application (T5), only a single weedy rice plant was present. Among the different treatments, T4 and T5 had significantly lower weedy rice population. A comparison between single stale followed by herbicide application (T2) and double stale with dry and wet tillage in between stales followed by herbicide application (T5) showed that there was 91 per cent decrease in the weedy rice population in T5, both at 30 and 60 DAS. Significantly lower weedy rice population in T4 (double stale with wet tillage in between followed by herbicide application) over T3 (double stale with shallow dry tillage in between followed by herbicide application) revealed the advantage of wet tillage over dry tillage during stale for exhausting the soil seed bank of weedy rice. It was observed that destruction of the first flush of weeds from the soil seed bank by wet tillage (T4) decreased the weedy rice population by 76 and 73 per cent, respectively at 30 and 60 DAS in the succeeding crop compared to dry tillage (T3).

The rice plant population also was influenced significantly by the treatments. There was significant difference among the effects of treatments on the rice plant population. Rice plant population was significantly higher in T5 (double stale with dry and wet tillage in between stales, followed by herbicide

Table 19. Effect of stale seed bed on the management of weedy rice in succeeding crop (Location -2 - Manimalakkadu)

Treat ment	Plant population, No. m^{-2}				Weed dry weight, g m^{-2}		Plant height, cm		Productive tillers, No. m^{-2}		Plant height, cm	Crop yield, kg ha^{-1}	
	30 DAS		60 DAS		30 DAS	60 DAS	45 DAS		100 DAS		100 DAS		
	WR	R	WR	R	WR	WR	WR	R	WR	R	R	Grain	Straw
T 1	*7.0 (49)	7.2 (51)	6.7 (45)	6.9 (47)	8.2 (67.7)	14.3(206.2)	51.3	48.0	8.0 (64)	13.1 (171)	93.5	1725	3250
T 2	3.4 (11)	9.5 (90)	3.3 (11)	9.4 (88)	3.6 (12.5)	7.3 (53.3)	51.3	52.0	4.3 (19)	18.5 (343)	100.3	6000	7143
T 3	4.2 (17)	9.2 (85)	3.9 (15)	9.1 (83)	5.0 (24.5)	8.2 (67)	48.3	51.8	5.1 (26)	17.6 (310)	95.8	4525	6090
T 4	2.1 (4)	9.5 (91)	2.0 (4)	9.3 (86)	2.4 (5.38)	3.8 (13.8)	52.3	52.6	2.9 (9)	19.7 (387)	105.0	7468	7670
T 5	1.2 (1)	10.2 (105)	1.0 (1)	9.7 (94)	0.38 (0.9)	1.4 (1.9)	37.0	53.3	1.5 (2)	21.8 (475)	107.3	7800	8480
CD (P=0.05)	0.7 (7.6)	0.4(6.86)	0.7 (6.9)	0.4 (7.2)	0.8 (10.2)	1.4 (31.2)	17.5	NS	1.0 (8.85)	0.8 (30.3)	4.5	496	594

*Square root transformed value, figures in the parenthesis are original values
T 1. Control
T 2. First stale f. b. glyphosate application
T 3. First stale f. b. shallow dry tillage + second stale f.b. glyphosate application
T 4. First stale f.b. shallow wet tillage + second stale f.b. glyphosate application
T 5.First stale f.b. shallow dry and wet tillage + second stale f.b. glyphosate application
f.b - followed by, WR – Weedy rice, R- Rice, DAS- Days after sowing

application) followed by T4 (double stale followed by wet ploughing and destruction of germinated seedlings by application of herbicide) at 30 DAS. Rice plant population in T5 was almost double than that in T1 (control) both at 30 and 60 DAS. The crop stand in T5, T4 and T2 were on par at 60 DAS and significantly higher than that in T1and T2.

Biomass of weedy rice

The different stale seed bed operations were found to influence the biomass of weedy rice. Among the treatments, weedy rice biomass was significantly lower and on par in T5 and T4 at 30 and 60 DAS. The treatment T2 (single stale + herbicide application) had significantly higher weedy rice dry weight than T4 (double stale + wet tillage + by herbicide application) at 60 DAS, though it was on par at 30 DAS. The decrease in weedy rice dry weight was 99 per cent in double stale with both dry and wet tillage (T5), 92 and 93 per cent in double stale with wet tillage (T4), 74 and 81 per cent in single stale without tillage (T2) and 64 and 67 per cent in double stale with dry tillage (T3), compared to control (T1), at 30 and 60 DAS.

Productive tiller count of rice

The treatment effects varied significantly on the number of productive tillers in rice crop depending on the infestation of weedy rice. The productive tiller count was significantly lower in the control plot (T1) followed by T3 and T2. Rice plants in treatment T5 (double stale with dry and wet tillage operations in between stales followed by herbicide application) had significantly higher productive tillers than those in other treatments, followed by T4 (double stale with wet tillage in between followed by herbicide application). There was 23 per cent increase in the number of productive tillers in T5 compared to T4.

Height of rice plants

There was significant difference between treatments in the height of rice plants at 45 DAS. The height of rice plants at 45 DAS in T5 (double stale with dry and wet tillage in between stales followed by herbicide application) was the highest (53.3 cm), closely followed by T4, T2 and T3. The height of rice plants in T3 (double stale with dry tillage in between followed by herbicide application) and those in T1 (control plots) was on par. The best treatment (T5) had rice plants with 14 per cent more height than those in T1 (control).

The height of rice plants at100 DAS was significantly higher in T4 and T5 than in other treatments. The plants attained 12 and 14 per cent increase in height in T4 (105.0 cm) and T5 (107.3 cm), respectively compared to that in control (93.5 cm). T1 and T3 were on par with respect to rice plant height at100 DAS and significantly lower than the other treatments. It was observed that plant height at100 DAS was more in fields with wet tillage (T4 and T5) compared to dry tillage (T3).

Crop yield

There was significant difference between treatments in the grain and straw yield of rice plants (Table 19). Double stale operations with two tillage in between followed by herbicide application (T5) and double stale with wet tillage followed by herbicide application (T4) had significantly higher grain yield (7800 kg ha^{-1} and 7468 kg ha^{-1}) and were on par compared to double stale with dry tillage followed by herbicide application (T3) and control (T1), where the yields were the lowest (4525 kg ha^{-1} and 1725 kg ha^{-1}). Treatment T1 (control) had 78 per cent reduction in grain yield than T5, the best among the treatments. Single stale followed by herbicide application (T2) had lower yield compared to double stale with wet tillage followed by herbicide application (T4). Single stale followed by herbicide application (T2) gave 33 per cent increase in yield compared to double stale with dry tillage in between followed by herbicide application (T3). There was 67 per cent increase in grain yield in T4 (double stale + wet tillage + herbicide application) than T3 (double stale + dry tillage + herbicide application). On comparing the effect of wet tillage and dry tillage in between the two stales, it was found that wet tillage had significantly higher grain yield of 7468 kg ha^{-1} (T4) compared to 4525 kg ha^{-1} in dry tillage (T3). It was noted that taking two tillage operations in between two stales (dry followed by wet tillage in between stales-

T5) gave 10 and 28 per cent more yield than double stales with wet or dry tillage (T4 and T3), respectively.

Straw yield of T5 was superior to other treatments. Straw yield in T5 was 8480 kg ha^{-1} and that in control plot (T1) was 3250 kg ha^{-1}, ie., threefold increase in straw yield was obtained in the best treatment T5 compared to T1(control plot). Straw yield in T4 (7670 kg ha^{-1}) was on par with T2 (7143 kg ha^{-1}). T3 had straw yield of 6090 kg ha^{-1} and T2 had 7150 kg ha^{-1}.

4.3.1.2. Management of weedy rice by straw burning

The data presented in Table 20 showed that there was significant difference among treatments on the management of weedy rice in the succeeding crop after burning of the straw following the harvest of the previous crop in severely weedy rice infested fields. In this experiment, as the field had weedy rice infestation for the past two years, the contribution of the soil seed bank has also added to the weedy rice population in the next crop season. There was 60 per cent reduction in the weedy rice population in the best treated plots (burnt and zero tilled ie., T2 and T4) compared to the control. The plots that were tilled (TI and T3) before sowing (burnt after the harvest of the crop) had on par weedy rice population with control. It was also noted that on tilling the soil before sowing of the succeeding crop there would be addition of the dormancy broken seeds to the surface from the soil beneath (which was kept flooded for two weeks or more). The results showed that there was no significant difference among treatments on using kerosene while burning the field for weedy rice control (Plate 13).

Comparison of the yield in different treatments also showed that yield was lower when tillage was given after straw burning, before sowing the seeds. The yield in these plots (T1 and T3) was 2050 kg ha^{-1} and 2155 kg ha^{-1} compared to 3505 kg ha^{-1} and 3580 kg ha^{-1} (T2 and T4) where zero tillage was followed after burning of straw. The treatments T1 and T3 were on par and yielded significantly lower compared to T2 and T4 which were on par and yielded high. There was no additional benefit from spraying kerosene before burning the straw. Straw yield

A. Burning after spraying kerosene – thick flame

B. Burning without kerosene – slow burning with smoke

Plate 13. Burning of straw for management of weedy rice

Table 20. Effect of burning of straw and tillage on the weedy rice infestation and yield of rice in succeeding crop

Sl. No.	Treatments	Weedy rice count, No. m^{-2}		Crop yield, kg ha^{-1}	
		25 DAS	70 DAS	Grain	Straw
1	Burning straw f.b. tillage	15 [a]	19 [a]	2050 [b]	3505 [b]
2	Burning straw f.b. zero tillage	8 [b]	7 [b]	3650 [a]	5230 [a]
3	Burning straw + kerosene f.b. tillage	16 [a]	19 [a]	2155 [b]	3755 [b]
4	Burning straw + kerosene f.b. zero tillage	7 [b]	9 [b]	3580 [a]	5105 [a]
5	Control	18 [a]	20 [a]	1860 [b]	2770 [c]
CD (P=0.05)		3.5	3.5	527	220

In a column, figures followed by the same alphabets do not vary significantly in DMRT

f.b. - followed by DAS - Days after sowing also showed a similar pattern as grain yield, recording 5230 and 5105 kg ha^{-1} in T2 and T4 and 3505 kg ha^{-1} and 3755 kg ha^{-1} in T1 and T3, respectively.

4.3.1.3. Management of weedy rice by soil solarisation

The experiment to evaluate the efficiency of solarisation on the management of weedy rice was conducted during the summer season of February-March, 2012. These fields were severely infested with weedy rice during the previous years and were left fallow. The field had ≥15 weedy rice plants per square metre. Estimation of the count of weedy rice seeds in the soil revealed that there were 1100 seeds per cubic metre in the soil seed bank (Plate 14 and 15).

Variation in soil temperature

Variation in soil temperature at different depths on solarisation is presented in Table 21. Soil temperature in all treatments decreased with increase in soil depth. At 3 cm depth of soil, temperature during solarisation varied from 47.1^{0}C to 47.9 ^{0}C, 47.3 ^{0}C to 49.7 ^{0}C, 41.1^{0}C to 50.2^{0}C, 42.1^{0}C to 49.5^{0}C and 42.2^{0}C to 48.7^{0}C in T1, T2, T3, T4 and T5, respectively, whereas the soil temperature at 5 cm depth of soil during solarisation ranged from 44.2^{0}C to 46.3 ^{0}C, and 44.9 ^{0}C to 47.0 ^{0}C, 44.1 to 47.5, 44.7^{0}C to 47.4^{0}C and 40.0^{0}C to 46.6^{0}C, respectively. At 10 cm depth of soil, soil temperature during solarisation varied from 41.8^{0}C to 44.4^{0}C, and 41.2 ^{0}C to 45.0^{0}C, 42.8^{0}C to 47.1^{0}C and 42.5^{0}C to 45.0^{0}C in T1, T2, T3, T4 and T5, respectively. Soil temperature inside the solarised sheet at different soil depths was 10^{0}C to 12^{0}C higher than the air temperature. As the number of days of solarisation increased in treatments T1 to T5, the number of days to which the soil was subjected to high temperature increased. Compared to the control plots, the solarised soil had higher temperature at three and five centimetre depth of the soil (Table 21).

Weedy rice population

Observation on the germination of weedy rice from the solarised soil for 20 days during the succeeding *Kharif* season of Kuttanad (experiment plots were

A. After 20 days of solarisation

B. Measuring temperature using portable sensor

C. Stage wise removal of sheet

Plate 14. Field view of soil solarisation experiment

A. Less germination in solarised fields compared to control

B. Germination along the borders of solarised plots

C. Zero germination in the solarised areas

Plate 15. Field view of germination in soil solarised plots during the next season

Table 21. Effect of duration of soil solarisation on soil temperature at different depths of soil, ^{0}C

Treatment (Days of solarisation)	3 cm depth of soil							5 cm depth of soil							10 cm depth of soil						
	Number of days after covering the soil																				
	5	10	20	25	30	35	40	5	10	20	25	30	35	40	5	10	20	25	30	35	40
T I - 20	47.9	47.9	47.1	**37.7**	**34.8**	**38.3**	**36.2**	46.3	45.7	44.2	**36.3**	**34.5**	**37.1**	**36.2**	44.4	43.6	41.8	**35.7**	**33.8**	**36.5**	**35.3**
T 2 - 25	49.7	47.3	48.2	48.3	**36.3**	**38.3**	**37.3**	47.0	44.9	45.4	44.9	**35.1**	**37.5**	**36.5**	45.0	43.0	41.2	42.4	**35.9**	**36.6**	**35.6**
T 3 - 30	50.2	48.6	48.9	47.1	41.4	**38.7**	**37.4**	47.5	45.5	45.8	44.1	39.5	**38.2**	**36.0**	47.1	44.4	42.8	42.9	38.1	**37.3**	**35.5**
T 4 - 35	49.5	47.6	48.3	47.7	42.1	46.3	**38.4**	47.4	45.0	45.6	44.7	39.7	44.0	**37.3**	45.2	43.6	42.8	42.9	38.0	42.5	**36.2**
T 5 - 40	48.6	48.7	48.0	46.0	42.2	47.2	46.0	46.6	46.2	45.7	43.8	40.0	45.4	43.8	45.0	43.4	42.5	42.8	38.7	43.6	41.2
T 6 - 0	**38.3**	**37.4**	**36.9**	**37.1**	**34.8**	**38.5**	**36.4**	**36.2**	**36.2**	**35.1**	**36**	**34.1**	**37.1**	**36**	**34.1**	**34.1**	**34.3**	**35.8**	**33.3**	**36.1**	**35.5**

Bold figures are the soil temperature under non-solarised situation

Table 22. Effect of pre emergence herbicides on weedy rice infestation and crop yield (Location- 1- Kole)

Sl. No.	Herbicide	Rate, kg ha $^{-1}$	Time of application	Method of application	Rice plants m^{-2}, No. m^{-2}		WR DW, g m^{-2}	WR ear heads, No. m-^{2}	Crop yield, kg ha^{-1}	
					20 DAS	75 DAS	45 DAS	75 DAS	Grain	Straw
1	Pretilachlor	1	3 DBS	Incorporation	148 ^{bcd}	68 ^{cd}	34.3 ^{bcd}	52 ^{a}	2340 ^{def}	3260 ^{hi}
2	Pretilachlor	1.5	3 DBS	Incorporation	146 ^{cde}	60 ^{fg}	30.7 ^{efgh}	33 ^{fgh}	2482 ^{cd}	3541 ^{ef}
3	Pretilachlor	0.5	3 DBS	Surface	140 ^{efgh}	70 ^{abc}	31.0^{efg}	48 ^{ab}	2380 ^{de}	3348^{gh}
4	Pretilachlor	1	3 DBS	Surface	138 ^{fgh}	72 ^{abc}	27.0 ^{ghi}	44 ^{bc}	2539 ^{c}	3631 ^{de}
5	Oxyfluorfen	0.2	3 DBS	Incorporation	145 ^{def}	69 ^{bc}	22.3 ^{jk}	28 ^{hi}	2590 ^{c}	3713 ^{cd}
6	Oxyfluorfen	0.3	3 DBS	Incorporation	146 ^{cde}	62 ^{ef}	19.0 ^{k}	17 ^{j}	3158 ^{a}	3872 ^{bc}
7	Oxyfluorfen	0.1	3 DBS	Surface	153 ^{abc}	75 ^{a}	23.0 ^{ijk}	18 ^{j}	2778 ^{b}	3813 ^{c}
8	Oxyfluorfen	0.2	3 DBS	Surface	147 ^{cde}	73 ^{ab}	14.7 ^{l}	10 ^{k}	3233 ^{a}	4049 ^{a}
9	Butachlor	2.5	3 DBS	Incorporation	138 ^{fgh}	60 ^{fg}	32.7 ^{def}	26 ^{i}	2416 ^{cd}	3429^{fg}
10	Butachlor	3.75	3 DBS	Incorporation	135 ^{hi}	56 ^{g}	35.0 ^{bcd}	22 ^{ij}	2050 ^{gh}	3325 ^{hi}
11	Butachlor	1.25	3 DBS	Surface	136 ^{hi}	62 ^{ef}	28.0 ^{fgh}	39 ^{cde}	2204 ^{efg}	3199^{i}
12	Butachlor	2.5	3 DBS	Surface	130 ^{i}	58 ^{fg}	26.3 ^{hij}	32 ^{gh}	2130 ^{g}	3032 ^{j}
13	Pretilachlor	0.5	6 DAS	Surface	148 ^{bcd}	61 ^{fg}	36.3 ^{bc}	42 ^{cd}	2140 ^{g}	3398^{fgh}
14	Oxyfluorfen	0.1	6 DAS	Surface	146 ^{cde}	63 ^{def}	33.7 ^{cde}	38 ^{def}	2175 ^{fg}	3627 ^{de}
15	Butachlor	1.25	6 DAS	Surface	142 ^{defgh}	60 ^{fg}	38.0 ^{b}	35 ^{efg}	2061^{gh}	3215^{i}
16	Hand weeding				155 ^{ab}	70 ^{abc}	4.0 ^{m}	4 ^{l}	3040 ^{a}	4000 ^{ab}
17	Unwweeded control				158 ^{a}	49 ^{h}	46.0 ^{a}	30 ^{ghi}	1890 ^{h}	2445 ^{k}
	CD P=0.05)				7.0	5.3	4.0	5.2	187.2	164.7

In a column, figures followed by the same alphabets do not vary significantly in DMRT

DBS – Days before sowing, WR DW - Weedy rice dry weight maintained as fallow and surrounding fields were cultivated) revealed that the germination of weedy rice (during the first 20 days) was higher in control plots (19 weedy rice plants per square metre) compared to all the solarised plots. The germination from the soil seed bank after solarisation was high in the treatments T1 and T2 (9 and 4 weedy rice plants per square metre), while it was two weedy rice plants per square metre in T3. Treatments T4 and T5 had no germination from the soil seed bank. The result shows that subjecting weedy rice infested fields to solarisation for 30-40 days can effectively destroy weedy rice seeds in the soil seed bank. It was also noticed that germination increased in treatments T1, T2, T3 and T6 as days of observation proceeded showing the reduced control of weedy rice seeds from the deeper layers (5-10 cm depth) where the soil temperature was 3-4 ^{0}C lower than that at 3 cm depth of soil.

4.3.2. Chemical methods

4.3.2.1. Effect of pre emergence herbicides on the infestation of weedy rice and crop yield

Selective management of weedy rice in rice field using herbicides is practically not feasible because of the similarity between weedy rice and rice. However, herbicide selectivity can be achieved by altering the time and method of application. Results of the trials in this direction are given below.

Location- 1(Purathoor Padavu in Kole)

The effect of different doses and method of application of pre emergence herbicides is presented in Table 22. The treatments significantly affected the crop stand at 20 DAS. Crop stand was significantly higher with hand weeding at 20 and 40 DAS and on par in treatments where surface application was done three DBS using pretilachlor (0.5 kg ha^{-1} and 1.0 kg ha^{-1}) and oxyfluorfen (0.1 kg ha^{-1} and 0.2 kg ha^{-1}). Crop stand was significantly lower in pre sowing surface application and incorporation of butachlor and pretilachlor. At 75 DAS, crop stand in butachlor incorporation (3.75 kg ha^{-1}) at three DBS was significantly lower (56 plants per square metre) and on par with butachlor surface application three DBS (2.5 kg ha^{-1}) and pretilachlor incorporation (1.5 kg ha^{-1}). Weed dry weight at 45 DAS was significantly lower in oxyfluorfen applied plots than in butachlor or pretilachlor plots. Incorporation of oxyfluorfen at double the recommended dose could also control weedy rice during the initial phases of crop but there was significant reduction in crop stand. The number of weedy rice earheads at 75 DAS was significantly lower in soil incorporation and surface application of oxyfluorfen at 0.3 kg ha^{-1} and 0.2 kg ha^{-1}, respectively at three DBS.

