Management strategies for weedy rice in Asia

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2013

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Suggested citation: Bhagirath Singh Chauhan. 2013. Management strategies for weedy rice in Asia. Los Baños (Philippines): International Rice Research Institute. 16 p.

Cover design: Emmanuel Panisales
Page makeup and composition: Emmanuel Panisales
Figures and illustrations: Emmanuel Panisales

ISBN 978-971-22-0928-8

Foreword

Rice is the principal source of food for more than half of the world population. In Asia, it is commonly grown by manual transplanting of seedlings after tillage in wet conditions. In recent years, however, growers in many Asian countries are slowly moving toward direct seeding of rice in response to the labor and water scarcity and increased production costs. Direct-seeded systems have several advantages; however, weeds, including weedy rice, are the major problem in these systems.

In Asia, the adoption of direct-seeded rice systems makes weedy rice infestation one of the most serious problems that growers encounter. This is mainly because of the morphological and physiological similarities of weedy rice to cultivated rice and the absence of standing water at the time of crop emergence. By infesting rice fields, weedy rice increases production costs and reduces farmers' income by decreasing grain yield and grain quality. Chemical control measures to manage weedy rice in conventional rice cultivars are not an easy option, simply because of the similar physiological and morphological traits between weedy rice and cultivated rice. Therefore, managing weedy rice is a challenging and increasing problem for farmers in Asia. In the absence of selective herbicides, cultural weed management strategies may help reduce the problem of weedy rice.

This publication describes various cultural weed management strategies, both preventive and cultural, to reduce the problem of weedy rice in direct-seeded rice systems. This information will help researchers and extension specialists to develop programs to manage weedy rice in rice production systems.

Robert S. Zeigler
Director General
International Rice Research Institute

Acknowledgment

I would like to thank the Rural Development Administration of Korea for funding this publication.

Management strategies for weedy rice in Asia

Rice is the principal source of food for more than half of the world population. More than 90% of this rice is grown and consumed in Asia, where it is commonly grown by manual transplanting of seedlings after puddling (cultivation in wet conditions). The operations of puddling and transplanting consume a significant quantity of water. In recent years, there have been concerns of water shortage due to competition with urban areas. By 2025, a significant rice area may suffer from economic and physical water scarcity. Transplanting is usually performed by rural labor and recently laborers have tended to migrate from rural areas to the cities. This has increased the labor cost very rapidly. In some areas, it is hard to find labor at the critical time of transplanting, which results in transplanting of aged seedlings and lower yield. Because of these concerns and increased production costs, growers in many Asian countries are slowly moving toward direct seeding of rice.

Asia has two main direct-seeded rice systems: dry and wet. In dry direct-seeded rice, dry seeds are sown after tillage in dry conditions or under zero-till conditions (Fig. 1A). In wet direct-seeded rice, pregerminated seeds are broadcast or sown using a drum seeder on the surface of puddled soil (Fig. 1B). In some places, growers are also practicing mechanical transplanting of seedlings in response to labor scarcity.

Compared with labor-intensive and puddled-transplanted rice, direct-seeded rice has several advantages, such as being more rapid and easy to sow, less labor intensive, and less water intensive, the crop matures earlier, is conducive to mechanization, and has fewer methane emissions. Weeds, however, are the major problem in direct-seeded rice systems, mainly because (1) the suppressive effect of standing water on weed growth at crop emergence is absent, and (2) the size differential between the crop and the weeds is absent.

Fig.1. (A) Dry and (B) wet direct-seeded rice

The adoption of direct-seeded systems has increased weedy rice infestation in Asia

Weedy rice (also called red rice in the Americas), with its populations of annual *Oryza* species, has been recognized as one of the most problematic weed species in rice production systems (Fig. 2). Because of the morphological and physiological similarities of weedy rice to cultivated rice and the absence of standing water at the time of crop emergence, the adoption of direct-seeded rice systems in Asia

Fig. 2. Weedy rice

makes weedy rice infestation one of the most serious problems that farmers encounter.