Crop yield was significantly higher in oxyfluorfen incorporation and surface application at 0.3 kg ha^{-1} and 0.2 kg ha^{-1} at three DBS. Hand weeding at 20 and 40 DAS also gave yield on par with pre sowing application of oxyfluorfen at 0.2 kg ha^{-1}.

Location – 2 (Devasomkari Padam in Kuttanad)

All the herbicides and the different methods of application resulted in significant reduction in the count and dry matter production of weedy rice compared to unsprayed control (Table 23). Among the herbicides, oxyfluorfen resulted in significant reduction in the count and dry weight of weedy rice consistently at both the stages of observation (25 and 45 DAS) and its surface application (T11 and T12 at 0.2 kg $ha^{-1}$and 0.3 kg ha^{-1}) was found to be better than soil incorporation (T9 and T10 at 0.2 kg $ha^{-1}$and 0.3 kg ha^{-1}). Surface application of pretilachlor at 2 kg ha^{-1} (T 8) was also promising.

Grain and straw yield was the maximum for surface application of oxyfluorfen at 0.2 kg ha^{-1} (T11), followed by surface application of oxyfluorfen at 0.3 kg ha^{-1} (T12), incorporation of oxyfluorfen at 0.3 kg ha^{-1} (T10) and hand weeding at 20 and 40 DAS (T13). Number of rice seedlings was significantly higher and on par in oxyfluorfen treated plots.

Location - 3 (Manimalakkadu Padam in Kuttanad)

All the treatments (herbicide applied as surface application three days before sowing) resulted in significant reduction in weedy rice count compared to unsprayed control at 25 and 70 DAS (Table 24). At 70 DAS, pretilachlor and oxyfluorfen showed significantly lesser weed population than unweeded control.

The count of rice seedlings in oxyfluorfen treated plots was on par with hand weeding and unweeded control at 15 DAS (except at 0.4 kg ha^{-1} of oxyfluorfen), whereas, other herbicide treatments had lesser crop stand. Grain and straw yields were maximum in hand weeded plots (T9) and the least in unweeded control (T10) and these treatments differed significantly from other treatments. Among the herbicide treatments, oxyfluorfen at 0.2 kg ha^{-1} was the best (T7) followed by oxyfluorfen at 0.3 kg ha^{-1} (T3). These two treatments were significantly better than all other treatments (Plate 16).

4.3.2.2. Management of weedy rice by post emergence herbicides

4.3.2.2.1. Development of the prototype of a device for direct contact application of herbicides

Direct contact application (DCA) of non-selective broad-spectrum post emergence herbicides is a management strategy for the control of tall growing weeds than rouging (Plate 17 and 18). Hence an attempt was made for the selective drying of weedy rice panicles using wick applicator imported from Taiwan. As the imported equipment was heavy and less user friendly it was decided to design a new prototype for selective drying of weedy rice panicles by DCA. The new prototype of the hand held herbicide wiper device (Fig. 9) has a five litre herbicide containing tank which can be hung on the shoulder of the operator. A sprayer pump is attached to the herbicide tank to develop pressure. The pressurized herbicide from the tank flows through a hose, placed on a 'U' shaped frame fitted with a handle. A nozzle present at the proximal end of the hose is used to dispense the herbicide. Chances for dripping of the herbicide can be avoided by an easy to operate control valve with button switch or tilting the device to spread the chemical on to the cloth, fastened on the herbicide carrying 'U' shaped frame of the device.

The 'U' shaped hose mounting frame is connected to the front end cap

A. Field lay out (Kole)

B. Field lay out (Kuttanad)

C. Crop at 25 DAS (Kole)

A. Crop at 70 DAS (Kuttanad)

Plate 16. Pre-sowing application of herbicide for weedy rice management

A. Early flowering and maturation in weedy rice

B. Rouging of weedy rice earheads at heading stage

C. Rouging of weedy rice earheads before harvest

Plate 17. Management of weedy rice earheads by removing panicles

A. Height difference of rice and weedy rice

B. Wick applicator for DCA

C. Sweeping in progress

C. Dried earheads of weedy rice

Plate 18. Post emergent management of weedy rice by DCA

Table 23. Effect of pre-sowing surface application of herbicides on weedy rice infestation and crop yield (Location -2- Kuttanad)

No.	Herbicide	Rate, kg ha $^{-1}$	Method of application	WR count, No. m $^{-2}$		Rice count, No. m $^{-2}$	Weedy rice DW, g m $^{-2}$		Crop yield, kg ha $^{-1}$	
				25 DAS	45 DAS	45 DAS	25 DAS	45 DAS	Grain	Straw
1	Butachlor	2.5	Incorporation	12 ^{c}	14 ^{bc}	81 ^{e}	4.16 ^{c}	10 ^{bc}	3240 ^{h}	4808 ^{g}
2	Butachlor	3	Incorporation	11 ^{cd}	15 ^{bc}	87 ^{cde}	4.12 ^{c}	12.1 ^{b}	3480 ^{g}	5218 ^{f}
3	Butachlor	2.5	Surface	12 ^{c}	12 ^{cdeg}	71 ^{f}	4 ^{cd}	9 ^{cd}	3100 ^{hi}	4515 ^{h}
4	Butachlor	3	Surface	16 ^{b}	16 ^{b}	68 ^{f}	5.3 ^{b}	12 ^{b}	3420 ^{g}	5127 ^{f}
5	Pretilachlor	1.5	Incorporation	12 ^{c}	14 ^{bc}	86 ^{de}	4 ^{cd}	10.8 ^{bc}	3700 ^{f}	5583 ^{e}
6	Pretilachlor	2	Incorporation	11 ^{cd}	13 ^{bcde}	83 ^{e}	4 ^{cd}	11 ^{bc}	3910 ^{e}	5937 ^{d}
7	Pretilachlor	1.5	Surface	9 ^{de}	10 ^{degh}	84 ^{de}	3.4 ^{de}	10 ^{bc}	4250 ^{cd}	6275 ^{bc}
8	Pretilachlor	2	Surface	8 ^{e}	9 ^{gh}	73 ^{f}	3.5 ^{de}	9.2 ^{cd}	4120 ^{d}	6130 ^{cd}
9	Oxyfluorfen	0.2	Incorporation	9 ^{de}	9 ^{gh}	91 ^{abc}	3.2 ^{ef}	7.1 ^{de}	4322 ^{c}	6355 ^{bc}
10	Oxyfluorfen	0.3	Incorporation	7 ^{ef}	8 ^{hi}	93 ^{ab}	3 ^{efg}	6.5 ^{de}	4400 ^{bc}	6560 ^{ab}
11	Oxyfluorfen	0.2	Surface	5 ^{fg}	5 ^{i}	94 ^{a}	2.8 ^{fg}	5.1 ^{e}	4610 ^{a}	6792 ^{a}
12	Oxyfluorfen	0.3	Surface	4 ^{gh}	5 ^{i}	90 ^{abcd}	2.4 ^{g}	4.8 ^{e}	4420 ^{ab}	6601 ^{a}
13	HW 20, 40 DAS			2 ^{h}	1 ^{j}	82 ^{e}	0.5 ^{h}	1 ^{f}	4300 ^{c}	6463 ^{b}
14	Un weeded control			25 ^{a}	23 ^{a}	68 ^{f}	6.8 ^{a}	20.2 ^{a}	2040 ^{i}	2995 ^{i}
	CD P=0.05)			2.5	3	6.1	0.6	2.5	195	292

In a column figures followed by the same alphabets do not vary significantly in DMRT

All the herbicides were applied at 3 DBS,   HW - Hand weeding, WR DW – Weedy rice dry weight

Table 24. Effect of pre-sowing surface application of herbicides on weedy rice infestation and crop yield (Location - 3 - Kuttanad)

Sl. No.	Treatments	Rate, kg ha $^{-1}$	Plant count, 15 DAS No. m^{-2}		Weedy rice count No. m^{-2}		Crop yield kg ha $^{-1}$	
			Weedy rice	Rice	25 DAS	70 DAS	Grain	Straw
1	Butachlor	2	12 ^{bc}	150 ^{cde}	14 ^{ab}	15^{ab}	3010 ^{g}	4820 ^{e}
2	Butachlor	2.5	11 ^{bcd}	124 ^{f}	12 ^{abcd}	15 ^{ab}	2970 ^{g}	4740 ^{e}
3	Pretilachlor	1.5	11 ^{bcd}	157 ^{cd}	13 ^{abc}	14 ^{b}	3290 ^{def}	5460 ^{d}
4	Pretilachlor	2	9 ^{cde}	138 ^{def}	9 ^{de}	12 ^{bc}	3120 ^{fg}	4990 ^{e}
5	Oxyfluorfen	0.1	8 ^{def}	180 ^{ab}	11 ^{bcd}	13 ^{bc}	3160 ^{efg}	5110 ^{de}
6	Oxyfluorfen	0.2	7 ^{ef}	170 ^{abc}	10 ^{cd}	10 ^{cd}	4100 ^{bc}	6580 ^{bc}
7	Oxyfluorfen	0.3	5 ^{fg}	161 ^{abc}	6 ^{ef}	8 ^{de}	3880 ^{bc}	6200 ^{bc}
8	Oxyfluorfen	0.4	3 ^{g}	147 ^{cd}	5 ^{f}	7 ^{de}	3420 ^{d}	5450 ^{d}
9	Hand weeding 20 & 40 DAS		20 ^{a}	178 ^{ab}	3^{f}	5 ^{e}	4830 ^{a}	7740 ^{a}
10	Un weeded control		22 ^{a}	183 ^{a}	15 ^{a}	18 ^{a}	1710 ^{h}	2790 ^{f}
	CD (P=0.05)		3	22.4	3	3	245.5	404.2

Figure followed by the same alphabets do not vary significantly in DMRT All the herbicides were applied at 3 DBS,

DAS : Days after sowing

of handle which in turn was connected to the rear end cap. The hose dummy is present at the distal end of the hose to seal the end of the hose.

The ‘U’ shaped hose has eight pores, four pores on each parallel limb (Fig.10). The pores are covered with a cloth towel which gets saturated by the herbicide coming out from the pores. The ‘U’ shaped frame increases the working efficiency and area coverage by the device. Herbicide can be smeared on both the sides of the panicle along the entire length by the horizontal swinging movement of the wiper applicator (Plate 19).

The prototype of the hand held wiper device developed was tested in farmers’ field. It could be effectively utilised at 60-65 days after sowing for direct contact application of broad spectrum herbicides, to selectively dry the weedy rice panicles taking advantage of 12-15 cm height difference between rice and weedy rice plants. Patent application has been filed for the wiper device at the Patent office, Chennai (Application No. 1763/CHE/2014 dated 1.04.2014). The details are given in Appendix VI.

4.3.2.2.2. Effect of direct contact application of herbicides on weedy rice infestation

The efficiency of the various herbicides in selective drying of weedy rice panicles by DCA with wick applicator was experimented using three broad spectrum herbicides, paraquat dichloride, glyphosate and glufosinate ammonium.

Location 1

The experiment was conducted at Purathoor Padavu in Kole with severe infestation of weedy rice. Among the chemicals used in the experiment, the efficacy of glufosinate ammonium at five per cent concentration was inferior to all other treatments (Table 25). At 15 per cent concentration, it was on par with glyphosate at 10 and 15 per cent and paraquat dichloride at 15 per cent concentration.

The number of ear heads that were not dried by herbicidal action varied significantly among treatments. Number of ear heads escaping the DCA was

A. Wiper device developed for managing weedy rice by DCA

B. DCA on weedy rice earheads

C. Drying of weedy rice earheads

Plate 19. Management of weedy rice by wiper device

significantly higher in glufosinate ammonium at five per cent concentration while, it was significantly lower and on par in T3, T4, T2 and T7 ie., higher concentration of glufosinate ammonium (15%), glyphosate at both the concentrations (10% and 15%) and paraquat dichloride (15%). The treatments which were on par in the control of weedy rice ear heads exhibited 83 to 88 per cent control efficiency.

Location 2

A similar experiment was also conducted in severely weedy rice infested direct seeded rice fields of Devasomkari padasekharam in Kuttanad. Both the concentrations of glyphosate (10% and 15%) did not vary significantly in the control of weedy rice ear heads (Table 26). Glufosinate ammonium at five per cent was inferior in controlling weedy rice compared to its higher concentrations at 10 and 15 per cent, which were on par. Among the different herbicides tried, glufosinate ammonium @ 15 per cent had the highest per cent of control followed by glyphosate and paraquat dichloride at 15 per cent and glufosinate ammonium at10 per cent concentration.

The number of ear heads that escaped from the herbicidal contact varied significantly among treatments. Number of ear heads remaining unaffected was significantly higher for the contact herbicides glufosinate ammonium (5%) at lower concentration followed by glufosinate ammonium (10%) and paraquat dichloride at10 per cent concentration. Number of weedy rice panicles that were skipped in DCA was significantly low and on par at higher concentration of glufosinate ammonium (15%), paraquat dichloride (15%) and glyphosate (at both the concentrations 10% and 15%).

The dried ear heads were collected for checking the viability using Tetrazolium test and it was found that majority of the spikelets were either in the

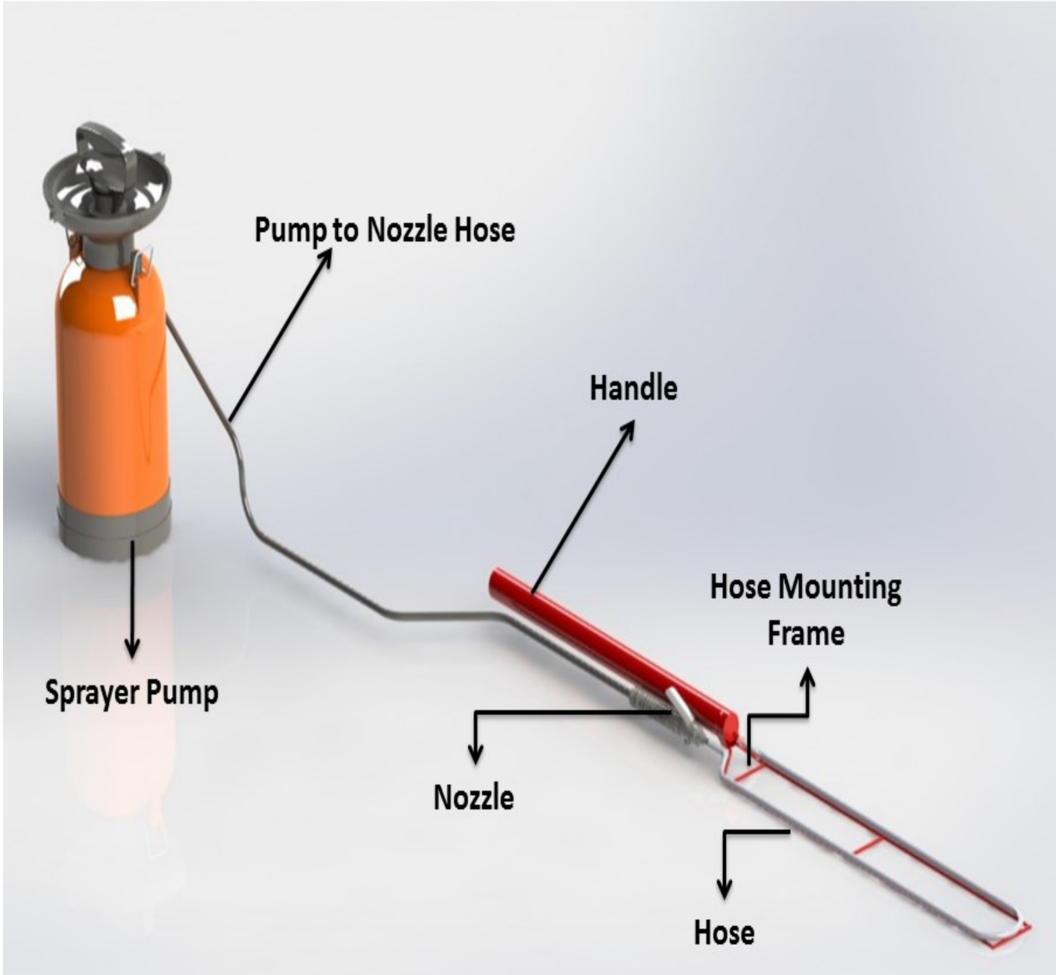
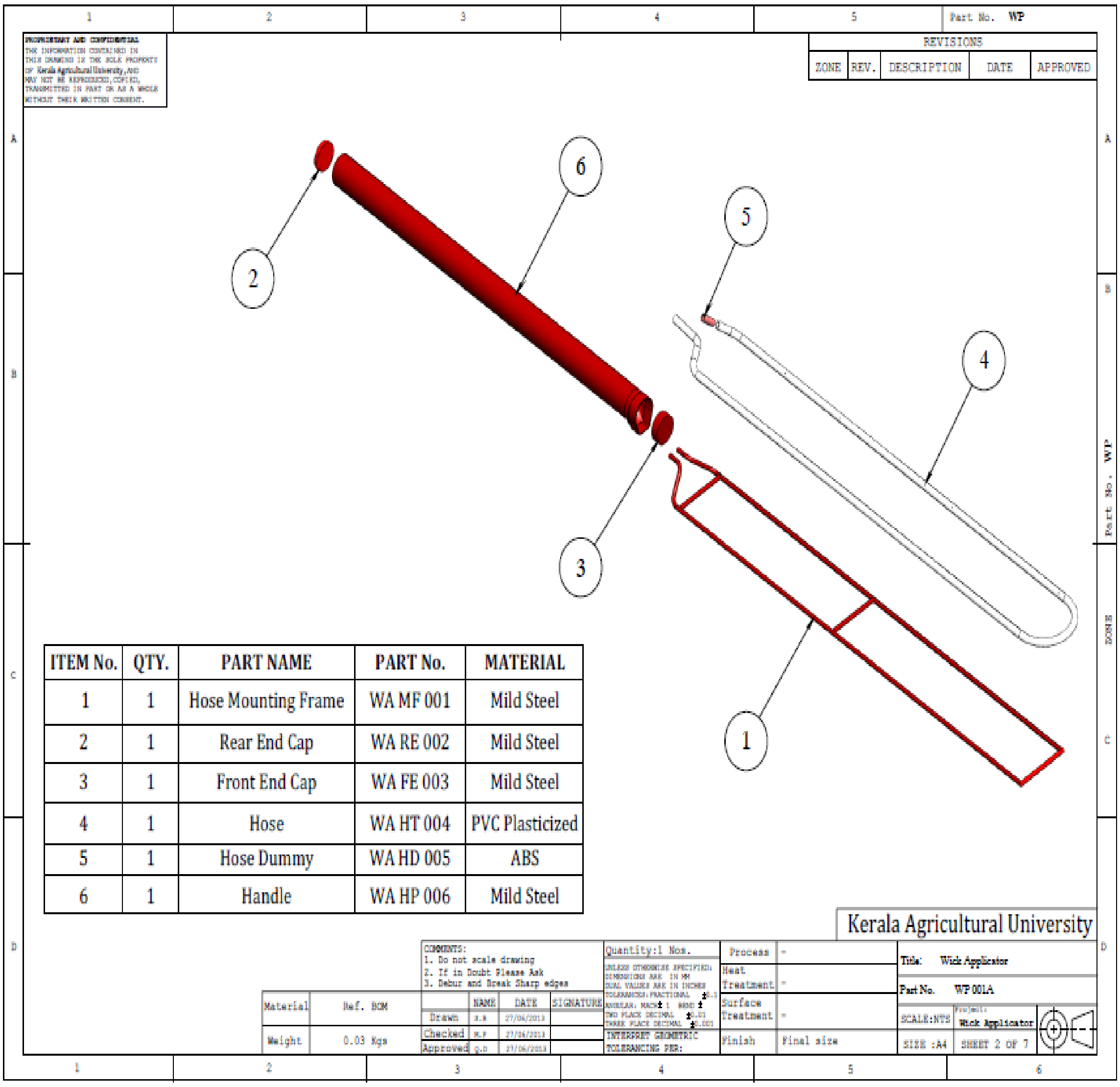


Fig.9. Prototype of hand held wiper device for management of weedy rice by DCA



ITEM No.	QTY.	PART NAME	PART No.	MATERIAL
1	1	Hose Mounting Frame	WA MF 001	Mild Steel
2	1	Rear End Cap	WA RE 002	Mild Steel
3	1	Front End Cap	WA FE 003	Mild Steel
4	1	Hose	WA HT 004	PVC Plasticized
5	1	Hose Dummy	WA HD 005	ABS
6	1	Handle	WA HP 006	Mild Steel

Fig.10. Illustration of hand held wiper device for management of weedy rice by DCA

Table 25. Effect of DCA on the post emergent management of weedy rice (Location 1- Kole)

Sl. No.	Herbicide, formulation in %		Panicles, No. m^{-2}		Panicles dried, %
			Before sweeping	Not dried	
1	Paraquat dichloride 24 SC	10	42	*4 (11) [cd]	74 [bc]
2	Paraquat dichloride 24 SC	15	41	3 (7) [de]	83 [ab]
3	Glyphosate 41 SL	10	43	3 (6) [de]	85 [ab]
4	Glyphosate 41 SL	15	41	2 (5) [e]	88 [a]
5	Glufosinate ammonium 15 SL	5	40	5 (22) [b]	45 [d]
6	Glufosinate ammonium 15 SL	10	43	4 (13) [c]	69 [c]
7	Glufosinate ammonium 15 SL	15	43	3 (7) [de]	85 [ab]
8	Control	-	44	7 (44) [a]	0 [e]
CD (P=0.05)			NS	1.7 (5)	12.7

*Square root transformed value

Figures in the parenthesis are original values and those followed by the same alphabets in a column do not vary significantly in DMRT

Table 26. Effect of DCA on the post emergent management of weedy rice (Location 2- Kuttanad)

Sl. No.	Herbicide, formulation in %		Panicles, No. m^{-2}		Panicles dried, %
			Before sweeping	Not dried	
1	Paraquat dichloride 24 SC	10	41	*4 (15) bc	63 bc
2	Paraquat dichloride 24 SC	15	44	3 (7) c	78 ab
3	Glyphosate 41 SL	10	44	4 (13) bc	71 ab
4	Glyphosate 41 SL	15	45	4 (12) bc	73 ab
5	Glufosinate ammonium 15 SL	5	39	4 (19) b	52 c
6	Glufosinate ammonium 15 SL	10	43	4 (15) bc	67 bc
7	Glufosinate ammonium 15 SL	15	44	3 (9) c	80 a
8	Control	-	42	7 (42) a	0 d
	CD (P=0.05)		NS	1.3 (8.4)	16.0

*Square root transformed value. Figures in the parenthesis are original values and those followed by the same alphabets in a column do not vary significantly in DMRT dough stage or sterile. The ear heads which dried on application of the herbicide subsequently fell off from the plant within 10-15 days. Depending on the nature of the herbicide, there can be re-growth from the base of the plant. It was observed that the newly emerged sprouts on using contact herbicides (glufosinate ammonium and paraquat dichloride) were slow in growth and did not put up ear heads before the crop season finished. While using glyphosate, it was noticed that the entire weedy rice plant dried by the action of the herbicide (Plate 18).

The above experiments show that weedy rice ear heads can be selectively dried without affecting rice plants by direct contact application of glufosinate ammonium at15 per cent, paraquat dichloride at15 per cent or glyphosate at10-15 per cent concentration, if there is a height difference between rice and weedy rice, due to the difference in flowering.

4.4. Participatory technology demonstration (PTD)

The technologies which were found promising for the management of weedy rice were tested in farmers' field appropriately modifying to suit the local conditions with the active participation of the farmers. The details of the trials are given below.

4.4.1. Management of weedy rice by stale seed bed technique

A. Location -1

Name of farmer	Sri. Krishnan Namboothiri
Location	Kuruvapadam, Nedumudy Panchayath
Phone No.	9495269363
Year and season	*Kharif 20*12 (June - October)
Area	One hectare
Variety used	Uma (MO 16)
Time of sowing	15th June, 2012
Technology adopted	The straw left after the harvest of the *Punja* crop of 2011-12 was burnt and single stale seed bed operations were undertaken by

	allowing germination from soil seed bank for 12 days followed by glyphosate application @ 0.8 kg ha^{-1} and flooded after five days till sowing (Plate 20).
Infestation of weedy rice before PTD	8-10 weedy rice plants per square metre
Infestation of weedy rice after PTD	2-3 weedy rice plants per square metre
Crop yield in the control plot	2200 kg ha^{-1}
Crop yield in the treatment plot	5750 kg ha^{-1}

B. Location -2

Name of farmer	Sri. Joseph Antony
Location	Pazhupadam, Kainakari Panchayath
Phone No.	0477 2724888
Year and season	*Kharif* 2012 (June - October)
Area	One hectare
Variety used	Uma (MO 16)
Time of sowing	20^{th} June, 2012
Technology adopted	After the harvest of *Punja* crop of 2011-12, the land was moistened for germination from soil seed bank for 15 days. The land was reflooded for wet ploughing to exhaust the soil seed bank. The field was drained to germinate the second flush of weeds for 10 days. Broad-spectrum herbicide glyphosate was applied @ 0.8 kg ha^{-1} and land was

A. Germination from soil seed bank during SSB preparation

B. Wet ploughed field drained for germination

Plate 20. PTD on Stale Seed Bed Technology (SSB)
Location 1, 2 and 3

	flooded after five days (Plate 20).
Infestation of weedy rice before PTD	10-12 weedy rice plants per square metre
Infestation of weedy rice after PTD	2-3 weedy rice plants per square metre
Crop yield in the control plot	2800 kg ha^{-1}
Crop yield in the treatment plot	6750 kg ha^{-1}

C. Location- 3

Name of farmer	Smt. Pushpy Joseph
Location	Manimalakkadu Padasekahram, Champakulam
Phone No.	9447409993
Year and season	*Kharif* 2012 (June - October)
Area	Two hectare
Variety used	Uma (MO 16)
Time of sowing	10^{th} June, 2012
Technology adopted	The straw left after the harvest of the *Punja* crop of 2011-12, was burnt and field was moistened for germination for 15 days to exhaust the soil seed bank. The germination was destroyed by shallow dry ploughing followed by wet ploughing for allowing germination from soil and creating a puddled condition. The land was levelled during these operations for better water management in the succeeding crop. The field was drained to germinate the seeds on the soil surface for 10

	days. Broad-spectrum herbicide glyphosate was applied @ 0.8 kg ha^{-1} to destroy the germination and land was flooded after five days. Before flooding the field, lime application was done @ 300 kg ha^{-1} to prevent build up of soil acidity in the crop season (Plate 20).
Infestation of weedy rice before PTD	6-8 weedy rice plants per square metre
Infestation of weedy rice after PTD	1-2 weedy rice plants per 40 square metre
Crop yield in the control plot	3000 kg ha^{-1}
Crop yield in the treatment plot	7200 kg ha^{-1}

D. Location- 4

Name of farmer	Sri. Pankajakshan K.
Location	Secretary, Ezhukadum Padasekahram, Champakulam
Phone No.	8547175813
Year and season	*Kharif* 2013 (June - October)
Area	60 hectare
Variety used	Uma (MO 16)
Time of sowing	10th June, 2013
Technology adopted	After the harvest of the *Kharif* crop of 2012, the straw was burnt and moistened for germination for 15 days to exhaust the soil seed bank. The

	germination was destroyed by shallow dry ploughing followed by wet ploughing for allowing germination from soil and creating a puddled condition. The land was levelled during these operations for better water management in the succeeding crop. The field was drained to germinate the seeds on the soil surface for 10 days. Broad-spectrum herbicide glyphosate was applied to destroy the germination and land was flooded after five days. Before flooding the field, lime application was done @ 300 kg ha^{-1} to prevent build up of soil acidity. The crop was taken during *Kharif* 2013 (Plate 21).
Infestation of weedy rice before PTD	8-10 weedy rice plants per square metre
Infestation of weedy rice after PTD	1-2 weedy rice plants per 100 square metre
Crop yield in the control plot	2600 kg ha^{-1}
Crop yield in the treatment plot	7000 kg ha^{-1}

2. Management of weedy rice by pre-sowing surface application of herbicide

A. Location 1

Name of farmer	Sri. Joshi S
Location	Koolippurakkal, Nedumudy, Alapuzha
Phone No.	9497633637
Year and season	*Punja* 2013-14 (November - March)
Area	One hectare

A. Dry ploughing during SSB preparation

B. Collection of soil for soil seed bank assessment

Plate 21. PTD on Stale Seed Bed Technology(SSB)

Location 4

Variety used	Uma (MO 16)
Time of sowing	20th November, 2013
Technology adopted	There is a local practice to exhaust the soil seed bank of all weed seeds by allowing the germination for 5-7 days followed by flooding to destroy the germinated weed seedlings. After draining the field, pre emergence herbicide oxyfluorfen was applied @ 0.2 kg ha^{-1} on the field. Pre germinated seeds of the crop was sown on the third day of application of herbicide. It was observed that the crop was free of all the weeds till 15 DAS. Thereafter, germination of weedy rice seedlings was noticed, but with reduced intensity. The land which had stagnant water at the time of herbicide application had better control of weedy rice and other weeds compared to the field which was dry at the time of herbicide application (Plate 22).
Infestation of weedy rice before PTD	3-4 weedy rice plants per square metre
Infestation of weedy rice after PTD	0.2 weedy rice seedlings per square metre
Crop yield in the control plot	3400 kg ha^{-1}
Crop yield in the treatment plot	6200 kg ha^{-1}

A. Herbicide application in standing water and field at three days after treatment

B. Weedy rice free crop at 14 DAS and 40 DAS

Plate 22. PTD on pre sowing application of herbicide Location 1, 2 and 3

B. Location -2

Name of farmer	Sri. P. J. Thomas
Location	Chempumpuram, Champakulam
Phone No.	9446921353
Year and season	*Kharif* 2013 (June - October)
Area	One hectare
Variety used	Uma (MO 16)
Time of sowing	30^{th} May, 2013
Technology adopted	The local practice of exhausting the soil seed bank of all weed seeds by allowing the germination for 5-7 days followed by flooding to destroy the germinated weed seedlings was done. After draining the field, pre emergence herbicide oxyfluorfen was applied @ 0.2 kg ha^{-1} on the field. Pre germinated seeds of the crop was sown on the third day of application of herbicide. It was observed that the crop was free of all the weeds till 12 DAS (Plate 22).
Infestation of weedy rice before PTD	10-12 weedy rice plants per square metre
Infestation of weedy rice after PTD	3-4 weedy rice plants per square metre
Crop yield in the control plot	2500 kg ha^{-1}
Crop yield in the treatment plot	5000 kg ha^{-1}

C. Location-3

Name of farmer	Sri. Chellappan
Location	Manimalkkadu, Champakulam
Phone No.	04772705554
Year and season	*Kharif* 2012 (June- October)
Area	One hectare
Variety used	Uma (MO 16)
Time of sowing	13th June, 2012
Technology adopted	After allowing the germination of soil seed bank of all weed seeds for 5-7 days, the field was flooded to destroy the germinated weed seedlings. After draining the field, pre emergence herbicide oxyfluorfen was applied @ 0.2 kg ha^{-1} on the field. Pre germinated seeds of the crop was sown on the third day of application of herbicide (Plate 22).
Infestation of weedy rice before PTD	5-7 weedy rice plants per square metre
Infestation of weedy rice after PTD	2 weedy rice plants per square metre
Crop yield in the control plot	2900 kg ha^{-1}
Crop yield in the treatment plot	5200 kg ha^{-1}

technology for preventing the addition of weedy rice seeds to the soil seed bank rather than cutting the panicles of weedy rice at 60 DAS. An area of one hectare each of severely weedy rice infested fields was identified for the demonstration in the fields of these three farmers. Results of the DCA are presented below. More farmers are hiring the newly developed device to adopt the technology due to labour shortage and high cost (Plate 23).

Sl. No.	Name and address of farmer	Earheads of weedy rice, No.m^{-2}		Control, %
		Before DCA	Dried on DCA	
1	Sri. Sajeev, Kainakary, Alapuzha	42	35	83
2	Sri. Joshi S, Koolippurakkal, Nedumudy, Alapuzha	30	23	76
3	Sri.Gopalakrishnan, Panachikkad, Kottayam	49	40	81
	Average control, %			80

4. Integrated management of weedy rice

The demonstration on the integrated management of weedy rice was taken up in larger area in 12 ha of Manimalakkadu Padasekahram of Champakulam Panchayath during the *Punja* 2013, as a part of the RKVY Project on Paddy Mission of Govt. of Kerala (which gave partial financial support for this study). The infestation of weedy rice in the area was to the tune of 10-12 weedy rice plants per square metre and crop was yielding less than 2300 kg ha^{-1}. Farmers of The entire padasekharam were willing to test our technology, as they found it uneconomic to raise the crop without proper managemet of weedy rice(plate 24)

The soil seed bank of weedy rice was destroyed by taking double staling operation with wet tillage in between to exhaust the soil seed bank followed by

A. Sweeping of wick applicator and dried panicles

B. Selective drying of weedy rice panicles on DCA

Plate 23. PTD on post emergent weedy rice management

Location 1, 2 and 3

A. Appraisal of PTD

B. Field at maturity

Plate 24. PTD on integrated weedy rice management

application of broad-spectrum herbicide and flooding. Before flooding the field for 10 days, lime application was done @ 300 kg ha^{-1} to prevent build up of soil acidity. On draining water, pre emergence herbicide oxyfluorfen was applied @ 0.2 kg ha^{-1} on the soil with two inches of standing water in the field. The field was left for facilitating evaporation/drainage of standing water. By the third day, the field was free of water and pre germinated seeds of the rice was sown in moist field.

The integrated management of weedy rice by double staling followed by the pre-sowing surface application of oxyfluorfen could give more than 95 per cent control of weedy rice and yielded 8000 kg ha^{-1}. Convinced of the success of the technology, more farmers in Kuttanad have started adopting of the integrated management of weedy rice.

The economics of the various weedy rice management strategies based on the PTD was also worked out (Table 27). Hand weeding resulted in B:C ratio of 2.5, whereas other methods resulted in B:C ratio 6-10. For hand weeding the cost is higher than the other methods because of the high requirement of labourers. In spite of this, only partial control of weedy rice could be achieved resulting in lesser yield than the stale seed bed methods. Though the yield in weedy rice control by pre sowing surface application of oxyfluorfen is not the highest, the cost of the operation is lower than the other treatments, resulting in the B:C ratio of 10. Because of the lesser time required for the field preparation (compared to stale seed bed techniques) and the lower cost involved, farmers have a preference for pre sowing surface application of oxyfluorfen.

_Table 27. Economics of the weedy rice management methods based on the PTD

Sl. No.	Technology demonstrated	Cost of cultivation excluding the weedy rice management method, Rs ha^{-1}	Cost for the weedy rice control method, Rs ha^{-1}	Total cost of cultivation, Rs ha^{-1}	Crop yield, t ha^{-1}	B:C ratio	B:C ratio of the weedy rice control method
1	Single stale seed bed followed by hand weeding	40,000	11,000	51,000	5750	2.0	6.2
2	Single stale seed bed with dry ploughing followed by hand weeding	40,000	14,750	54,750	6750	2.5	6.0
3	Single stale seed bed with dry ploughing followed by wet ploughing	40,000	12,750	52,750	7200	2.8	7.6
4	Pre sowing surface application of oxyfluorfen @ 0.2 kg ha^{-1}	40,000	5,000	45,000	5000	2.1	10.0
5	Hand weeding at 30 and 45 DAS	40,000	30,000	70,000	6000	1.6	2.5
6	Unweeded control	40,000	0	40,000	2200	1.0	-

5. DISCUSSION

5. 1. Part 1- Survey on weedy rice infestation in major rice growing tracts of Kerala

5.1.1. Extent of infestation of weedy rice in the major rice tracts of Kerala

It was revealed from the survey that infestation of weedy rice is alarmingly increasing in all the rice growing tracts. Out of the total area surveyed in the three major rice growing tracts, 72 per cent area had low to severe infestation. The extent of low, moderate and high infestation in the area was 31, 23 and 18 per cent, respectively. In Kole lands, 25 per cent of the area had severe infestation and 36 per cent each with moderate and low infestation (Fig. 11). In Kuttanad, the infestation was low in 38 per cent area, 17 and 25 per cent area was rated as, medium and severe, respectively (Fig. 12). In Palakkad district, only five per cent area had severe infestation. Low infestation was noticed in an area of 20 per cent and medium in 18 per cent area(Fig. 13).

Only 25 per cent of the area in Kole and Kuttanad had severe infestation, while three and 20 per cent area in Kole and Kuttanad was free of infestation. Hence, urgent action is required to control the spread to these areas. Otherwise rice farming will be impossible and farmers will be forced to leave the field fallow. In Palakkad, 50 per cent of the area is free of infestation and spread to these areas has to be prevented by adopting strict quarantine measures, use of good quality seeds and strict rouging in cropped field.

The results of the survey revealed that in all the rice growing areas the intensity of infestation varied depending on the cropping intensity, management practices, labour availability, etc. In all the double cropped areas where the farmer does not get ample time for proper land preparation and other intercultural operations, the infestation was moderate to severe.