Weedy rice is thought to be the result of hybridization between cultivars or crossing between cultivars and wild rice, or a result of segregation from landraces. In the United States, weedy rice has been a serious problem for many years. In Asia, however, weedy rice is an emerging problem. Weedy rice infestations, for example, were first reported in Malaysia in 1988, the Philippines in 1990, and in Vietnam in 1994. They infest rice fields in almost all the rice-growing areas in South and Southeast Asia. The Mekong River Delta in Vietnam, Thailand, India, Malaysia, Sri Lanka, and the Philippines, for example, have a significant area infested with this problematic weed. In different countries, weedy rice is known by different names: *padi angina* in Malaysia, *jungli dhan* in India, *khoa nok* in Thailand, and *valvi* in Sri Lanka.

By infesting rice fields, weedy rice increases production costs and reduces farmers' income by decreasing yield. In addition, its infestations reduce the value of the harvested crop by staining the rice grain with undesirable pericarp color. Rice yield losses due to weedy rice depend on the amount of infestation. Weedy rice can cause rice yield loss by 50–60% under moderate infestation (15–20 weedy rice panicles m^{-2}), 70–80% under high infestation (21–30 panicles m^{-2}), and total yield loss under heavy infestation as this may cause lodging in rice plants. In Malaysia, infestations by about 35 weedy rice panicles m^{-2} caused a yield loss of about 1 t ha^{-1}. In the United States, 1–3 plants m^{-2} of weedy rice were reported as the threshold to prevent yield losses of rice, whereas the corresponding density for barnyardgrass (a problematic C_4 grass weed) was 5–10 plants m^{-2}. Such information suggests that weedy rice may be more aggressive than other weeds.

Growth of weedy rice varies considerably among different biotypes

The growth of weedy rice varies considerably among different biotypes due to differences in plant height, tillering, or leaf-producing capacity. Recently, in the Philippines, compared with weedy rice biotype I, weedy rice biotype II significantly lowered the grain yield of cultivated rice. Such results suggest that different biotypes can affect the grain yield of cultivated rice differently. Some of the important traits of weedy rice are early shattering of its seed (Fig. 3A, B), variable seed dormancy, and high seed persistence in the soil. Weedy rice grains can shatter easily with a slight handgrip of panicles (Fig. 3C); however, grain shattering varies among different weedy rice biotypes. As weedy rice is an annual species and depends on seed production for survival, early seed shattering ensures that a portion of weedy rice seed drops on the soil surface before and during rice harvesting and, in this way, shattering contributes to the persistence and spread of this weed. The seed longevity of weedy rice is generally longer and more variable than that of cultivated rice.

Important traits of weedy rice are early shattering of seed, variable seed dormancy, and high seed persistence in the soil

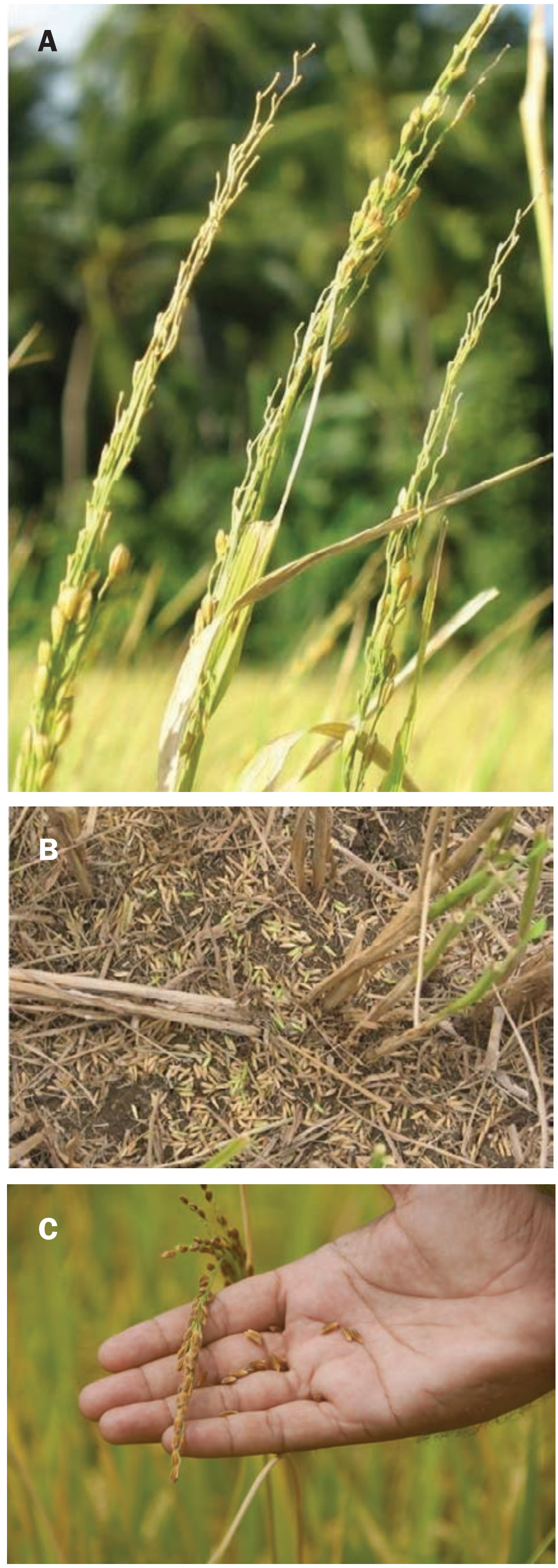

Fig. 3. Early shattering of grains (A & B) and handgrip test (C) for shattering of weedy rice

In addition to early shattering and dormancy in weedy rice seed, weedy rice may have a greater nutrient response than cultivated rice. In Asia and the United States, weedy rice has been found to have greater nitrogen-use efficiency for biomass production than cultivated rice. Weedy rice also has the potential to become a more problematic weed in the future. In the U.S., for example, a weedy rice population had greater competitive ability under rising carbon dioxide concentrations than a cultivated rice cultivar. Such information suggests that weedy rice may become even more difficult to control in future climate conditions.

Because of similar physiological and morphological traits between weedy rice and cultivated rice, selective herbicides to control weedy rice in conventional rice systems are not available and therefore managing weedy rice is a challenging and increasing problem for farmers in Asia. In the absence of selective herbicides, cultural weed management approaches may help reduce the problem of weedy rice. The information used in this publication is adapted from a recent article: Strategies to manage weedy rice in Asia (Bhagirath Singh Chauhan, *Crop Protection*, 2013).

Management strategies

Preventive measures

The most important preventive measure in reducing weedy rice infestation is the use of clean rice seed. In many countries, weedy rice seed has spread from an infested area to a clean area through the distribution of rice seed contaminated with weedy rice seed to farmers. A small fraction of weedy rice seed in cultivated rice seed may result in heavy weedy rice infestations within a few crop seasons. In double and triple rice cropping systems, heavy infestation may occur within a year. It is therefore important that weedy rice plants in crops not be allowed to produce and drop seed. Growers should use certified seed to avoid contaminated rice seed. Because of less use of certified seed in some regions, weedy rice and other weed seeds are commonly found as the major rice seed contaminators. In some areas, for example, in Sri Lanka, growers uproot weedy rice plants at heading and sometimes throw the plants into irrigation canals or flowing water and unknowingly spread weedy rice seed to other fields.

Use rice seeds free from weeds and weedy rice seeds

The farm implements used for land preparation, planting, harvesting, and threshing should be cleaned before moving them from one field to another. Field borders and irrigation canals free from weeds may also help in reducing weed problems. Growers need to inspect their fields regularly and should pull out weedy rice plants if present. To better understand the importance of clean seed and problems of weedy rice, there is a need to increase the awareness of weedy rice among growers.

Clean farm implements before entering them in a field

Stale seedbed practice and tillage

The seed bank of weedy rice and other weeds can be reduced using the stale seedbed practice. In this practice, after a light shower or irrigation, weedy rice, volunteer rice, and other weed seedlings are allowed to germinate and are then killed using nonselective herbicides (glyphosate or paraquat) or tillage (Fig. 4). The use of the stale seedbed practice helps reduce the size of the seed bank and number of weedy rice plants in the crop. However, the efficacy of this practice will depend on the degree of dormancy in the weedy rice seeds, as dormant seeds have a protracted emergence response. Growers need to decide themselves whether they have enough time to exploit the benefit of the stale seedbed technique, especially in the era of crop intensification.

A stale seedbed helps reduce the weed seed bank and weed density in the crop

Growers in some regions (e.g., India and Sri Lanka) practice straw and stubble burning (Fig. 5) and they consider burning as an effective strategy in reducing weedy rice seed present on the soil surface. This practice, however, is not desirable mainly because of smoke pollution. In addition, concern exists about the depletion of soil organic matter. Therefore, burning should not be practiced in fields.