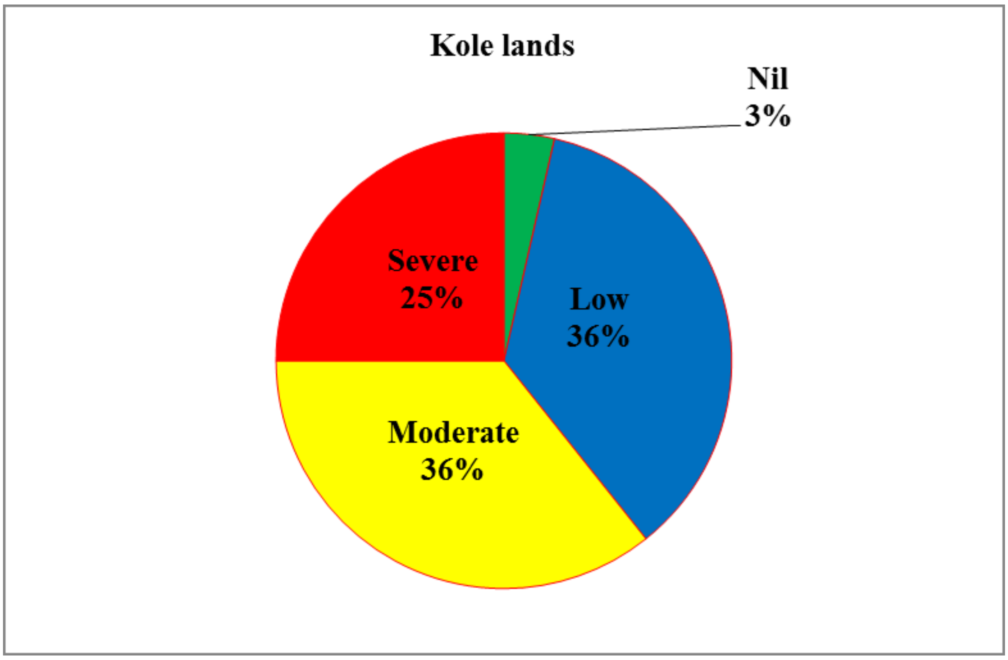


Fig. 11. Extent of infestation of weedy rice in Kole lands

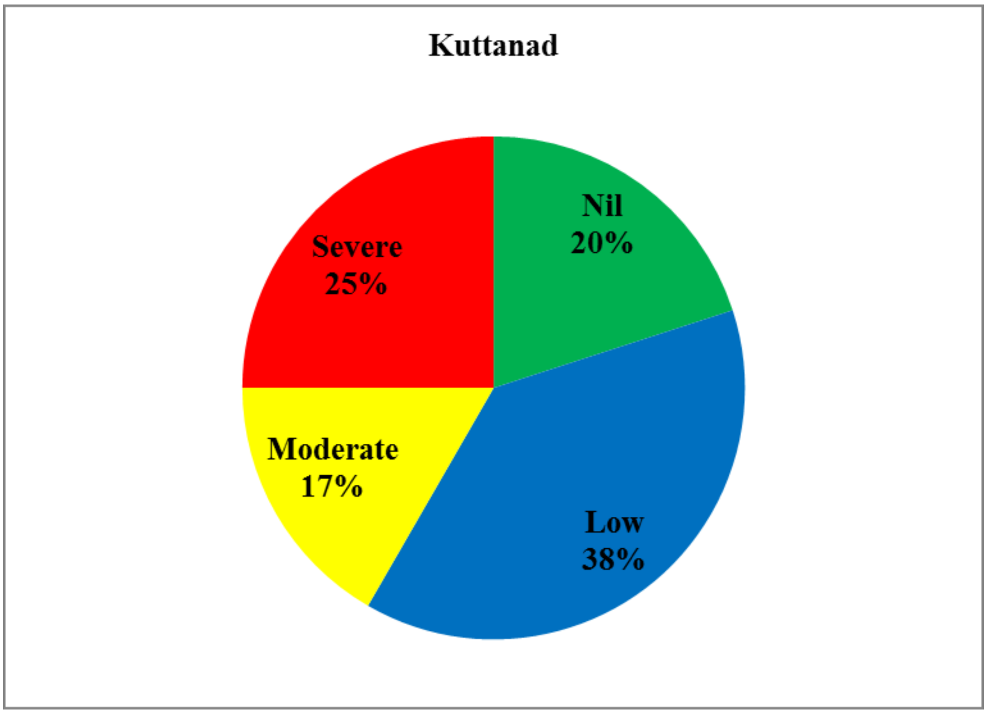


Fig. 12. Extent of infestation of weedy rice in Kuttanad

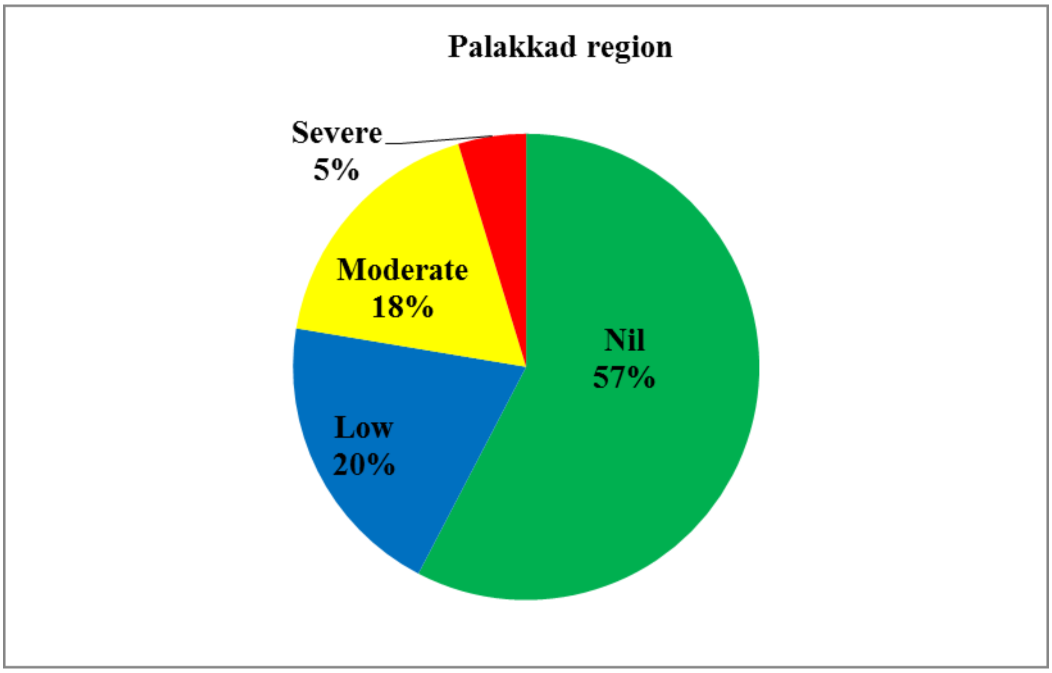


Fig. 13. Extent of infestation of weedy rice in Palakkad region

Lack of awareness of farmers on biology of weedy rice and its scientific management adds to the spread and distribution. In areas where transplanting was adopted, infestation of weedy rice was not seen. This situation exists in Malappuram Kole and second crop season of Palakkad and Kole areas. Acute labour shortage and high cost of production keep the farmers away from the transplanting. Use of transplanting machines is getting popular in Kole and some pockets of Kuttanad, where sinking of the machine, lack of adoption in large areas due to high initial investment and access of the area are still obstacles in adoption of the technology. Adoption of stale seed bed technique in severely infested areas and repeated tillage to exhaust the soil seed bank are measures that can be adopted as management strategy.

As heavy infestation of weedy rice reduces crop yield substantially to the tune of 50 -70 per cent, adoption of scientific management strategies have to be encouraged on Padasekharam basis by providing financial assistance to farmers.

5.1.2. Traditional knowledge of farmers on weedy rice biology and management

Majority of the farmers were aware of the problems of weedy rice and biological characters which make it highly competitive in cultivated rice fields. Early flowering and seed shattering character of weedy rice help to shed seeds before the harvest, thereby enabling build-up of soil seed bank. As weedy rice mimics cultivated rice, hand weeding is difficult and incomplete (in addition to the prohibitively high labour charges). There is difference in opinion among the farmers whether weedy rice is taller than rice, probably due to the existence of weedy rice morphotypes with varying heights, because of introgression with cultivated rice (Fig. 14). Many farmers felt that weedy rice has high longevity leading to recurrence of the problem in subsequent crops. On the whole, it was seen that farmers had high level of awareness on biological characters of weedy rice which make it highly competitive.

The survey revealed that farmers are rich in ITKs for managing weedy rice (Fig. 15). Transplanting is one option, almost 87 per cent of the farmers suggested for weedy rice management. However, because of high requirement of labourers, which is scarce and costly, farmers are not in apposition to adopt this. Popularisation of mechanised

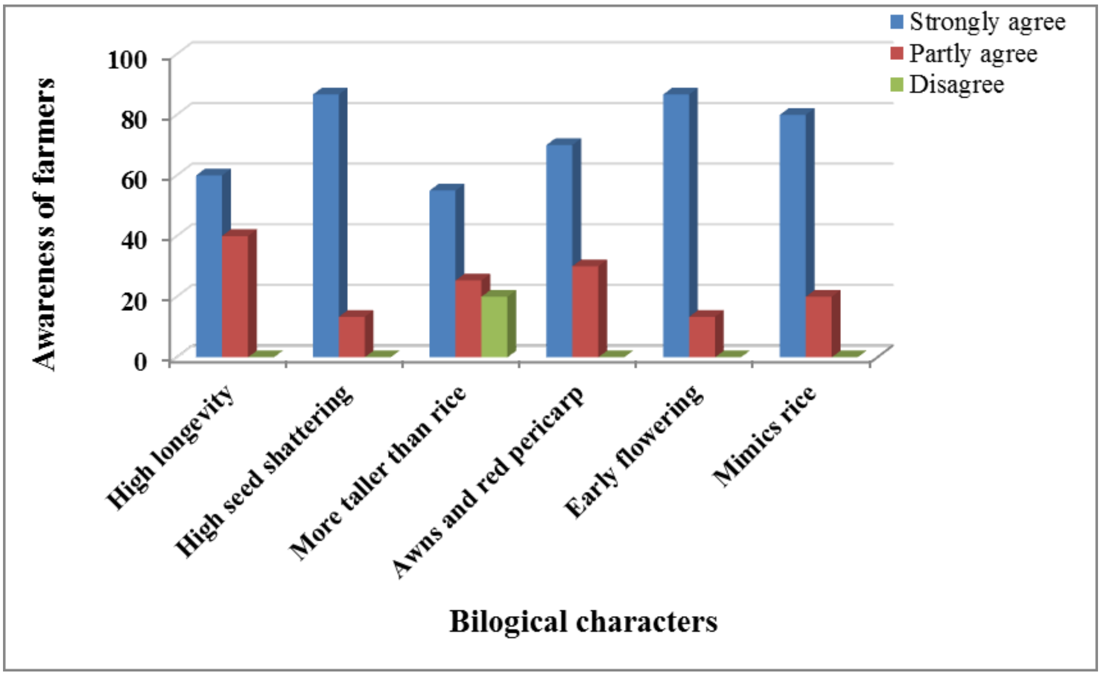


Fig. 14. Perception of the farmers on the biological characters of weedy rice

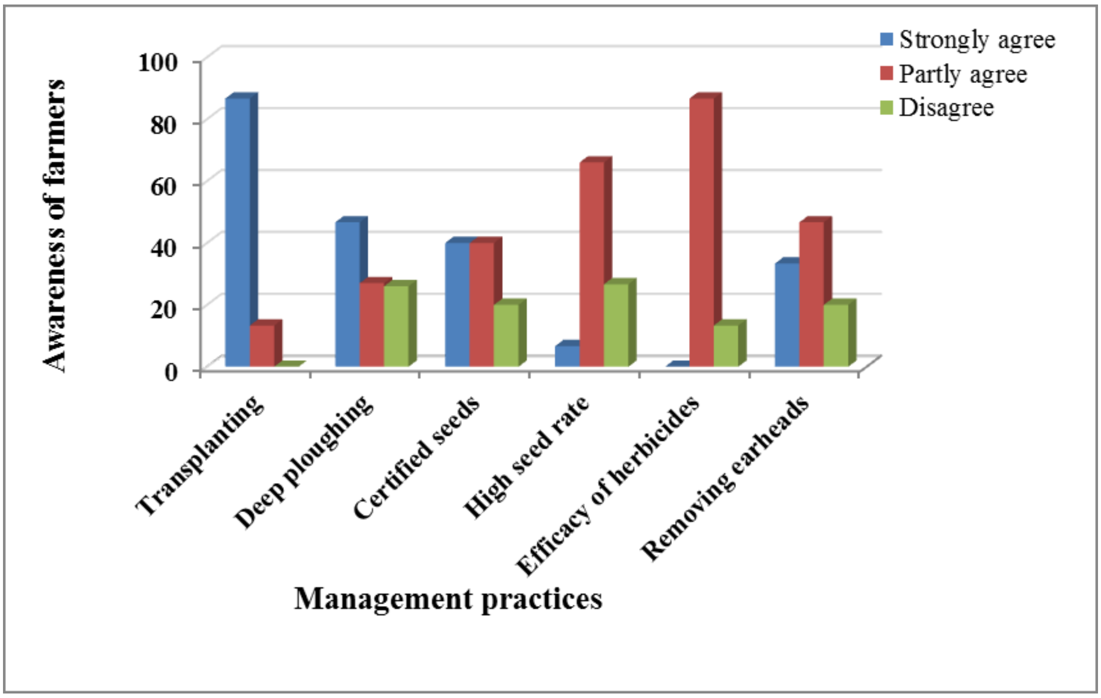


Fig. 15. Perception of farmers on the technologies for management of weedy rice

transplanting may be an alternative. Farmers are not definitely aware of the use of any herbicides for controlling weedy rice. The fact that majority of them have opted for may be true' for the statement on 'Herbicides are effective' for weedy rice control, indicates that they have some expectation that scientists would bring out a solution for the chemical control of weedy rice. A few farmers showed confidence in removing the ear heads as a method for managing weedy rice, may be because of the difficulty in successfully removing all the earheads, due to non-synchronous emergence and high requirement of labourers. However, 33 per cent of farmers believed that removing the earheads will reduce weedy rice infestation in the next crop. This indicates that selective drying of earheads by the application of herbicides can be a successful technology which farmers would be ready to adopt.

There was no unanimity in the opinion on the use of certified seed as a method to reduce weedy rice infestation. This may be because weedy rice has already infested the fields, and even if they use certified seed, the problem will recur due to the emergence from soil seed bank. Moreover, it is difficult to get seeds free of weedy rice as infestation has spread to most areas in the state.

5.2. Part 11-Biology and ecology of weedy rice

5.2.1. Morphomertic studies of vegetative and reproductive descriptors of weedy rice morphotypes

The analysis of morphometric characters of the morphotypes revealed the competitive nature of weedy rice over cultivated rice in terms of vegetative characters. Variation between morphotypes also indicates the high possibility of natural hybridisation of weedy rice with the cultivated rice. Chang *et al.* (1982) and Khush (1997) have observed high rate of natural crossing between *O. rufipogon* and *O. sativa*, resulting in numerous intergradations between the two species. In the present study, it was also noticed that the morphotypes did not vary significantly in the number of filled grains per panicle, and length or width of grains. Hence, it can be assumed that the relative advantage of weedy rice plants in vegetative growth compared to the rice plants is not expressed in the reproductive capacity.

Significant difference observed between weedy rice plants in terms of height, number of tillers and length of leaves, reveal the variation in competitive ability of weedy rice plants during the vegetative phase. Hence, depending on the intensity of infestation and vegetative growth of weedy rice, there can be variation in the yield of crop. Estorninos *et al.* (2002) reported that growth of weedy rice varies among different variants and differential growth of weedy rice can affect the growth and yield of cultivated rice differently.

Comparison of the morphometric characters of weedy rice with that of rice (popular cultivar 'Uma'- MO 16) revealed that weedy rice has more height, number of tillers and leaves, and length of internodes and leaves (Table 12 and 13). Number of grains per panicle in rice was much higher than that in weedy rice. High per cent of chaffing (to the tune of 50 per cent or more) was observed in weedy rice. These features, along with the increased number of stomata in weedy rice than rice on the adaxial and abaxial surface, and deposition of silica and wax on the leaf surface (revealed from SEM studies) render weedy rice highly efficient in photosynthesis, though not expressed in the yield.

5.2.2. Morphological characterisation of weedy rice using scanning electron microscope

The SEM studies revealed that mature weedy rice seeds had more overlapping of lemma and palea compared to immature ones. This reveals the tightness of packing of glumes which delays germination of mature weedy rice seeds compared to immature seeds. Higher angular distance noticed in immature weedy rice seeds compared to mature seeds also confirms the tightness of packing of lemma and palea in mature seeds. These results are in conformity with the results of laboratory studies on germination of fully matured and half matured seeds. The weedy rice seed surface has parallel rows of trichomes which can help in dispersal of seeds by sticking on to clothes, straw, chaff etc., give better grip for seeds preventing wash out during heavy rains.

The leaves of weedy rice has more micro hairs and epicuticular wax on the surface (Plate) which can reduce transpiration, reflect away excessive heat and enhance water use efficiency. More stomata are seen on the adaxial surface compared to the abaxial surface. These features can also enhance the competitive efficiency of weedy rice plants compared to the cultivated rice.

SEM studies conducted by Hamid *et al*. (2007) have also revealed the topographical and morphological peculiarities of weedy rice grains and leaves which enhanced the competitive ability of weedy rice.

5.2.3. Methods of propagation

The main mode of propagation in weedy rice is through seeds. They are highly efficient in regeneration of growth even from almost dried and rotted nodal cuttings, root clumps and plant stumps. The weedy characters of weedy rice like staggered germination, non-synchronous flowering, seed shattering and variable seed dormancy also aid in spread and distribution to new locations.

5.2.4. Admixture of weedy rice in paddy harvested by machines

The purity analysis of paddy samples collected from various weedy rice infested areas recorded very high number of weedy rice seeds getting mixed with the paddy harvested using machines. Even the presence of a single weedy rice seed in seed lot would contaminate entire stock. The carry-over of weedy rice seeds along with harvested paddy occurs due to the presence of weedy rice seeds which still remain on the panicles of weedy rice, due to the staggered germination and non-synchronous flowering in weedy rice. Being a highly noxious, objectionable weed in rice fields, the spread of the weed to newer locations should be prevented by the use of certified seeds, and cleaning machinery and implements after the harvest of infested fields.

5.2.5. Influence of dormancy breaking treatments on the germination of weedy rice

The higher efficiency of germination of half matured weedy rice seeds than fully matured ones, revealed the less tightness of packing of lemma and palea. Tang and Morishima (1997) have also reported that there was variation in seed dormancy in weedy rice. Studies conducted by Gu *et al*. (2003), observed that seed dormancy at zero days after harvest was dominant, and that dominance for duration of seed dormancy was incomplete when judged by days to 50 per cent germination. Rao (1994) has emphasized the influence of environmental factors during seed development and storage on germination of weedy rice. It was also observed that scraping of the hull could induce germination compared to the intact seeds of weedy rice. Seshu and Sorrells (1986) have suggested hull scraping using razor blade for quick germination of weedy rice seeds.

The results revealed that all the dormancy breaking treatments had influenced germination of weedy rice seeds as evidenced by variation in the germination per cent as well as the length of root and shoot of the seedlings. Germination in T 3 was the least and was significantly lower than the control, probably due to the damage of seeds on exposure to high temperature of 40ºC for six hours (Fig. 16). The highest germination and subsequent growth of seedlings, in terms of root and shoot length (Fig. 17 & 18), was seen in seeds treated with nitric acid and low temperature. Cohn *et al*. (1983) and Bose *et al*. (2010) have reported that pre-soaking in various salts of 15 mM nitrate for 72 hours could break dormancy of dehulled red rice and low pH conditions were required for maximum response. In highly dormant seeds, uptake was restricted by the hull.

Above 90 per cent germination on the 12^{th} day of soaking in treatments T 2 and T4 (exposure to low temperature and EC 5 dSm^{-1}) revealed the efficiency of low temperature and salt water treatment in stimulating the germination of weedy rice seeds. The results revealed that eventhough both low and high salt concentrations of 5 dSm^{-1} and 15 dSm^{-1} could increase weedy rice seed germination and initial growth, further growth was inhibited by high salt concentration. This clearly shows that intrusion of saline water of low concentrations in paddy fields can help in the germination of weedy rice. If the germinated seedlings can be destroyed before sowing rice, weedy rice problem can be reduced to a great extent. However, because of the short time available between the cropping seasons, many farmers are not in a position to adopt stale seed bed technology. On the other hand, in single cropped fields in Thakazhy and Thalavady panchayaths of Kuttanad, which gets saline water intrusion, farmers destroy the germinated weedy rice seedlings and get the succeeding rice crop with less infestation of weedy rice.

The influence of acidity and low temperature on germination and growth of seedlings was noticed in pre-soaking of weedy rice seeds in 0.6 per cent nitric acid and low temperature exposure of 20ºC for 48 hours (soaked seeds). It has been reported that dry storage of hulled and dehulled red rice at 20ºC to 30ºC for four weeks could break dormancy (Cohn and Hughes, 1981). This may be the reason for the high incidence of weedy rice in the P*unja* crop season of Kuttanad during November to March, when temperature is low and acidity problems are high. Footitt and Cohn (1992) have reported that embryo acidification in dormancy breaking treatments is linked to germination per cent.

The release of dormancy on removal of hull and rupture of pericarp, due to increased oxygen availability favouring pentose phosphate pathway for germination, has been reported by Ferrero (2010). Damages to hull on exposure of seeds to alternate wetting and drying as well as field operations during land preparation and harvesting may help the weedy rice seeds to overcome the dormancy and establish in the field, unless destroyed deliberately by herbicide application followed by flooding. In this study also, hull scraped weedy rice seeds had quick germination, but further growth was slow due to the exposure of endosperm for secondary contamination.

Germination of 75 per cent seeds obtained on the 12th day of soaking in control plots revealed that soaking of infested fields for 12 days can also facilitate germination of many weedy rice seeds. Hence, farmers can go for repeated germination of the soil seed bank to exhaust the seeds of weedy rice by alternate wetting and drying at 12 to 15 days interval. Chung and Paek (2003) have reported that twelve hour diurnal fluctuations of 20ºC and 10 ºC can induce seedling emergence in red rice than at constant temperature. They have reported the photoblastic nature of red rice and the ability to germinate by sensing light or diurnal variation in temperature on proximity to soil surface. According to Naredo *et al*. (1998), an appropriate combination of seed hull removal, dry heat and temperature regime particular for different species can result in breaking dormancy in red rice.