Fig. 4. Stale seedbed practice

Fig. 5. Straw burning

Deep tillage can bury weedy rice seeds below its maximum depth of emergence

In different direct seeding systems, tillage is performed in dry or wet soil conditions. In dry-seeded rice systems, soil is cultivated in dry conditions, whereas, in wet-seeded rice, soil is cultivated in wet conditions. Thorough land preparation has been well known to control weeds. Repeated tillage operations may help reduce the seed bank and seedlings of weedy rice in rice fields. Weedy rice seedlings that emerge after cultivation can be killed by subsequent cultivation operations. Different tillage operations could be used to bury weedy rice seeds deep so that they cannot emerge from that depth. Most weedy rice seedlings emerge from the top 6–8 cm of soil burial depths. Such information indicates that weedy rice emergence could be suppressed by deep tillage that buries seed below 8 cm. In such situations, however, subsequent tillage operations should be shallow in the next few seasons to avoid bringing back the buried and viable seed to the soil surface. Seed brought to the soil surface may reinfest the field.

Establishment methods

In some countries (e.g., Malaysia, Vietnam, and Sri Lanka), wet-seeded rice has already been practiced for a long time. Now, growers in these countries face the problem of weedy rice. In direct-seeded broadcast systems, it is hard to differentiate between weedy rice and cultivated rice at the early stages because the rice seeds are broadcast and seedlings of rice and weedy rice emerge simultaneously. The rotating crop establishment method from wet-seeded rice to transplanted rice may help reduce weedy rice infestation. As mentioned earlier, because of the unavailability of labor and/or high labor cost, growers may not be able to hire labor for manual transplanting. However, scope exists for mechanized transplanting using transplanters (Fig. 6). These transplanters are now being used in many Asian countries, including India and Malaysia.

Weedy rice can be suppressed by adopting transplanted rice systems

Fig. 6. Mechanical transplanting

In transplanted systems, rice seedlings are more competitive against the newly emerged weedy rice seedlings and it is easy to distinguish weedy rice seedlings from cultivated rice seedlings. Standing water present in the field at the time of transplanting also helps to suppress the emergence and growth of weedy rice seedlings. Growers in many countries, such as Korea, Malaysia, and Vietnam, have been successful in reducing weedy rice infestation by introducing transplanted rice. In many Asian countries, however, there is a need to develop "custom-hiring" systems as many growers cannot afford to buy transplanters. In some regions, for example, in Sri Lanka and Vietnam, seedling broadcasting is practiced in the absence of availability of effective transplanters. In this method, seedlings are grown in a nursery and thrown/broadcast randomly onto puddled soil. Standing water in the field at the time of seedling broadcast helps to suppress weedy rice. In Malaysia, too, seedling broadcasting was found effective in reducing weedy rice infestation.

Water seeding is also being tried in some regions, for example, in Sri Lanka and Vietnam, to suppress weedy rice and other weeds as weed seeds flooded and buried in the soil are not able to emerge (Fig. 7). In this method, pregerminated rice seeds are broadcast in standing water (water 10 to 50 cm deep). Water seeding is different from wet-seeded rice as there is no standing water at the time of seed broadcast in wet-seeded rice systems. At present, however, water seeding is not widely adopted by growers because cultivars capable of germinating under anaerobic conditions are not widely available in Asia.

Fig. 7. Water seeding

Cultivars

In any crop or seeding system, weed-competitive cultivars should be involved as a tool in integrated weed management strategies. Tall cultivars are usually more competitive against weeds, but they have lower yield potential than short-statured modern cultivars. In addition, tall cultivars may not be used widely in the future. Because of the ever-increasing population, there will be more pressure in future farming to produce more rice on less land. In such situations, growers may need to increase nitrogen fertilizer rates and high nitrogen is known to cause crop lodging. Overall, information on the effect of weed-competitive cultivars on weedy rice is very limited in Asia. In the absence of such information, the use of cultivars with the traits of early vigor and quick canopy closure may help suppress weedy rice growth. Short-duration cultivars that mature earlier than weedy rice may also help in reducing the weedy rice seed bank.

In the absence of effective management strategies for weedy rice, the use of cultivars with purple-colored leaves may help to reduce weedy rice infestation and the weed seed bank (Fig. 8). In broadcast rice systems, it is hard to differentiate weedy rice seedlings from cultivated rice at the early stage of the crop. The use of purple leaf-colored cultivars will help in differentiating weedy rice seedlings, which can be pulled out. In India, growers used such cultivars in the past to get rid of weedy rice seedlings. Because of their low yield potential, however, such cultivars were not popular among growers. Rather than abandoning fields due to high infestation of weedy rice, it would be better to include such cultivars in a season in rice-rice or rice-rice-rice cropping systems to substantially minimize the weedy rice seed bank. If these cultivars have a market and potential in reducing weedy rice infestation, efforts should be made in breeding to increase the yield potential of purple leaf-colored cultivars.

The use of cultivars with purple-colored leaves may help to reduce weedy rice infestation and the weed seed bank

Fig. 8. Purple-colored rice cultivars

High crop density and row-seeded crops

A dense crop may help to suppress weeds in rice. Growers in many regions in Asia use high seeding rates to reduce weeds and to compensate for poor seed quality and crop establishment. Growers also increase seeding rates to compensate for losses due to birds, rodents, insects, nematodes, and snails. In Asia, growers use high seeding rates (up to 150 kg seed ha^{-1}) mainly in a broadcast rice crop but, in other parts of the world (e.g., South America), high seeding rates are also used in a mechanized row-seeded rice crop. The use of high seeding rates in weedy rice-infested areas, for example, in Malaysia, helped to reduce the problem of weedy rice. High seeding rates may not increase rice yield in weed-free environments, but may help to reduce yield losses due to weed infestation in weedy or partially weedy environments. Recent studies in the Philippines suggested that increasing rice crop interference could substantially reduce tiller and leaf numbers, leaf area, and shoot biomass of different weedy rice biotypes. Nonetheless, the surviving weedy rice plants may produce enough seed to cause infestation in subsequent cropping seasons. Therefore, there is a need to combine other weed management approaches with the use of high seeding rates.

The use of high seeding rates may help to suppress weedy rice growth

In most Asian countries, direct-seeded rice is sown by broadcasting dry (dry-seeded rice) or pregerminated (wet-seeded rice) seed. In such seeding methods, however, it is difficult to distinguish weedy rice seedlings from cultivated rice seedlings until the plants reach the flowering stage. In such weedy rice–infested areas, row-seeded rice will have an advantage over broadcast rice as weedy rice seedlings emerging between the rows can be easily distinguished (Fig. 9). In row-seeded rice, manual and mechanical weeding is much easier to perform. In addition, growers can easily pull out escaped weedy rice seedlings and prevent the production and shattering of weedy rice seed. Because of the availability of seed drills suitable for two- or four-wheel tractors, growers in some countries (e.g., Bangladesh, India, and Pakistan) are moving toward row-seeded, dry-seeded rice systems.

In a row-seeded crop, weedy rice seedlings emerging between the rows can be easily distinguished and pulled out

Fig. 9. A row-seeded crop

Wet-seeded rice systems are common in Sri Lanka and Southeast Asian countries and, at present, growers mainly broadcast pregerminated rice seed in these systems. However, wet-seeded rice can also be sown in rows using drum seeders or other mechanized seeding systems. Drum seeders were introduced in Asia a long time ago; however, their adoption is very low because they are not easily available everywhere and growers believe that they are expensive. In addition, growers are not comfortable in pulling a seeder in puddled soil. Sometimes, because of the heavy weight of the seeders, the seed box touches the soil surface and this results in blocking of holes from where seeds fall on the soil surface. Therefore, there is a need to evaluate different kinds of seeders that can be pulled by two- or four-wheel tractors in puddled soils. As mentioned earlier, many growers in Asia have small landholdings and most of them cannot afford to buy seeders or seeding machines. There is thus a need to strengthen custom-hiring systems.

Flooding

In any rice establishment method, water management is crucial for weed management. Optimal timing, duration, and depth of flooding are critical in managing weeds and weedy rice in direct-seeded rice systems (Fig. 10). Flooding at an early stage, for example, is more effective than flooding at a later stage in suppressing

Fig. 10. Flooding can suppress weedy rice emergence and growth

weedy rice emergence and growth. Similarly, appropriate flooding depth also determines the extent of weedy rice suppression. A flooding depth of 5 to 10 cm may be able to suppress the germination and emergence of weedy rice effectively. Flooding may not have a significant effect on emergence and biomass of weedy rice seedlings when seeds are present on the soil surface. When seeds are buried in the soil, however, flooding may decrease seedling emergence and their biomass. Such information suggests that flooding in the field may influence weedy rice emergence and growth differently for weedy rice seeds present on the soil surface or buried in the soil.