Soaking the seeds in salt water and scraping of hull gave 80 per cent germination even on the third day of soaking compared to 35 per cent germination in the control. It

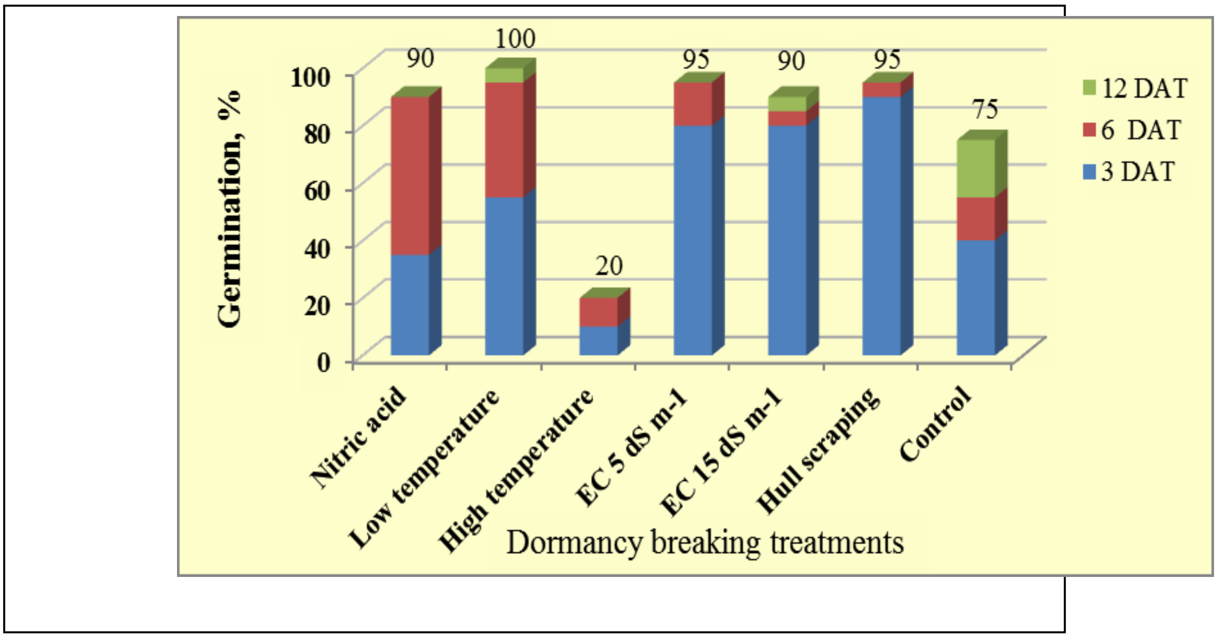


Fig. 16. Effect of dormancy breaking treatments on the germination of weedy rice seeds

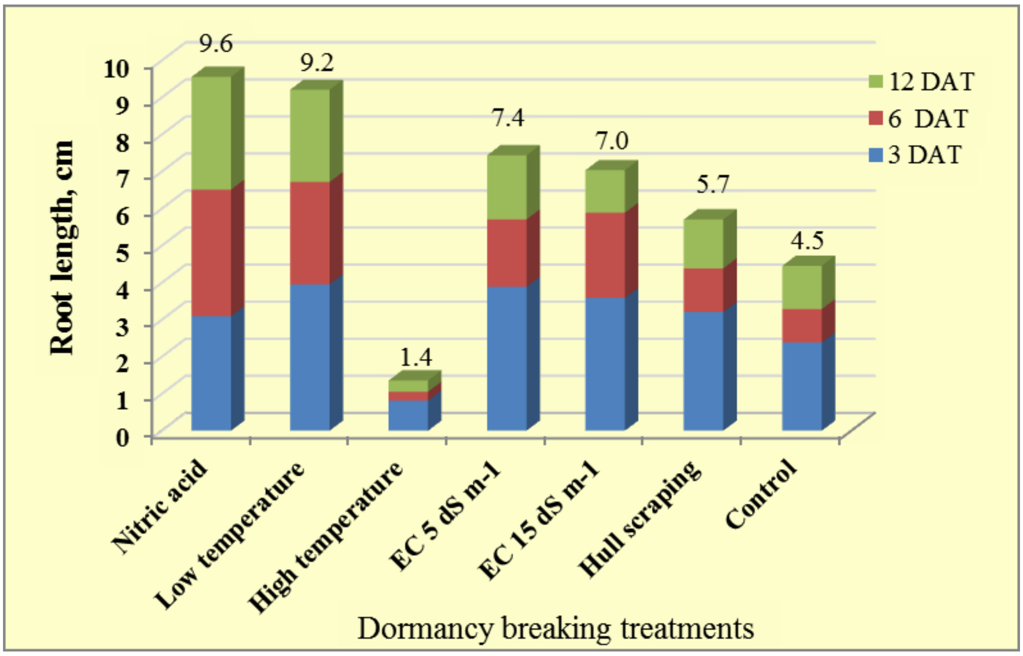


Fig. 17. Effect of dormancy breaking treatments on the root length of weedy rice seedlings

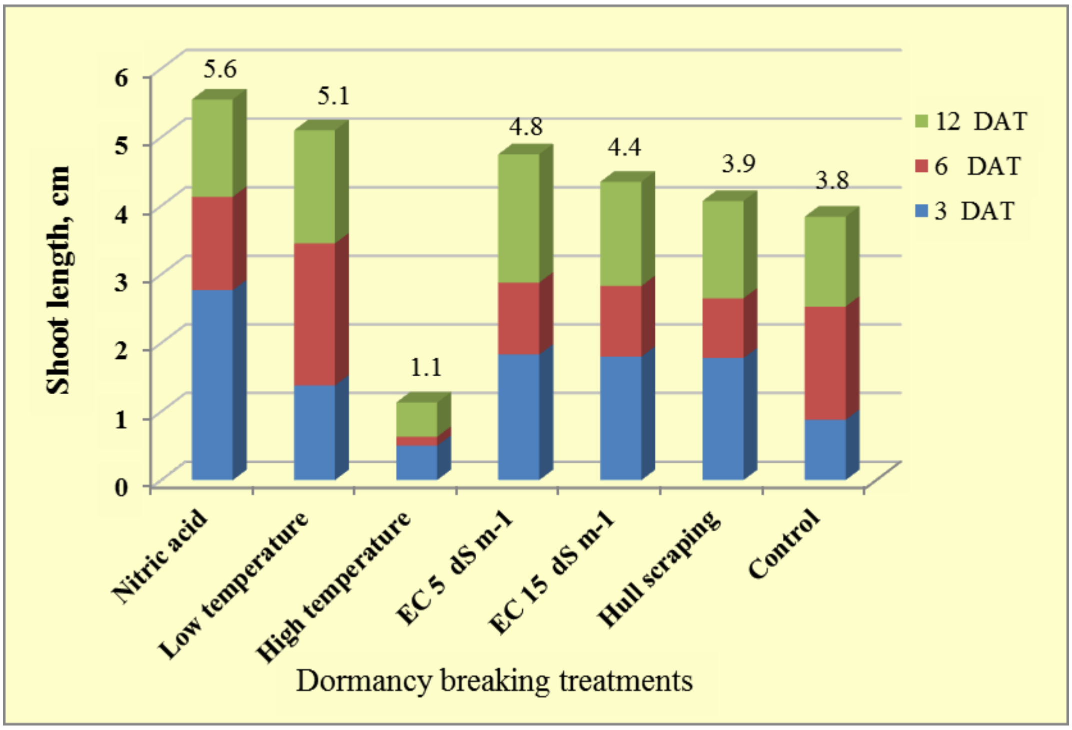


Fig. 18. Effect of dormancy breaking treatments on the shoot length of weedy rice seedlings

was noticed that there was subsequent increase in germination even up to 80 percent in all pre-soaking treatments on the sixth day (which later attained 95 percent in all treated seeds by 12th day), while in control it reached only 50 percent by sixth day. Further germination in the control plot to 75 per cent by 12th day of soaking revealed the inherent capacity of majority weedy rice seeds on the surface of soil to germinate by 12- 15 days under moist condition. These observations support the nature of staggered germination of weedy rice in cultivated fields.

5.2.6. Effect of depth of seed burial and presence of rice seeds on germination of weedy rice

The results of the study proved that there was lesser germination of weedy rice seeds from the deeper layers of 4-8 cm depth of soil (Fig. 19) than from the surface and two centimetre depth. This also indicates that if seeds are remaining on the surface, there is more likelihood of their germination, facilitating for an efficient stale seed bed technique. On the contrary, if ploughing is given after the harvest, it is likely to take the seeds to the deeper layers where they remain viable for longer period. Ferrero and Finassi (1995) also reported the influence of depth of seed burial on the delayed emergence of weedy rice. Seed burial studies conducted at Srilanka have shown that germination of seeds buried 20 cm deep reached maximum of 68 per cent four weeks after burial and decreased to 33 per cent at 80 weeks after burial on germinating under laboratory conditions (Abeysekara *et al*., 2010).

The quick and maximum germination obtained from weedy rice seeds (seeds were scraped to break hull induced dormancy) at surface and two centimetre depth of soil shows the chances of its heavy infestation in the next crop of rice. However, continuous flooding can prevent the germination as clearly understood from zero germination obtained in flooded pots. This is the reason for the lesser incidence of weedy rice in transplanted crop compared to the direct sown crop.

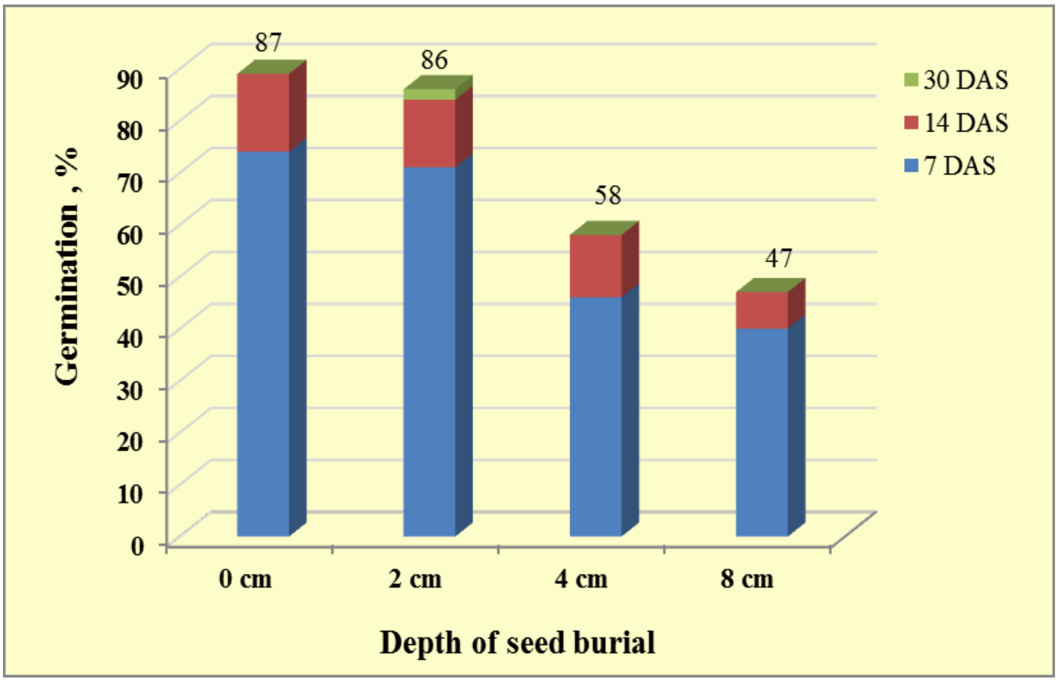


Fig. 19. Effect of depth of seed burial on the germination of weedy rice

It was also noticed that germination of scraped seeds from deeper layers reached its maximum during 7 to 14 days after soaking. Probably, staggered germination of weedy rice noticed in the infested cropped fields may be due to the ability of weedy rice seeds to germinate from deeper layers on alternate wetting and drying, as and when the dormancy is broken.

5.3. Part 111- Control methods

5.3.1. Physical methods

5.3.1.1. Management of weedy rice by stale seed bed technique (SSB)

Location -1* (*Kuruvapadam of Nedumudy Panchayath in Kuttanad)

Among the different treatments imposed in the first location, it was found that there was very effective reduction in the weedy rice population in T 5 (two staling operation with wet tillage in between followed by herbicide application and flooding) compared to control. This can be attributed to the exhaustion of soil seed bank on wet tillage in between two germinations. Wet tillage not only destroyed germinated seedlings but also brought the seeds buried in soil to top layers of soil along with the upward movement of water for quick germination.

The higher weedy rice population in T3 (single stale followed by herbicide application) compared to T5 (double stale with wet tillage in between followed by herbicide application) revealed that single staling can exhaust only a portion of soil seed bank. It was observed that T4 (one stale followed by shallow wet tillage) had significantly higher weedy rice population and weedy rice dry weight compared to T3 (one stale followed by herbicide application). Renu *et al*. (2000) also have reported the advantage of using herbicides instead of hoeing for destroying the germinated weed seedlings from seed bed, during stale seed bed preparation in rice.

The effectiveness of herbicide application at final germination of soil seed bank than flooding to destroy the germination was proved by the low weedy rice dry weight at 30 and 60 DAS in treatments T3 (13 g m^{-2} and 46 g m^{-2}) compared with T4 (35.5 g m^{-2} and 115.8 g m^{-2}). On germination of soil seed bank, the germinated seedlings are to be destroyed by herbicide application before flooding as weedy rice seedlings are not destroyed by flooding.

The weedy rice population in T1 (control) and T2 (hand weeding during previous season) were on par at 30 DAS revealing the huge quantity of seeds in the soil and their high longevity. Hence, in severely infested fields it is always better not to disturb the soil if stale seed bed operations cannot be taken up. It was reported by Fogliatto *et al*. (2011) that weedy rice seed burial delayed germination, while, seed placement on the dry soil surface enhanced it. They also stated that cycles of flooding and drying followed by spring tillage could improve weedy rice seed control.

The height of weedy rice plants in T3 (one stale followed by glyphosate application) and T5 (two stale followed by glyphosate application) were less compared to T1 and T2 was due to the delayed germination of weedy rice seeds from the deeper soil layers. The competition from these plants can be reduced by enhancing the competitive efficiency of the crop by increasing seedling vigour and tillering. There was significant reduction in the height of rice plants at 45 and 100 DAS depending on the severity of infestation. The treatment T5 had rice plants with height 55.8 cm and 108 cm at 45 and 100 DAS compared to the rice plants in T1 with 48.3 and 96.8 cm at 45 and 100 DAS, respectively. Similar was the trend in the productive tiller count in control plot (T1) and best treatment (T5), with 182 and 367 productive tillers per square metre. The advantage of initial weed free condition in providing better competitiveness for the crop to withstand and smother new flushes of weeds have been reported by Sindhu *et al*. (2011).

There was significant difference between treatments on the grain yield which proved that each treatment had its own influence in the management of weedy rice and consequent yield (Fig 20). As in other biometric observations, yield was superior in T5 closely followed by T3. The treatments T4, T2 and T1 had 51, 65 and 71 per cent reduction in yield compared to the best treatment T5. Similar was the trend noticed in straw yield also with yield reduction of 39, 51 and 61 per cent in T4, T2 and T1, respectively. The reduction in the straw yield in these treatments compared to grain yield was less due to the contribution of the straw of weedy rice to the dry weight.

Location - 2 (Manimalakkadu padam of Champakulam Panchayath in Kuttanad)

Based on the results of the experiment done in the first location, the second trial was undertaken with modification in the treatments. The treatment T4 was included to find out whether wet ploughing or dry ploughing is better than a combination of these two during the staling operation.

It was observed from the results of the experiment that wet ploughing is better than dry ploughing in controlling weedy rice. In wet tillage, the moist condition after the germination of soil seed bank can favour the establishment of germinated seedlings. However, better uplift of the weedy rice seeds from the deeper layers to the soil surface is possible by wet tillage. Moreover, puddling of the soil on wet tillage can reduce weed seed emergence from deeper layers during later stages of the crop season. Whenever the soil is disturbed by tillage, the germination from the inverted soil (SSB technique) is to done to prevent the early emergence of the seeds lying on the soil surface during the crop season.

Among the different treatments, wet ploughing alone in between stales (T4) and dry ploughing followed by wet ploughing in between stales (T5) had significantly low weedy rice population both at 30 and 60 DAS. The advantage of repeated rotovation in reducing weedy rice population has been reported by Cao *et al*. (2007). Weedy rice population in T2 and T3 were on par at 30 and 60 DAS. This suggests that if conditions are not favourable for exhaustive staling operation, single stale followed by herbicide application can give reasonably good weedy rice control and yield. But if inversion of the soil is done by tillage after first germination, it should be followed by a second germination from the inverted soil to destroy the seeds brought to the soil surface. Significantly higher weedy rice population in T3 than in T4 both at 30 and 60 DAS proved that among the tillage conditions, wet tillage is better than dry tillage in exhausting soil seed bank.

The dry weight of weedy rice was also significantly lower in T5 followed by T4 both at 30 and 60 DAS. The weedy rice biomass production in T5 and T4 was on par at 60 DAS. The parity of the treatments T5 and T4 in weedy rice dry weight at 60 DAS shows that these treatments are comparable in exhausting the soil seed bank of weedy rice. Significantly higher weedy rice dry weight in T3 than T2, T4 and T5 reveals the better exhaustion of soil seed bank on dry ploughing and chances for the emergence of weedy rice seeds from the deeper layers on inversion of the soil by dry ploughing. The seeds brought to the surface of the soil may have staggered germination due to variable dormancy of weedy rice seeds. Hence, whenever dry tillage is resorted to for exhaustion of soil seed bank, ample time (15 days or more) should be given for germination from the soil seed bank followed by herbicide application and flooding.

The treatment T4 had significantly low weedy rice population and weedy rice dry weight both at 30 and 60 DAS than T3 and T2. This proved that though wet tillage brought seeds from deeper layers of soil to the surface, the puddled condition due to wet tillage reduced the chances for early germination. Moreover, it gave competitive advantage to the crop. Studies conducted by Chauhan (2013 c) on the influence of variants of weedy rice on the yield of crop have shown that growth and yield of cultivated rice was affected differently by the variants. He observed that weedy rice reduced the yield by 30 and 47 per cent at densities of four and eight plants of weedy rice per pot of 25 cm height and diameter.

Depending on the intensity of infestation of weedy rice in various treatments, there was reduction in the crop plant height at 45 and 100 DAS. This confirms the competitive effect of weedy rice plants at vegetative and reproductive stage in terms of plant height, root spread, and nutrient and moisture uptake. Similar trend was also noticed in the count of productive tillers of rice.

Grain yield was significantly higher and on par in T4 (7468 kg ha^{-1}) and T5 (7800 kg ha^{-1}). Double staling with dry and wet tillage followed by application of herbicide (T5) and double staling with wet tillage alone followed by herbicide application (T4) had 77 and 76 per cent increased yield than the control (T1) (Fig. 21). On comparison of T2 (single stale) and T4 (double stale), it was observed that double staling gave 25 per cent more yield than single stale operation. Comparison of treatments having double staling operations, with dry tillage (T3) and wet tillage (T4), showed that there was 67 per cent increase in yield in double staling with wet tillage. Straw yield also showed significant difference among treatments with T5, T4, T2, T3 and T1 in decreasing trend.

Mansoor *et al*. (2012) stated the added advantage of repeated tillage to a depth of 10-15 cm ie., first tillage by 30 DBS as dry rotovation followed by second wet tillage at 15 DBS and third tillage one or two days before sowing, with herbicidal application in between tillage can reduce the weedy rice infestation to a great extent. Choice of the effective management strategy require sufficient knowledge on the soil seed bank, their age and vertical distribution in the soil profile.

5.3.1.2. Management of weedy rice by straw burning

The experiment revealed the efficiency of straw burning on the management of weedy rice. It was observed that in cropped fields which have the infestation of weedy rice during previous season seeds will be shattered on soil surface at the time of harvest of the crop. If left as such in the field after the harvest, they get ploughed in and add to the soil seed bank. This can be avoided by spreading and burning of straw after harvest so that the high temperature will either burn off the seeds or will help in breakage of hull, promoting germination. These burnt seeds on soil surface can be germinated by moistening the field and doing stale seed bed operations before the next crop. On germination, the seeds should be destroyed by using broad-spectrum herbicides before flooding.

It was observed from the results of the experiment that if burnt fields are tilled after burning of straw, there is every chance for bringing viable seeds from lower layers to the surface, resulting in nullifying the effect of straw burning (Fig. 22). Similar results were reported by Chauhan (2013 a) while using straw burning for the management of weedy rice.

It was also observed that there was no difference between treatments in straw burning with or without kerosene, indicating that the heat generated by burning of the straw itself is sufficient to kill weedy rice seeds on the soil surface. However, the practice of straw burning is not encouraged due to the pollution problems.

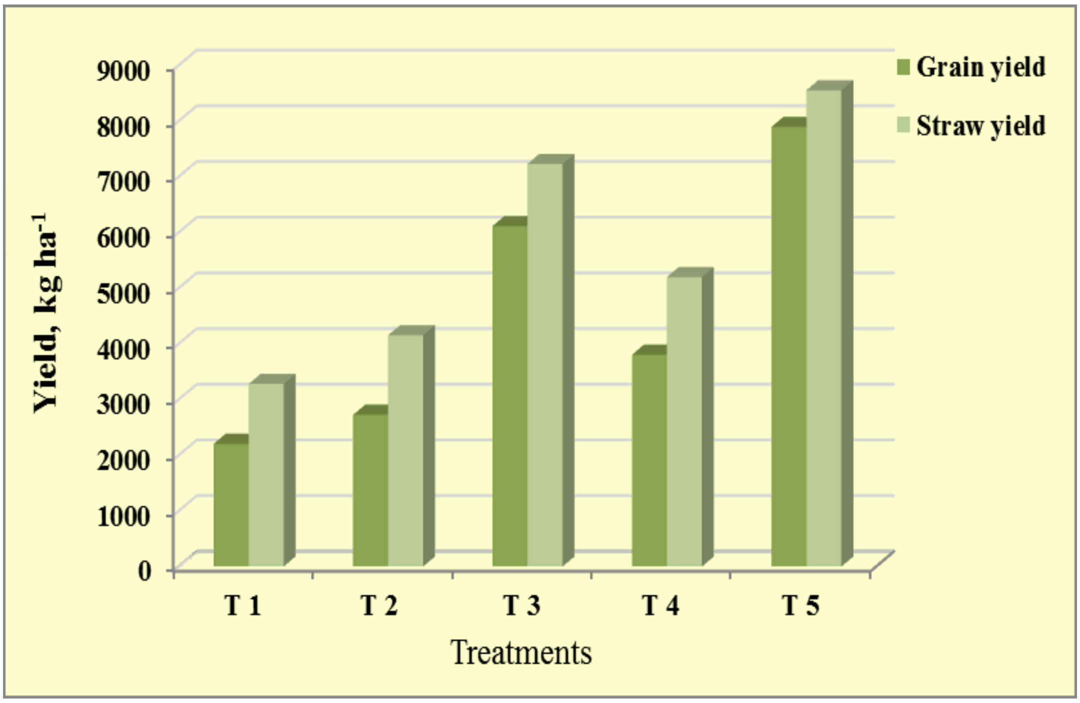


Fig. 20. Effect of stale seed bed techniques on yield of succeeding crop (Location-1)

T1- Control

T2- Hand weeded during previous season

T 3- Single stale f.b. glyphosate application

T 4- Single stale f.b. shallow wet tillage

T 5- First stale f.b. shallow wet tillage + second stale f.b. glyphosate application

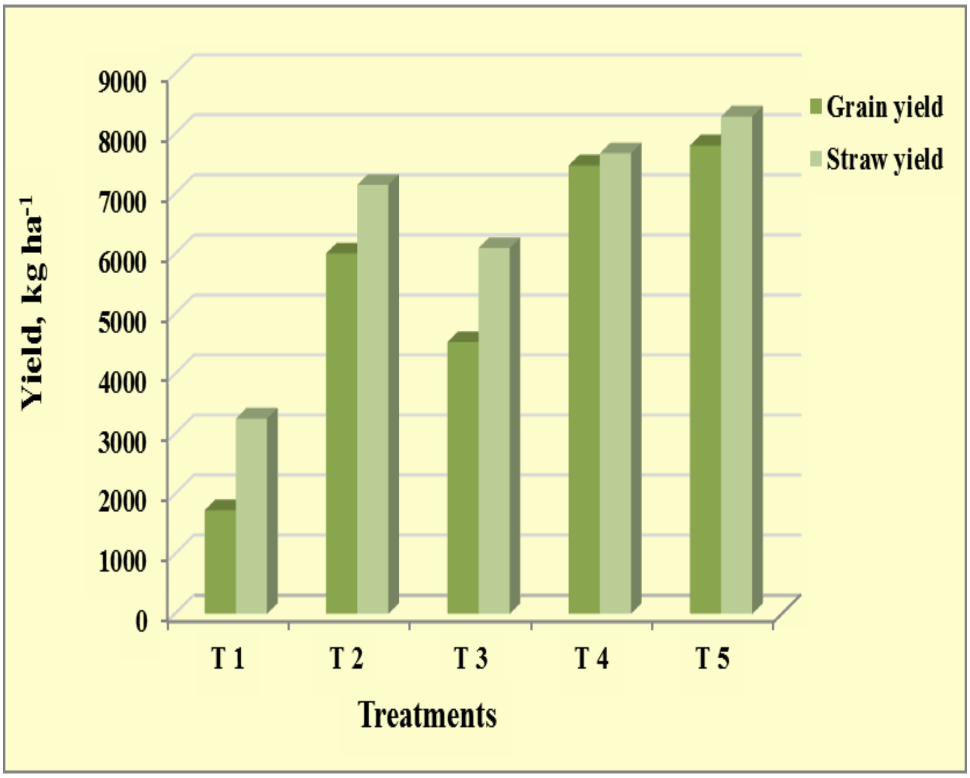


Fig.21. Effect of stale seed bed techniques on yield of succeeding crop (Location-2)

T 1. Control

T 2. First stale f. b. glyphosate application

T 3. First stale f. b. shallow dry tillage + second stale f.b. glyphosate application

T 4. First stale f.b. shallow wet tillage + second stale f.b. glyphosate application

T 5.First stale f.b. shallow dry and wet tillage + second stale f.b. glyphosate application

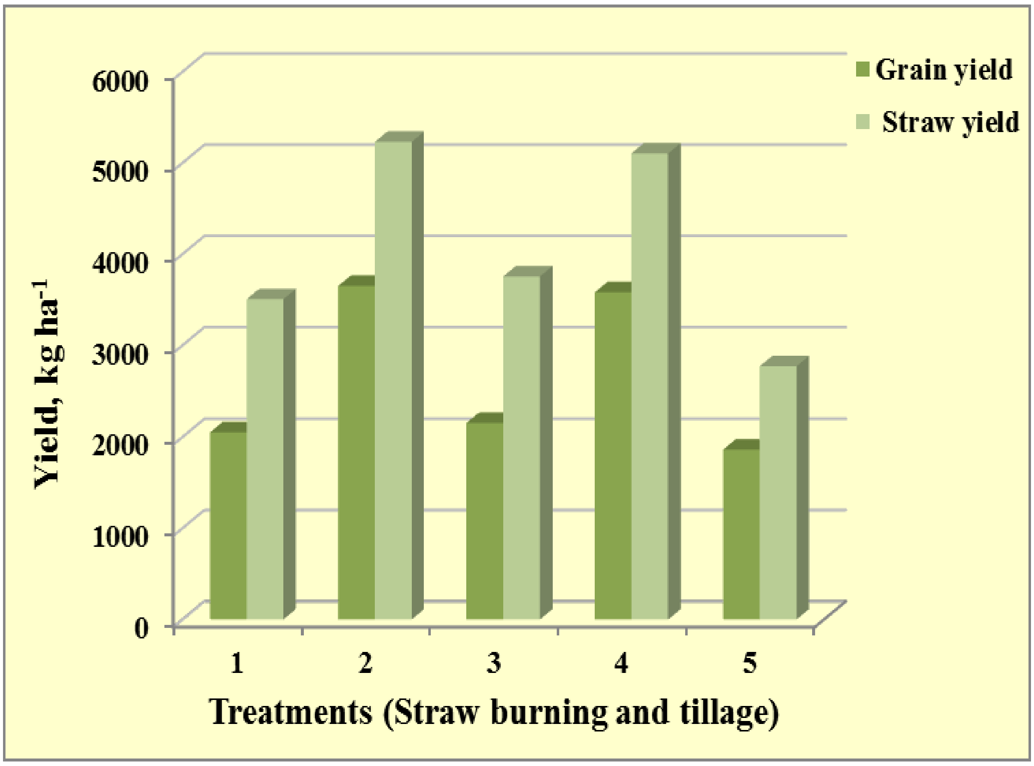


Fig.22. Effect of straw burning on the yield of succeeding crop

1. Burning straw f.b. tillage
2. Burning straw f.b. zero tillage
3. Burning straw + kerosene f.b. tillage
4. Burning straw + kerosene f.b. zero tillage
5. Control

5.3.1.3. Management of weedy rice by soil solarisation

It was observed that there was difference in temperature of the soil at different depths during solarisation. The mean maximum temperature at 3 cm depth of soil was 47.1^0C, while the mean minimum temperature was 33.3^0C. The mean maximum and mean minimum temperature at 5 cm depth of soil was 44.7^0C and 36.2^0C. At 10 cm depth of soil, the mean maximum and mean minimum temperature was 42.8^0C and 35.3^0C (Fig. 22 to 24). There was decrease in mean maximum soil temperature in all the solarisation treatments with increase in soil depth. The soil temperature at different soil depths was 10^0C to 12^0C higher in the solarized soil than non-solarized soil. As the number of days (duration) of solarisation increased (from treatment T1 to T5), the number of days to which the soil was subjected to high temperature increased.

The germination from soil solarized for 30, 35 and 40 days (T 3, T 4 and T 5) recorded lower values than in treatments T1 and T2 (solarized for 20 and 25 days). Therefore, if solarisation is adopted as a management strategy, it has to be done for minimum 30-35 days.

In all the treatments, soil temperature was low in the observation at 30 days after start of solarisation including the control. This was because of the rain received on the 27^{th} day of observation which soaked the soil. Figure 23 shows that at 3 cm depth of soil, temperature was 38^0C in the non-solarised soil while, the corresponding temperature in solarised soil was 50^0C. When the solarisation sheet was removed at 20, 25, 30 and 35 days after solarisation, soil temperature came down to a level very close to control. Thus, in solarisation treatment for 40 days (T 6), soil temperature remained at very high level for the entire period, the effect of which was reflected in the zero count of germinated seedlings. In the treatment T5 (solarisation for 35 days) also the same result was obtained, whereas, in T2, T3 and T4, where solarisation was for 20-30 days, only partial killing of the seeds occurred as indicated by the number of seedlings

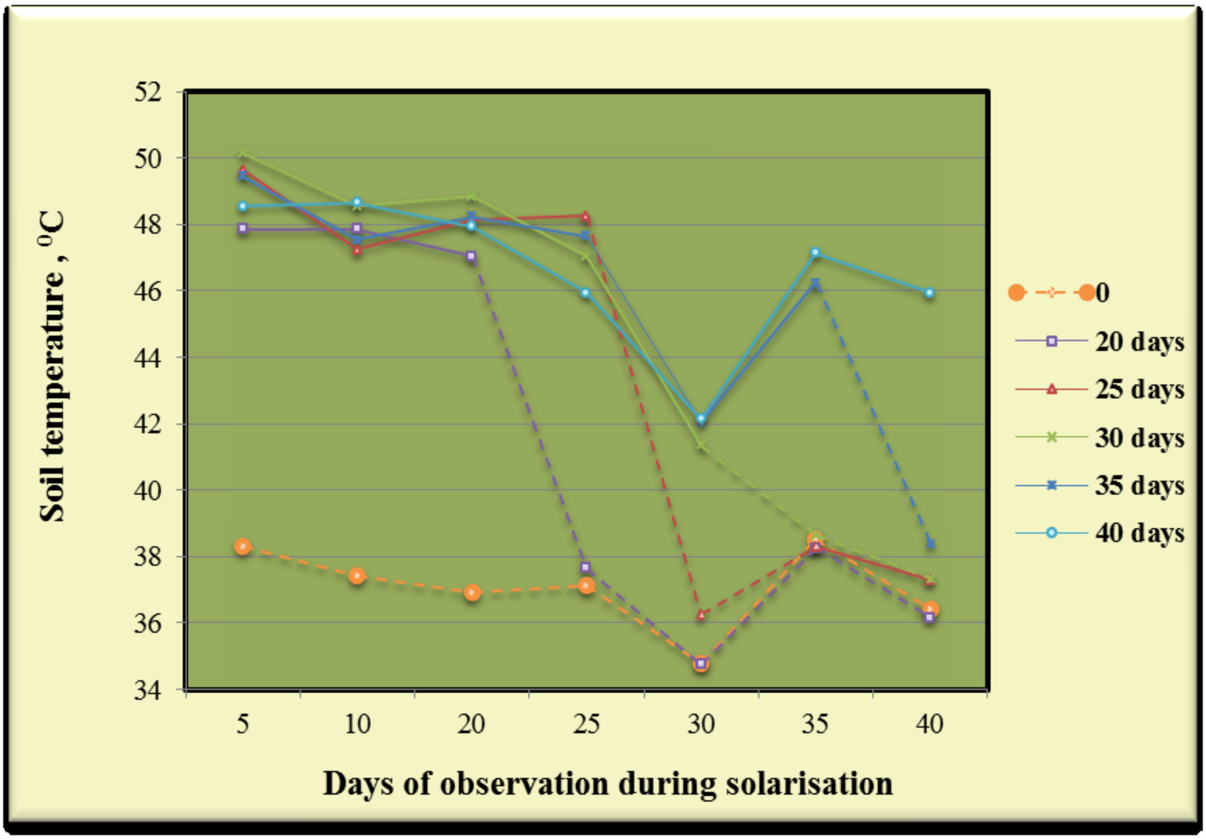


Fig. 23. Effect of soil solarisation on the soil temperature at 3 cm depth of soil

The dotted lines represent the soil temperature in non-solarised situation

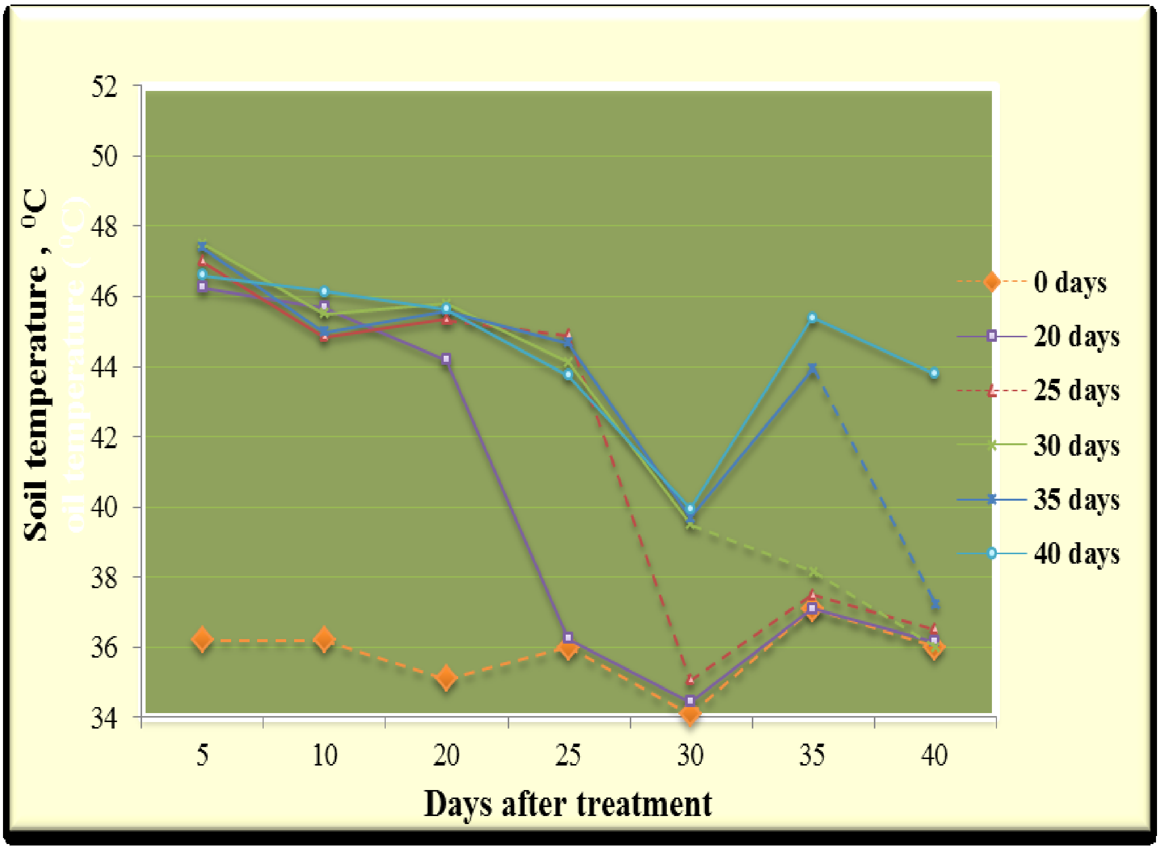


Fig. 24. Effect of soil solarisation on the soil temperature at 5 cm depth of soil

The dotted lines represent the soil temperature in non-solarised situation

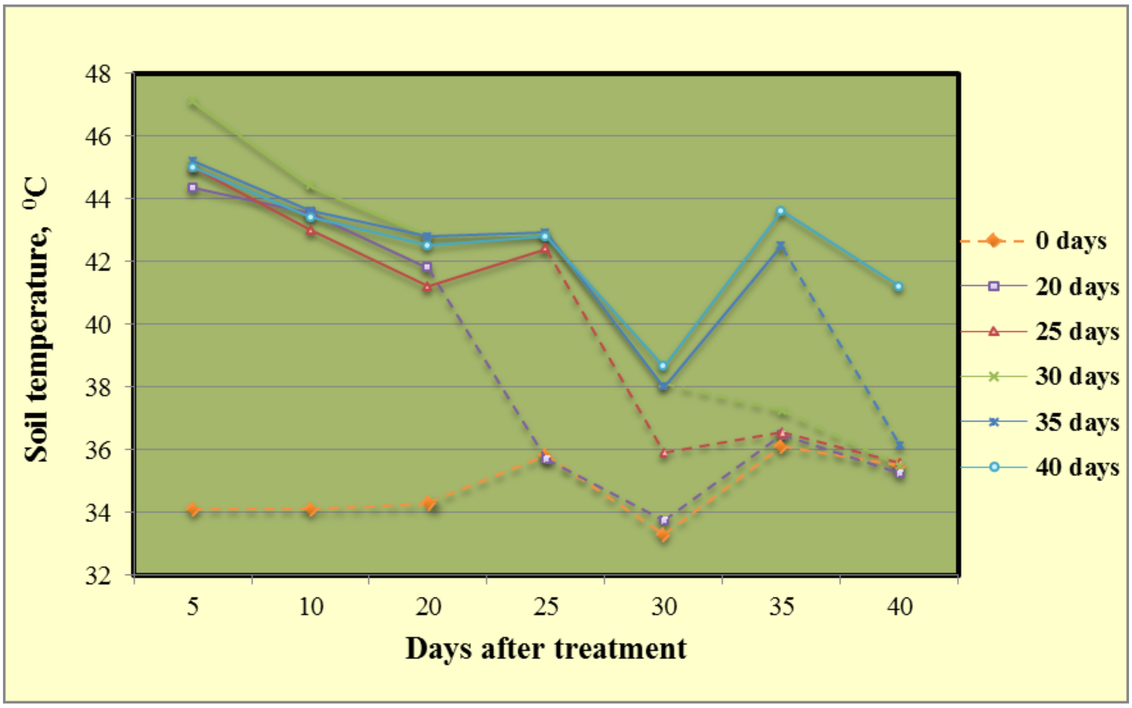


Fig. 25. Effect of soil solarisation on the soil temperature at 10 cm depth of soil

The dotted lines represent the soil temperature in non-solarised situation

germinated. Chauhan (2013 a) has also reported solarisation as a management strategy for reducing weedy rice infestation.

At lower depths of 5 and 10 cm also, the solarised soil resulted in high temperature than the control, even though the maximum temperature achieved was lower corresponding to the increase in depth (Fig. 24 and 25). Experiments conducted in Kerala by Sainudheen and Abraham (2001) have also shown similar trend in soil temperature on solarisation of vegetable fields heavily infested with weeds.

5.3.2. Chemical methods

5.3.2.1. Effect of pre emergence herbicides on the infestation of weedy rice and yield of rice

The results of the three trials of the experiment on the management of weedy rice using pre emergence herbicides have shown that all the pre emergence herbicides (butachlor, pretilachlor and oxyfluorfen) applied as pre sowing surface application, or incorporation, at doses higher than the recommended doses for pre emergence application, could reduce the weedy rice infestation in the cropped field (Fig. 26). It was reported by Chen *et al.* (2013) that application of pretilachlor at 0.9 kg ha $^{-1}$ along with safener, one hour after sowing can effectively control weedy rice. Maneechote *et al*. (2004) have reported that application of higher doses of herbicides like butachlor 2 kg ha $^{-1}$, pretilachlor 0.75 kg ha $^{-1}$ and oxyfluorfen 0.7 kg ha^{-1} in standing water at 8- 10 DAS was effective in reducing weedy rice population though a little phytotoxicity was noticed, which later recovered (Fig. 27). In the trials conducted in rice fields of Kuttanad, among the herbicides tried, oxyfluorfen at 0.2 kg ha^{-1} and 0.3 kg ha^{-1} as surface application and oxyfluorfen at 0.3 kg ha^{-1} as soil incorporation gave significantly lower weedy rice infestation than butachlor or pretilachlor, and significantly higher yield (Fig. 28). This is because oxyfluorfen is a selective contact herbicide which is absorbed more readily by shoots than by roots with very little translocation. In all the herbicides tried, surface application was found better than their soil incorporation at three days before sowing.