> Appropriate timing, duration, and depth of flooding are critical in managing weedy rice and other weeds in direct-seeded rice systems

In transplanted rice, flooding can be introduced a few days after transplanting. In direct-seeded rice systems, however, flooding is introduced only after the crop has emerged and, by that time, weedy rice seedlings may have also emerged. Emerged seedlings of weedy rice may be difficult to manage by flooding. At present, rice cultivars capable of emerging from the soil and floodwater are not commonly available in Asia. The availability and use of rice cultivars capable of emerging under anaerobic soil conditions may help in suppressing weedy rice emergence and growth during crop emergence in direct-seeded rice systems. The use of such rice cultivars may also help reduce herbicide use in rice-based cropping systems. Work is in progress at the International Rice Research Institute and other research institutes to develop suitable cultivars for different regions that are capable of emerging under anaerobic conditions.

The use of rice cultivars capable of emerging under anaerobic soil conditions will suppress emergence and growth of weedy rice during crop emergence in direct-seeded rice systems

Chemical control measures

Nonselective herbicides can be used to kill weedy rice before planting the rice crop. After repeated cultivation and irrigation, weedy rice seedlings would emerge and nonselective herbicides (glyphosate or paraquat) can be used to kill emerged seedlings of weedy rice and other weeds.

Selective herbicides to control weedy rice in conventional rice systems are not available as weedy rice and cultivated rice belong to the same species and they are similar in anatomical and physiological traits. Preplant application of effective soil-active herbicides may help to suppress weedy rice emergence; however, there is a need to modify the method and timing of such herbicide application. In some countries, growers apply pretilachlor (with a safener) before or after tillage operations under standing water to reduce weedy rice infestation. After 2 to 4 days, the standing water is drained and pregerminated rice seeds are broadcast. Herbicides such as oxadiazon and metolachlor at high rates may also provide effective control of weedy rice; however, these herbicides could have a phytotoxic effect on rice emergence, too. To avoid any such phytotoxic effect on rice, these herbicides should be applied around 2 weeks before rice planting. The phytotoxic effect on cultivated rice can be minimized by using high seeding rates.

Herbicide-resistant rice

Herbicide-resistant rice cultivars are resistant to a particular herbicide or herbicides that would otherwise damage the rice crop. These particular herbicides are sprayed on the resistant rice cultivar and they will not affect the rice but will instead kill weedy rice and other weeds in the crop. Therefore, in the absence of selective herbicides in conventional rice systems, herbicide-resistant rice cultivars could provide an attractive management solution to problems such as weedy rice and other hard-to-control weed species. Until now, three herbicide-resistant systems have been developed in rice: imidazolinone-, glufosinate-, and glyphosate-resistant cultivars. The imidazolinone resistance is based on chemical mutagenesis (i.e., nontransgenic), while glyphosate and glufosinate resistance is based on transgenic rice.

Herbicide-resistant rice is a double-edged sword

Two imidazolinone-resistant rice (Clearfield®) cultivars were released in Malaysia in 2010 to reduce weedy rice infestation and they may be introduced soon in other Asian countries. Herbicide-resistant rice is a double-edged sword. The use of herbicide-resistant rice may benefit rice farmers by improving weedy rice control and reducing weed control costs in the short term. The introduction of these technologies in Asia, however, raises a number of questions, including the potential gene flow to wild and weedy rice, the control of volunteer rice seedlings, the impact of changing patterns of herbicide use, the risk of damaging a neighbor's crop by herbicide drift, and the consequences of increased farmer dependence on input supply chains. In addition, the continuous use of a single herbicide may hasten the development of herbicide resistance in other weeds. Furthermore, imidazolinone residue in soil may affect the emergence of nontolerant rotational crops. In countries where herbicide-resistant rice has been grown for a long time, the evolution of resistance in weedy rice has caused more complications in managing weedy rice. As a result, some countries have withdrawn herbicide-resistant rice cultivars from the market because of severe infestation of resistant weedy rice populations in their rice fields.