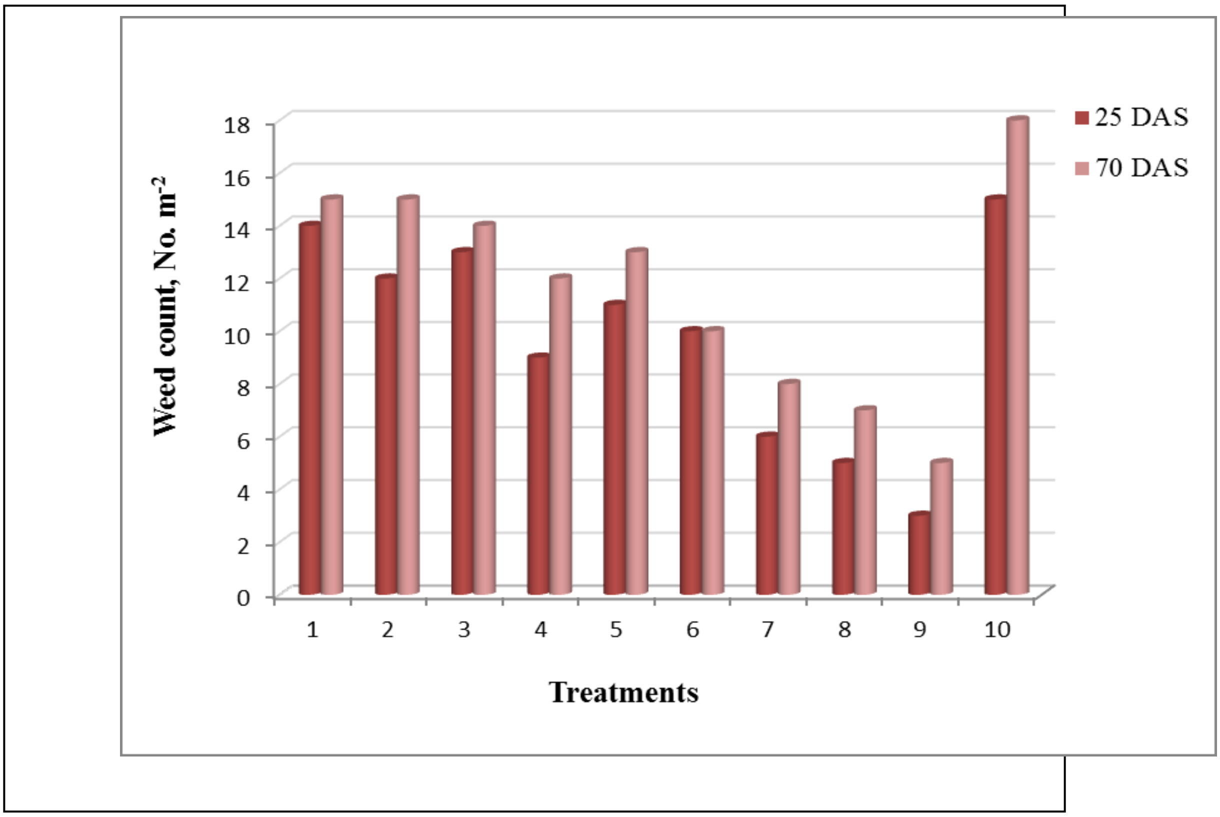


Fig. 26. Effect of pre sowing application of herbicides on weedy rice infestation (Location - 3)

T 1	Butachlor @ 2.0 kg ha^{-1}	T 6	Oxyfluorfen @0.2 kg ha^{-1}
T 2	Butachlor @ 2.5 kg ha^{-1}	T 7	Oxyfluorfen @ 0.3 kg ha^{-1}
T 3	Pretilachlor @ 1.5 kg ha^{-1}	T8	Oxyfluorfen @ 0.4 kg ha^{-1}
T 4	Pretilachlor @ 2.0 kg ha^{-1}	T 9	Hand weeding 20 & 40 DAS
T 5	Oxyfluorfen @ 0.1 kg ha^{-1}	T 10	Un weeded control

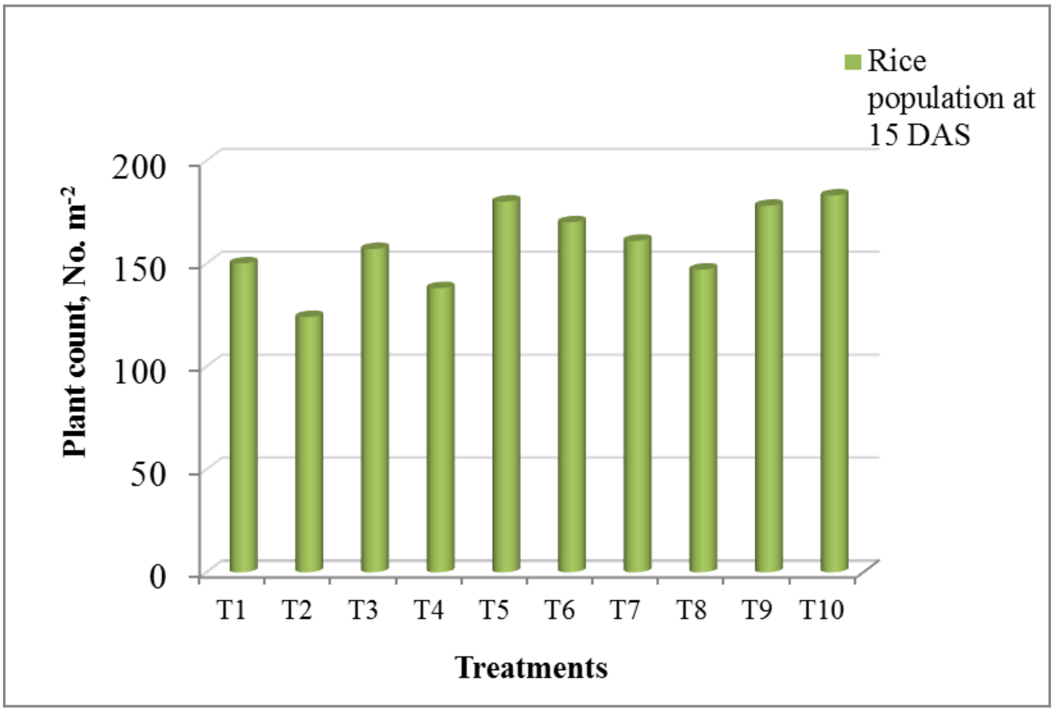


Fig. 27. Effect of pre sowing application of herbicides on rice plant population (Location - 3)

T 1	Butachlor @ 2.0 kg ha^{-1}	T 6	Oxyfluorfen @0.2 kg ha^{-1}
T 2	Butachlor @ 2.5 kg ha^{-1}	T 7	Oxyfluorfen @ 0.3 kg ha^{-1}
T 3	Pretilachlor @ 1.5 kg ha^{-1}	T8	Oxyfluorfen @ 0.4 kg ha^{-1}
T 4	Pretilachlor @ 2.0 kg ha^{-1}	T 9	Hand weeding 20 & 40 DAS
T 5	Oxyfluorfen @ 0.1 kg ha^{-1}	T 10	Un weeded control

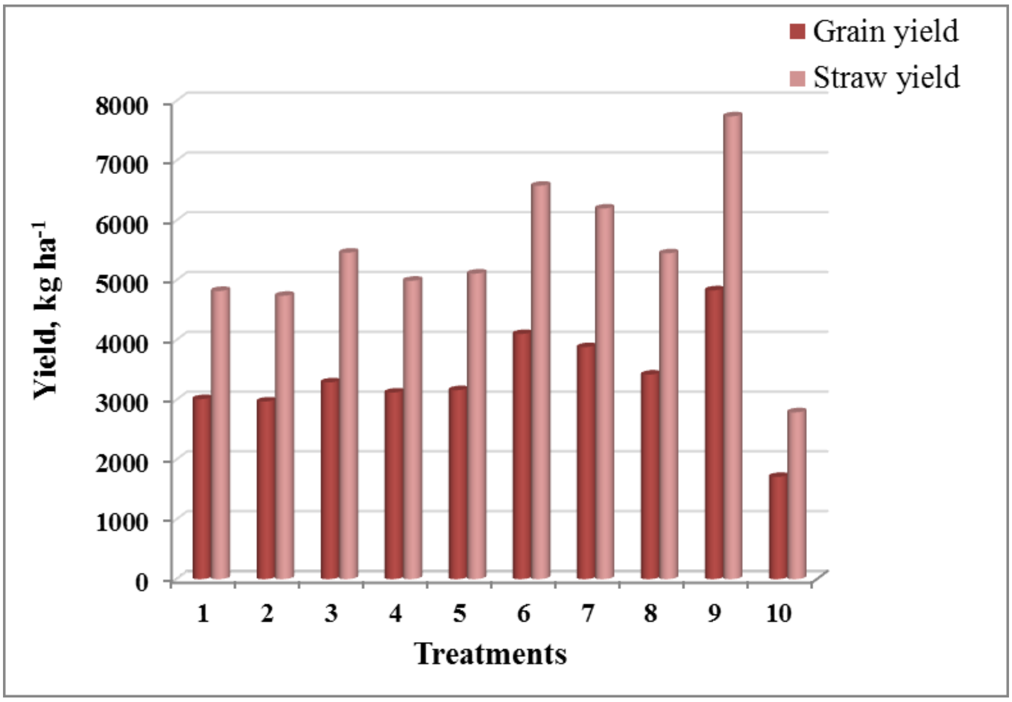


Fig. 28. Effect of pre sowing application of herbicides on grain and straw yield (Location - 3)

T 1	Butachlor @ 2.0 kg ha^{-1}	T 6	Oxyfluorfen @0.2 kg ha^{-1}
T 2	Butachlor @ 2.5 kg ha^{-1}	T 7	Oxyfluorfen @ 0.3 kg ha^{-1}
T 3	Pretilachlor @ 1.5 kg ha^{-1}	T 8	Oxyfluorfen @ 0.4 kg ha^{-1}
T 4	Pretilachlor @ 2.0 kg ha^{-1}	T 9	Hand weeding 20 & 40 DAS
T 5	Oxyfluorfen @ 0.1 kg ha^{-1}	T 10	Un weeded control

On soil application of these herbicides, they are absorbed by the emerging shoots of seedlings. When herbicide is applied on surface, rice seedlings get selectivity as pre germinated seeds are broadcasted above the herbicide layer. The weedy rice seedlings and other weed seedlings which emerge through the herbicide treated layer come in to contact with the herbicide and get killed. When incorporated, rice seeds are in the soil containing herbicide. This is the reason for the lower population of rice seedlings in the treatments where herbicides were incorporated. The treatments where the herbicides were incorporated in to the soil were less efficient compared to the surface application, probably because of the dilution of the herbicide on mixing with the soil.

The better performance of the surface applied oxyfluorfen must be due to the better adsorption of the herbicide on the upper layer of the soil. Haworth and Hess (1988) have reported that the generation of singlet oxygen by oxyfluorfen is independent on photosynthesis and is the primary cause for the lethality. In a study on leaching behavior of herbicide at KAU centre of the AICRP on Weed Control, it was reported that oxyfluorfen sprayed on rice fields remained in the upper 2 cm of soil and the quantity getting leached down to lower layers of soil was very low. On the other hand, retention of butachlor and pretilachlor was less and most of these herbicides got leached down faster (Devi and Abraham, 2008). The adsoption of oxyfluorfen on the organic matter and has also been reported by Vencil (2002). Microbial analysis of the soil 20 days after surface application of oxyfluorfen at 0.2 kg ha^{-1} has revealed that there is no adverse effect on microbial population.

5.3.2.2. Development of prototype of a device for direct contact application of herbicides

There is no viable technology for post emergence management of weedy rice with herbicides due to its mimicry to the cultivated rice and lack of herbicides for selective control weedy rice which has the similar genome as cultivated rice. Direct contact application (DCA) is an effective method for controlling seed production and multiplication of weedy rice in rice fields. Stroud and Kempen (1989) have also reported the efficiency of wick applicator in selective drying of weedy rice ear heads in severely infested fields.

If weedy rice panicles are not destroyed soon after flowering, the seeds will fall and contaminate soil before the harvest of rice due to shattering nature of weedy rice grains. Because of severe crop loss due to weedy rice infestation and difficulties in managing weedy rice effectively, many farmers are abandoning rice fields infested with weedy rice. This novel hand held wiper device developed can reverse the trend. The novel hand held wiper device is simple, handy and cost effective. It is eco-friendly with more area coverage using low volume of spray fluid.

The hand held wiper device (which has been filed for patent) has become popular among the farmers of Kuttanad for selective drying of weedy rice panicles in severely infested fields.

Precautions while using wick applicator

While sweeping the herbicide over the crop, utmost care should be taken to prevent dripping of the herbicide from the applicator lance and touching the crop canopy which is at minimum permissible height difference with weedy rice ear heads. The efficiency of the wick applicator depends primarily on the mode of action of the chemical and its concentration. The skill of the person using the equipment and his perceptions on the mode of action of the chemical, either contact or systemic also affects the efficacy of DCA.

5.3.2.3. Post emergence management of weedy rice by direct contact application (DCA)

Post emergence management of weedy rice by DCA using broad-spectrum herbicides takes advantage of the height difference between rice and weedy rice plants (weedy rice panicles are at 15-20 cm height above the crop stand at 60 – 65 DAS). By the swinging action of the herbicide carrying wiper, over weedy rice ear heads, the weedy rice panicles are smeared with the herbicide and selective drying of the weedy rice panicles can be achieved. Ferrero and Vidotto (1999) have observed 90 per cent reduction in germination of dried seeds collected after sweeping weedy rice panicles with wick applicator using glyphosate (10-15%) at 65 DAS in infested cropped fields.

The efficiency of selective drying depends on the herbicide used, its concentration, stage of the crop and weed, and skill of the personal engaged for DCA. While selecting herbicides for swabbing, it is always better to use those with contact broad-spectrum action (glufosinate ammonium and paraquat dichloride) than systemic action (glyphosate) to prevent accidental drying of the rice plants. However, if a skilled personnel is engaged, even systemic herbicides can be used to dry the entire weedy plants. The use of the herbicide paraquat dichloride, being a highly toxic chemical, is banned in Kerala state. Glufosinate ammonium ('Basta' by Bayer Crop Science) is not available in the market at present (though it is likely to be available soon). Thus, glyphosate is the only option to the farmers at present.

At the time of ear head emergence of weedy rice, the second internode from the top elongates, pushing the ear head above the crop canopy to a height of 15-20 cm. The rice plants which grow in competition with weedy rice at densities more than 5-8 weedy rice plants per square metre are usually shorter (70-80 cm at 60 DAS) than the weedy rice plants (90-100 cm at 60 DAS). The uniformity among the rice plants and among weedy rice population in a crop stand decides the effectiveness of the device in selective drying of the ear heads of weedy rice without affecting the crop stand beneath.

Although hand weeding/rouging was the post emergence management strategy to reduce weedy rice soil seed bank replenishment before 2006-2008 (when weedy rice infestation appeared as a serious problem in cropped fields of Kerala), it is not practically feasible at present. As weedy rice has staggered germination in cropped field, repeated use by DCA can be resorted at around 60-65 and/or 70-75 DAS, when the weedy rice panicles are at a height of 15 cm above the crop canopy.

Among the different herbicides tried for DCA using wiper device, glufosinate ammonium at 15 per cent (T7), glyphosate at 10-15 per cent (T3 and T4) and paraquat dichloride at 15 per cent concentration (T2) were found to be superior to other treatments in selective drying of the weedy rice ear heads (Fig. 29 and 30). As the wick touches the panicle for only a fraction of a minute during the operation, lower concentrations of the herbicides were not as effective as their higher concentrations.

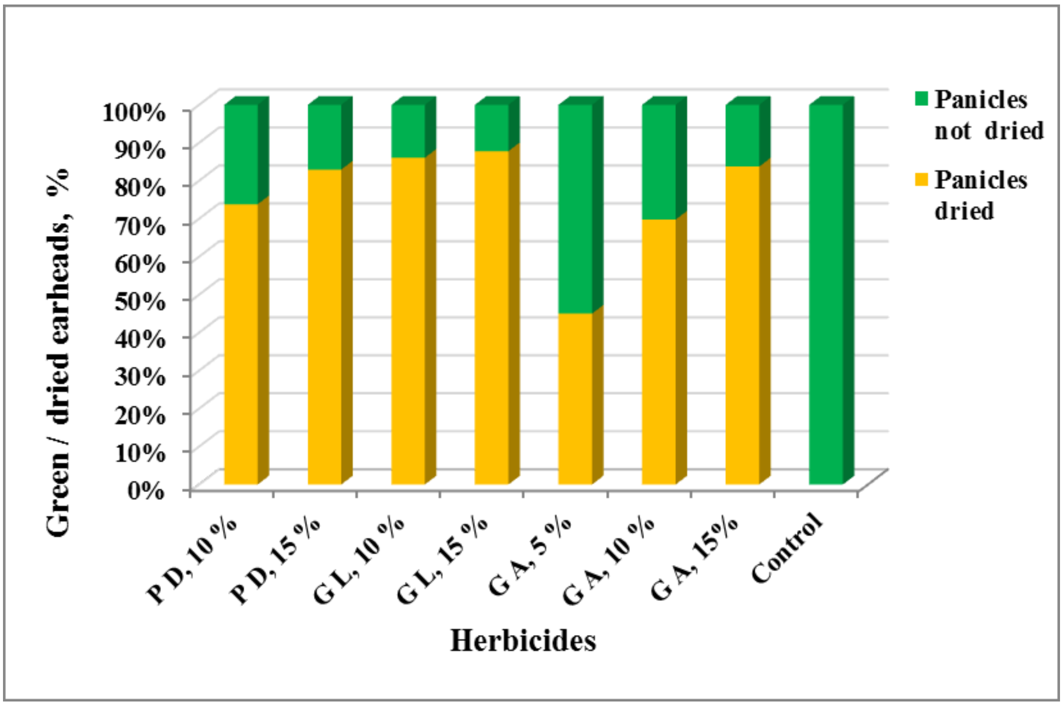


Fig. 29. Effect of DCA on the post emergence management of weedy rice (Location -1)

PD.	Paraquat dichloride
G. L.	Glyphosate
G.A.	Glufosinate ammonium

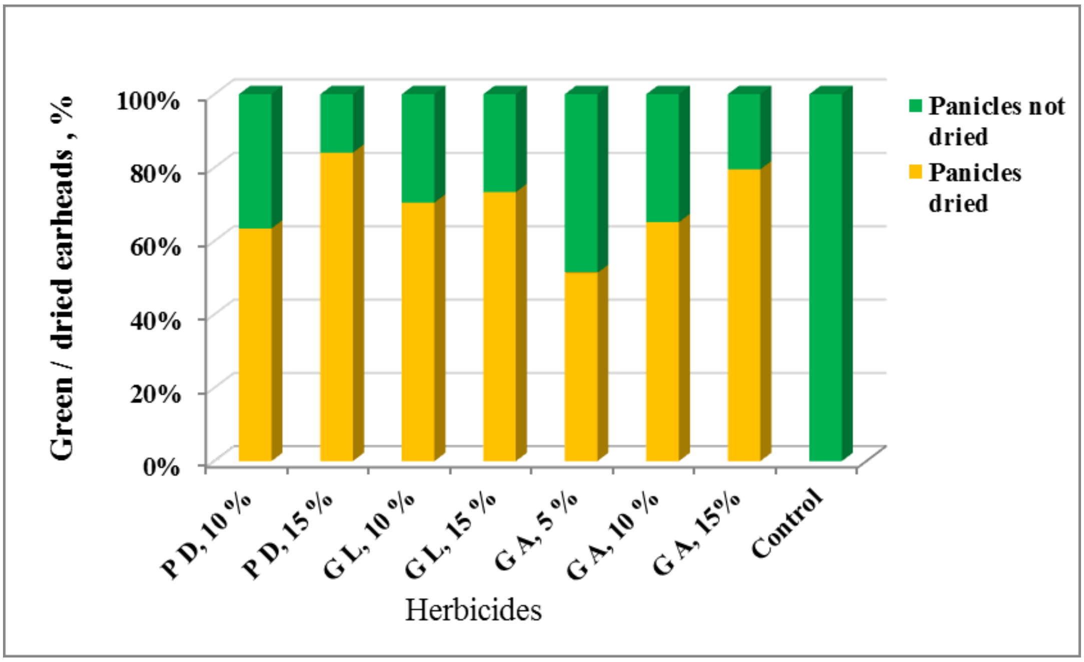


Fig. 30. Effect of DCA on post emergence management of weedy rice

(Location-2)

PD.	Paraquat dichloride
G. L.	Glyphosate
G.A.	Glufosinate ammonium

The quantity of herbicide required for swabbing an area of one hectare with moderate weedy rice infestation (6-10 weedy rice ear heads per square metre) is 2.0 to 2.5 litre, at 10 per cent concentration of the herbicide. Using the novel wiper device, one hectare of moderately infested fields can be covered in 3-4 hours. This mode of control is highly energy efficient, less labour intensive, and more eco-friendly compared to hand weeding, cutting of weedy rice ear heads or application of large quantity of herbicides using sprayers. The chances for weedy rice seed rain to soil can also be very effectively prevented by DCA.

6. SUMMARY

Rice farming practices of the country have changed in the recent years due to socio-economic and ecological constraints. Shift in the crop establishment method from transplanting to direct sowing of pre germinated seeds, dependence on pesticides especially herbicides, reduced tillage practices, acute shortage and high cost of labour etc. have led to several biotic and abiotic stresses in rice. A perennial constraint in rice cultivation is weed infestation, and of late, weedy rice infestation has become a serious threat in the rice belts of India. Weedy rice is a complex of morphotypes of *Oryza* species widely distributed in rice fields, especially in areas where farmers have switched to direct seeding.

India has the earliest history of rice cultivation and hence highly variable population of weedy/wild rice types due to introgression are seen in rice growing areas of the country. The scarcity of labour coupled with increased dependence on herbicides and zero tillage practices have resulted in shift in the weed flora. Heavy infestation of weedy rice and subsequent reduction in crop yield (50-70%) in rice fields of northeastern and southern parts of the country have become a threat to profitable rice production. In Kerala also, weedy rice infestation is severely hindering profitable cultivation even in all rice bowls of the state, Kole, Kuttanad and Palakkad. During recent years, heavy infestation of weedy rice and subsequent huge reduction in yield has forced many farmers to abandon the rice crop without harvesting and subsequently leave the field fallow.

Mimicry of weedy rice to cultivated rice in morphological characters makes hand weeding/rouging incomplete and ineffective. As the present recommendations of chemical weed control in rice are not effective for selective control of weedy rice, modifications in the time, method and dose of herbicide application need to be evaluated for formulating recommendations for effective control of weedy rice without adversely affecting rice. Other agronomic practices like stale seed bed technique, water management, burning of straw, soil solarisation, alterations in the method of crop establishment etc., also have to be evaluated for developing a management strategy suited for the area.

With these objectives, a research programme was chalked out which included survey in the weedy rice infested rice belts of Kerala, studies on the biology, ecology, spread and distribution of weedy rice, evaluation of different approaches for management of weedy rice and finally demonstration of the successful technologies in the farmers' field in a participatory mode for further refinement.

The salient findings of the study are summarised below:

a) Survey on the weedy rice infestation in the major rice growing tracts of Kerala

Survey conducted in the major rice growing tracts of Kerala, Kole, Kuttanad and Palakkad, revealed that more than 65 per cent of the area had low to severe weedy rice infestation. Twenty six panchayaths in the major rice areas of Kerala had severe infestation while, 36 had moderate and 49 had low infestation of weedy rice. In Kole lands, 25 per cent of the area had severe infestation whereas, 36 per cent each had moderate and low infestation. In Kuttanad, the infestation in 38, 17 and 25 per cent area was rated as low, moderate and severe, respectively. In Palakkad district, only five per cent area had severe infestation. Eighteen per cent area had medium and 20 per cent had low infestation of weedy rice.

The extent of infestation was more in Kole lands and Kuttanad rice belts. Severe infestation was noticed in Adat, Ayyanthole, Arimpoor, Anthikkad and Manaloor panchayaths in Thrissur Kole and Nannamukku panchayat in Malappuram Kole. In Palakkad region, the infestation was severe in Alathoor, Pallassana and Polpully panchayaths. It was observed that wherever the farmers were practising transplanting, weedy rice infestation was moderate.

Survey revealed the presence of weedy rice variants/morphotypes with respect to morphological characters like number of tillers per plant, plant height, ligule length, panicle characters, colour of grains, and length and colour of awns.

Studies on indigenous traditional knowledge of the farmers on biology and management of weedy rice indicated that more than 60 per cent of farmers were well aware of the problems from weedy rice, but scientific intervention was expected by them for developing recommendations for the integrated management with chemicals and other strategies. Transplanting, deep tillage, cutting of earheads of weedy rice at flowering, and use of higher seed rate were the traditional practices followed for managing weedy rice.

b) Biology and ecology of weedy rice

Among the vegetative characters studied, there was significant difference between weedy rice morphotypes in the number of tillers per plant (2.5 - 10.8), length of leaves (28.5 - 48.0 cm) and height of plants (81.3 - 140.5 cm). Among the reproductive characters observed, there was significant difference between morphotypes in length of panicle (18.4 - 29.5 cm) and length of awns in the grains of a panicle (1.1 – 7.0 cm). Comparison of the morphometric characters of weedy rice with that of cultivated rice (the popular cultivar 'Uma'- MO 16) revealed that, rice plants are shorter in plant height (98- 110 cm), number of tillers (5-6 per plant), and length of internodes (15.6-21.0 cm). The number of grains per panicle in rice (140-158) was much higher than that in weedy rice (63-112). High per cent of chaffing to the tune of 50 per cent or more was observed in weedy rice. It can be concluded that the relative advantage of weedy rice plants in vegetative growth compared to rice plants is not expressed in its reproductive capacity.

Scanning electron microscopic studies (SEM) revealed the presence of indentations on the exterior surface of weedy rice seeds with silica in the mid region. The weedy rice seed surface had parallel rows of trichomes. SEM studies also confirmed that lesser overlapping of lemma and palea contributed to quicker germination of half matured straw coloured weedy rice grains whereas, slow germination in black coloured mature seeds was due to the clear overlapping of lemma and palea. Presence of more number of stomata both on the adaxial (7.5/ mm^2) and abaxial surface (3.8/mm^2), silica deposits and hairy out-growths on leaves and high root volume in weedy rice (9.5-12 cm^3) also contributed to its early vigour, growth and competitiveness.

Studies conducted on the germination of weedy rice seeds revealed that there was no significant difference between the germination of weedy rice in the presence and absence of rice seeds in the soil. It was noticed that more seeds germinated from the upper 2 cm layer after seven days of soaking. Seeds which were buried deeper (4-8 cm) took more time for germination and the total germination was also less.

Investigations on the dormancy revealed that hull induced dormancy in weedy rice could be broken by exposing seeds to 20ºC for 48 hours, treating with 0.6% nitric acid for six hours, rupturing the seed coat, or maintaining electrical conductivity of 5 dS m^{-1} for six hours in the growing media. Soaking the seeds in salt water and scraping of hull gave 80 per cent germination even on the third day of soaking compared to 35 per cent germination in the control. It was noticed that there was subsequent increase in germination even up to 80 per cent in all pre-soaking treatments on the sixth day, which later reached 95 per cent in all treated seeds by 12th day, while in control it reached only 50 per cent by sixth day. Further germination in the control plot to 75 per cent by 12th day of soaking revealed the inherent capacity of majority weedy rice seeds on the surface of soil to germinate by 12 days under moist condition. These observations proved the staggered germination of weedy rice in cultivated fields.

Efficient management of weedy rice infestation is complex due of its morphological similarities making it difficult to distinguish weedy rice from cultivated rice, until it comes to flowering. These characters along with variable dormancy causing staggered germination, high competitiveness, early flowering and seed shattering makes hand weeding incomplete. The present recommendations of weed management in rice are not effective against weedy rice. Hence, alternate methods were attempted in this study.

c) Management of weedy rice by stale seed bed technique (SSB)

Stale seed bed technique as a management strategy for weedy rice control was experimented in farmers' field with single and double staling operations with herbicide application and/or tillage to destroy the germinated seedlings from soil seed bank. Exhaustion of soil seed bank with wet and/or dry tillage was also studied for assessing its efficiency in managing weedy rice.

The results of the experiment in the first location revealed that single stale operation followed by herbicide application (to destroy the emerged seedlings) recorded 52 and 41 per cent reduction in weedy rice population and 63 and 60 per cent reduction in its dry weight of weedy rice at 30 and 60 DAS, than in single stale followed by tillage. Comparison of single and double stale operation (with wet tillage in between and herbicide application after second germination) revealed that double stale reduced the weedy rice plant population by 85 and 75 per cent and dry weight by 73 and 61 per cent over single stale, at 30 and 60 DAS, respectively. In double staling, the reduction in dry weight of weedy rice was 92 and 90 per cent, respectively at 30 and 60 DAS compared to control. It was observed that double stale could increase the grain yield by 22 per cent than single stale operation. Single stale followed by herbicide application gave 61 per cent higher in yield than single stale followed by dry tillage.

The experiment in the second location, revealed the superiority of wet tillage over dry tillage during staling operations for exhausting the soil seed bank of weedy rice. It was observed that destruction of the first flush of weeds from the soil seed bank by wet tillage decreased the weedy rice population by 76 and 73 per cent and weed dry weight by 78 and 80 per cent, respectively at 30 and 60 DAS in the succeeding crop compared to dry tillage in between two stales. There was 67 per cent increase in grain yield in wet tillage (double stale + wet tillage + herbicide application) than dry tillage in between two stales (double stale + dry tillage + herbicide application). Wet tillage in between two stales had significantly higher grain yield of 7468 kg ha^{-1} compared to 4525 kg ha^{-1} in dry tillage. It was also noted that taking two tillage operations (dry followed by wet tillage) in between two stales gave 10 and 28 per cent more yield than double stales with wet or dry tillage, respectively.

d) Management of weedy rice by straw burning

The experiment conducted in a weedy rice infested field in Kole lands of Thrissur showed that burning of straw after the previous crop resulted in significant reduction in the infestation of weedy rice in next crop. There was no additional benefit from spraying kerosene on straw before the burning. Ploughing the burnt field before sowing the next crop resulted in more weedy rice than compared to the field where the crop was taken under zero tillage. Compared to the control plot the weedy rice infestation was lower by 60 per cent and the yield was higher by 90 per cent in the plot which received burning of straw followed by zero tillage. The corresponding figures for the burnt and tilled plot were lower by five per cent and higher by ten per cent.

e) Management of weedy rice by soil solarisation

Soil solarisation of the infested fields with 100 micron transparent poly ethylene for 30 days or more during summer months can effectively control weedy rice population by killing the seeds due to the increased soil temperature (10^0C - 12^0C) in solarised condition for more days. There was 90 per cent control of weedy rice in the solarised field compared to control. However, this can be adopted as a management strategy only in rice nurseries, considering the practical difficulties and the possible environmental problems from large scale use of plastic.

f) Effect of pre emergence herbicides on the infestation of weedy rice and crop yield

As the present recommendations of chemical weed control in rice are not effective for selective control of weedy rice experiments were conducted with pre emergence herbicides, butachlor, pretilachlor and oxyfluorfen, applied as pre sowing surface application, or soil incorporation. Number of weedy rice earheads at 75 DAS was significantly lower and on par with hand weeding in oxyfluorfen surface application and incorporation at three DBS @ 0.2 kg ha^{-1} and 0.3 kg ha^{-1}. There was 45-55 per cent reduction in the weedy rice population in the pre sowing surface application of oxyfluorfen three days before sowing @ 0.2 and 0.3 kg ha^{-1} compared to control. Grain yield in the oxyfluorfen applied plots were 4100 kg ha^{-1} and 3880 kg ha^{-1}, respectively at 0.2 and 0.3 kg ha^{-1}, while control plot yielded only 1710 kg ha^{-1}.

g) Design of a wiper device for post emergence management of weedy rice using herbicides

Direct contact application (DCA) of non-selective broad-spectrum post emergence herbicides is a management strategy for the control of weedy rice growing taller than the crop canopy. Weedy rice usually flowers earlier than cultivated rice and produces the earheads well above the canopy of the crop. Hence an attempt was made for the selective drying of weedy rice panicles using the wick applicator imported from Taiwan. As the imported equipment was heavy and less user friendly, it was decided to design a new prototype. The novel hand held wiper device is light, easy to operate and is effective for DCA for control of taller weeds. It has been filed for Indian Patent at the Patent Office, Chennai (Application No. 1763/CHE/2014 dated 01.04.2014).

The efficiency of the wick applicator in selective drying of weedy rice panicles by DCA was tested using broad spectrum herbicides, paraquat dichloride, glyphosate and glufosinate ammonium. The results showed that weedy rice ear heads can be selectively dried without affecting rice plants by DCA using wick applicator with glufosinate ammonium at 15 per cent, paraquat dichloride at 15 per cent or glyphosate at 10-15 per cent concentration.

h) Participatory technology demonstration

The promising technologies standardised for managing weedy rice were demonstrated in the farmers' field in a participatory mode, with appropriate modifications to suit the local conditions. The following technologies were demonstrated.

1. Stale seed bed technology to exhaust the soil seed bank in rice fields severely infested with weedy rice.
2. Pre sowing surface application of oxyfluorfen three days before sowing @ 0.2 kg ha^{-1} in two inches of standing water to prevent the early emergence of weedy rice from the soil seed bank in rice fields moderately infested with weedy rice.
3. Direct contact application of glyphosate @ 10 per cent concentration at 60-65 DAS using specially designed wick applicator for selective drying of weedy rice panicles in rice fields severely infested with weedy rice.

The demonstrations have given good results and many farmers have already adopted the technologies for integrated management of weedy rice.

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APPENDIX 1

Weekly weather data during the experimental period at Kuttanad

(December 2010 to April 2011)

Std. week no.	Temperature, ^{0}C		R.H., %	Rainfall, mm	Mean Evp., mm
	Max.	Min.			
49	30.2	23.7	84.7	11.3	2.9
50	30.9	23.6	84.0	1.3	4.7
51	32.2	23.3	77.0	4.7	3.6
52	32.3	23.3	77.0	0.0	3.7
1	31.7	23.3	78.0	1.6	3.1
2	31.1	24.0	79.9	0.0	3.5
3	32.2	21.6	77.0	0.0	3.7
4	32.4	20.7	74.4	0.0	4.0
5	32.6	22.0	71.1	0.0	3.9
6	32.3	22.6	74.3	0.0	3.7
7	32.2	21.3	74.7	0.0	4.2
8	31.9	23.4	76.1	4.1	4.5
9	32.5	23.0	76.4	1.6	4.5
10	32.9	24.1	78.3	0.0	4.4
11	33.0	23.9	76.4	0.4	4.8
12	33.6	23.7	76.9	0.0	5.2
13	33.2	25.0	79.1	0.0	4.8
14	33.1	24.6	75.9	1.4	4.9
15	33.3	24.3	78.0	6.1	5.1

APPENDIX 11

Weekly weather data during the experimental period at Kole

(September 2010 to January 2011)

Std. week no.	Temperature, ^{0}C		R.H., %	Rainfall, mm	Mean Evp., mm
	Max.	Min.			
36	35.6	24.4	69.0	52.5	20.8
37	36.0	24.1	65.5	135.8	22.2
38	36.4	23.9	64.5	109.4	23.8
39	36.3	24.1	64.5	29.0	23.2
40	36.3	24.2	64.0	322.5	20.9
41	35.9	24.2	64.5	13.7	20.1
42	35.6	24.2	66.0	131.9	17.7
43	35.5	24.4	67.5	91.3	18.9
44	35.7	24.9	68.5	147.7	19.8
45	35.8	25.2	68.0	141.3	16.1
46	36.4	25.2	64.5	35.3	23.1
47	36.7	25.3	61.5	58.9	16.7
48	37.1	25.3	58.5	10.9	19.0
49	37.4	25.4	59.0	0	20.5
50	37.4	25.3	60.5	19.0	22.5
51	37.0	25.3	62.0	2.4	38.9
52	37.0	24.8	63.0	0	37.2
1	32.0	22.3	67.5	0	31.9
2	33.1	22.3	63.5	0	30.5

APPENDIX 111

Weekly weather data during the experimental period at Kole

(February 2011 to May 2011)

Std. week no.	Temperature, ^{0}C		R.H., %	Rainfall, mm	Mean Evp., mm
	Max.	Min.			
7	33.0	23.4	52.0	0	41.9
8	33.4	23.6	50.5	65.9	27.3
9	33.4	23.5	48.0	11.6	45.0
10	33.5	23.3	45.5	0	38.5
11	33.6	22.9	45.0	10.0	48.0
12	33.6	22.4	42.0	0	33.5
13	33.6	22.1	41.5	2.2	33.2
14	33.6	21.5	43.0	0	34.0
15	33.6	21.3	46.0	3.4	36.3
16	33.9	21.2	48.0	23.6	34.0
17	34.2	20.9	48.5	128.4	26.4
18	34.3	21.0	47.5	162.7	25.1
19	34.3	21.8	46.5	0	30.0
20	34.4	21.6	45.0	43.9	24.0
21	34.5	21.6	45.0	32.8	29.4
22	34.3	21.4	45.0	230.5	18.3

APPENDIX 1V

Weekly weather data during the experimental period at Kuttanad

(December 2011-April 2012)

Std. week no.	Temperature, ^{0}C		R.H., %	Rainfall, mm	Mean Evp., mm
	Max.	Min.			
49	32.0	23.3	76.7	2.4	3.4
50	33.1	23.7	73.4	0	4.0
51	32.4	23.0	73.4	0	3.3
52	31.3	22.3	80.0	13.6	3.0
1	32.4	21.8	76.1	7.3	3.4
2	32.7	23.3	75.1	0	3.8
3	32.1	20.7	74.9	0	3.8
4	32.1	20.9	72.7	0	4.1
5	32.6	21.5	69.9	0	4.1
6	33.1	23.3	76.9	0	4.2
7	32.4	23.6	77.3	0	3.9
8	32.9	22.7	76.1	0	4.3
9	33.0	22.2	76.5	0	4.8
10	32.1	23.9	78.3	0.1	4.7
11	32.4	24.5	82.3	5.8	4.5
12	32.4	25.1	79.6	0	4.7
13	33.1	24.9	78.9	0.1	4.8
14	33.3	24.5	79.7	4.3	4.5
15	33.4	25	77.1	3.2	3.7

APPENDIX V

Weekly weather data during the experimental period at Kuttanad

(June 2012-October 2012)

Std. week no.	Temperature, ^{0}C		R.H., %	Rainfall, mm	Mean Evp., mm
	Max.	Min.			
23	31.7	25.0	82.9	6.8	3.1
24	30.7	24.7	82.6	6.4	2.6
25	30.4	24.6	83.9	12.8	2.5
26	30.2	24.2	83.2	10.9	3.1
27	30.7	24.3	82.9	9.5	2.2
28	30.3	24.1	82.3	16.0	2.3
29	31.0	25.2	82.0	1.1	3.7
30	30.1	24.8	83.9	4.2	3.0
31	31.6	24.8	79.1	0	3.8
32	30.0	24.1	86.3	12.6	2.3
33	29.1	24.1	84.3	16.3	1.9
34	30.9	24.2	84.7	10.7	2.9
35	29.6	24.8	86.1	11.5	1.4
36	30.3	24.1	84.4	11.5	2.4
37	30.9	24.4	87.0	7.0	2.2
38	31.9	25.0	77.7	0.8	4.3
39	32.1	25.1	77.3	0.1	5
40	32.2	24.7	74.3	0	5
41	32.6	25.1	78.3	1.3	4.7
42	31.1	24.2	84.1	3.6	2.3

APPENDIX VI

Patent application for 'Wiper device for mangement of weedy rice' filed at Indian Patent Office, Chennai

Indian Patent Office Chennai

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Sr. No.	CBR No.	Reference Number /Application Type	Application Number	Title/Remarks	Amount Paid
1	5746	ORDINARY APPLICATION	1763/CHE/2014	HAND HELD WIPER DEVICE FOR WEEDY RICE CONTROL	8800
2		E-101/16386/2014-CHE	1763/CHE/2014	Correspondence	0
3		E-2/2159/2014-CHE	1763/CHE/2014	Form2	0
4		E-3/2038/2014-CHE	1763/CHE/2014	Form3	0
5		E-5/1515/2014-CHE	1763/CHE/2014	Form5	0
6	5746	3194/RQ-CHE/2014	1763/CHE/2014	Form18	22000
7		E-45/1177/2014-CHE	1763/CHE/2014	Form26	0
Total :					30800

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BIOLOGY AND MANAGEMENT OF WEEDY RICE

(*Oryza sativa* f. *spontanea*)

by

NIMMY JOSE

(2009-21-106)

ABSTRACT OF THESIS

Submitted in partial fulfilment of the requirements for the degree of

DOCTOR OF PHILOSOPHY IN AGRICULTURE

Faculty of Agriculture

Kerala Agricultural University, Thrissur

DEPARTMENT OF AGRONOMY

COLLEGE OF HORTICULTURE

VELLANIKKARA, THRISSUR 680 656

KERALA, INDIA

2015

ABSTRACT

Weedy rice is the complex of morphotypes of *Oryza* species 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. Taxonomically, Indian weedy rice is identified as *Oryza sativa* f. *spontanea* which belongs to the indica group. Invasion and spread of weedy rice in the cultivated rice fields have forced the farming community to abandon rice farming, leading to socio economic and ecological impacts in the rice bowls of Kerala.

Management of weedy rice infestation is complex mainly because of its morphological similarities to cultivated rice and lack of herbicides for selective control of weedy rice in cropped fields. Hence, the present research programme was undertaken to estimate the extent of infestation of weedy rice in rice bowls of Kerala, to study the biology and ecology, and to chalk out strategies for integrated management of weedy rice.

Survey conducted in the major rice belts of Kerala, viz., Kole, Kuttanad and Palakkad, revealed that more than 65 percent of the area has low to severe weedy rice infestation. In the major rice bowls of Kerala there was severe, moderate and low infestation of weedy rice in 26, 36 and 49 panchayaths, respectively,. The extent of infestation was more in Kuttanad in Alleppey, Kottayam and Pathanamthitta districts and Kole lands of Thrissur district. In Palakkad region, the infestation was more in panchayaths of Alathoor and Nemmara blocks. Survey revealed the presence of weedy rice variants with respect to morphological characters like number of tillers per plant, height of plant, length of ligule, panicle characters, colour of grains, and length and colour of awns.

Studies conducted on the germination of weedy rice seeds revealed that there was no significant difference between the germination of weedy rice in the presence and absence of rice seeds in the soil. It was noticed that seed germination was higher at the surface and 2 cm depth of the soil and there was drastic