Herbicide-resistant rice cultivars could prove very effective in managing weedy rice in the short term; however, there is a risk of their failure in the long term

In the short term, herbicide-resistant rice may prove an effective tool to manage weedy rice. In the long term, without careful implementation of management guidelines, herbicide-resistant rice may cause more difficulties in managing weedy rice and volunteer rice seedlings. Herbicide-resistant rice cultivars, for example, should not be grown in consecutive years in the same field and any weedy rice plants that escaped should be pulled out immediately before they shed seeds. A nonrice crop should be grown in rotation with herbicide-resistant rice cultivars. In Asia, there is an urgent need to develop stewardship guidelines for the use of herbicide-resistant rice cultivars. Government and nongovernment organizations, research institutes, and the private sector should come together and make joint efforts in developing and implementing stewardship guidelines (Fig. 11).

There is a strong need to develop guidelines for the use of herbicide-resistant rice

Crop rotation

Continuous growing of rice with similar management practices allows weedy rice to become dominant in the cropping system. Crops with different management practices, however, may help in disrupting the growth cycle of weedy rice. Therefore, a crop rotation is considered as the most effective control measure for weedy rice and other problematic weed species. In rice-rice or rice-rice-rice cropping systems, one rice crop (preferably in the dry season) could be rotated with an upland crop such as corn (maize), soybean, sesame, mungbean, etc. (Fig. 12). In these upland crops, the emerged seedlings of weedy rice can be killed by using a combination of different herbicides, which otherwise would not be used in a rice crop because of the nonavailability of selective herbicides to control weedy rice in the conventional rice system. Although there is a possibility of adoption of a crop rotation, there is a need to evaluate the availability of suitable crops and drainage of the rice fields in some areas. In addition, nonrice crops will not be adopted if their profit is less than that of the rice crop.

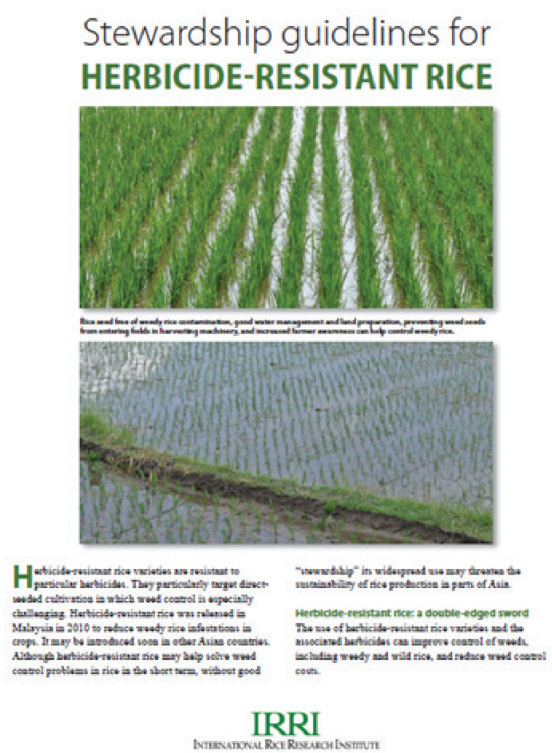

Fig. 11. Stewardship guidelines for herbicide-resistant rice

Crop rotation allows using different cultural practices in disrupting the growth cycle of weedy rice

One rice crop in monoculture rice systems can be rotated with an upland crop

Fig. 12. Rotation of rice with corn or soybean may help to reduce weedy rice problems

Conclusions

In Asia, weedy rice is an emerging problem in direct-seeded rice systems. It increases production costs and reduces farmers' income through lower yield and deteriorating seed quality. Selective herbicides to control weedy rice are not available in the conventional rice system and therefore managing weedy rice is a challenging and increasing problem for growers. Various cultural weed management strategies, however, may help lessen the problem of weedy rice. These strategies can include the use of preventive measures (clean seed and machinery), the use of a stale seedbed practice and thorough land preparation, rotation of rice establishment methods, the use of weed-competitive and purple leaf-colored cultivars, the use of high crop density and a row-seeded crop, the use of appropriate time, depth, and duration of flooding, the use of appropriate herbicides, and the adoption of crop rotation (Fig. 13).

Fig. 13. Possible management strategies for weedy rice in Asia

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