Strategy for Rice Production Technologies at IRRI

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Abstract

The targeted areas for IRRI to increase rice production with higher efficiency and more concern on sustainability are all rice-growing environments which can be divided into several basic agroecological units according to annual temperature and rainfall. Rice ecosystems are further characterized by the availability of water, which is closely related to the toposequence of the location, and roughly divided into upland, rainfed lowland, irrigated and flood-prone ecosystems. To promote more focused and interdisciplinary research, the research organization of IRRI was restructured in 1989 following a matrix which has ecosystems on one axis and scientific discipline on another. Another emphasis in the new structure is to further promote the association with national agricultural research systems (NARS) through the establishment of consortia, and strengthen the collaboration with advanced research institutes (ARI) for rapid access to latest research developments. With this setup, IRRI has endeavored to develop rice production technologies applicable to a particular ecosystem covering a wide range of research areas. In the irrigated ecosystem, where Japan has been so successful in increasing productivity, direct seeding technology has been tackled to cope with the decrease in labor availability and water resources due to the progression of industrialization and urbanization. A new plant type suitable for this technology with reduced tillering ability and large panicles has been developed from crosses between tropical and temperate japonicas. The stagnation or decline of crop yield under intensive cultivation has been recognized in most long-term experimental sites and analyzed in relation to nutrient management and insect/pest management to reverse this trend. The irrigated rice ecosystem occupies 54% of the world rice area and produces 75% of world rice. Since expansion of the rice area will be difficult due to the dense population and industrialization, the increase in production to meet the requirement of the ever-growing world population is only possible by raising yield productivity through germplasm improvement and integration of technologies.

Introduction

IRRI's achievements in the past highlight its strong breeding capabilities, which gave the world the famous IR 8 and the subsequent high-yielding, semidwarf varieties with various resistance genes to counter a wide range of biotic and abiotic stresses. The contribution of these seed-based technologies has been significant. In the Philippines, rice production in irrigated and rainfed areas has increased in conjunction with the adoption of modern high-yielding varieties (HYVs) which now account for more than 90% of cultivars grown by the farmers (David and Otsuka, 1994). However, the seed-based technology alone cannot express

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its full potential unless detailed knowledge on the management of crop, soil and insects/pests, socio-economic aspects and sustainability is integrated. IRRI has made considerable efforts to produce a package of knowledge-based technologies. Any successes brought about by the adoption of new HYVs are accompanied by the development of knowledge-based technologies.

This paper describes the recent research focus on irrigated ricefields instead of various types of technologies IRRI has developed for various eco-regions. The direct seeding technology is discussed as it will certainly replace the conventional transplanting technology in most of the rice-producing countries in tropical Asia. The latest research outputs relating to the direct seeding system will be briefly presented.

Rice ecosystems and agroecological zones

Rice plants are grown in a diverse range of environments. Although higher production is achieved in flooded fields, it does not necessarily mean that rice was originally cultivated under submerged conditions. There has been a long history of debate among rice scientists on the environmental conditions from which rice originated (Grist, 1975). To classify the environments where rice is now cultivated worldwide, surface hydrology should be taken into account as the dominant delineating variable, since rice growth is largely affected by surface flooding patterns. Most of the rice-growing environments are classified into irrigated, rainfed lowland, upland, and flood-prone ecosystems. The irrigated area occupies 54% of the total riceland and produces 75% of the world's rice (IRRI, 1997). The productivity in irrigated rice ecosystems reaches the 5 t/ha line, whereas that in other ecosystems remains low (2 t/ha or less, see Fig. 1). The prioritization of rice research, (i.e., how much focus or how much research funds should be allocated to a particular project) should require a detailed analysis of rice ecosystem classification. Several different geographic databases and maps have been developed. The FAO agroecological zone (AEZ) system is based on simple parameters such as duration of growing period and mean monthly temperature (Pingali *et al.*, 1997). It was adopted for research prioritization analysis across commodities and for resource allocation among the international agricultural research centers (Garitty *et al.*, 1996).

In the AEZ system, the terms arid, semiarid, subhumid and humid are defined according to the duration of the growing period, such as less than 75 days, 75–180 days, 180–270 days, and more than 270 days, respectively. Likewise, the terms tropics, subtropics, and temperate are defined according to the mean monthly temperature, such as more than 18℃ for all months, 5–18℃ for 1 or more months, and less than 5℃ for 1 or more months, respectively. Warm and cool describe the area where daily mean temperature during the growing period is more than 20℃, and 5–20℃, respectively.

Seven different AEZs exist in South, Southeast and East Asia (Fig. 2). The warm area consists of semiarid tropics (AEZ 1), subhumid tropics (AEZ 2), humid tropics (AEZ 3), semiarid subtropics (AEZ 5), subhumid subtropics (AEZ 6), and humid subtropics (AEZ 7). The cool area consists of only the subtropical temperate zone (AEZ 8). More than half of the ricefields in this region are located in AEZs 2 and 3. Rice production is almost equally shared among AEZs 2, 3, 6 and 7, ranging from 18–25%. The contribution of AEZs 5 and 8 is nearly

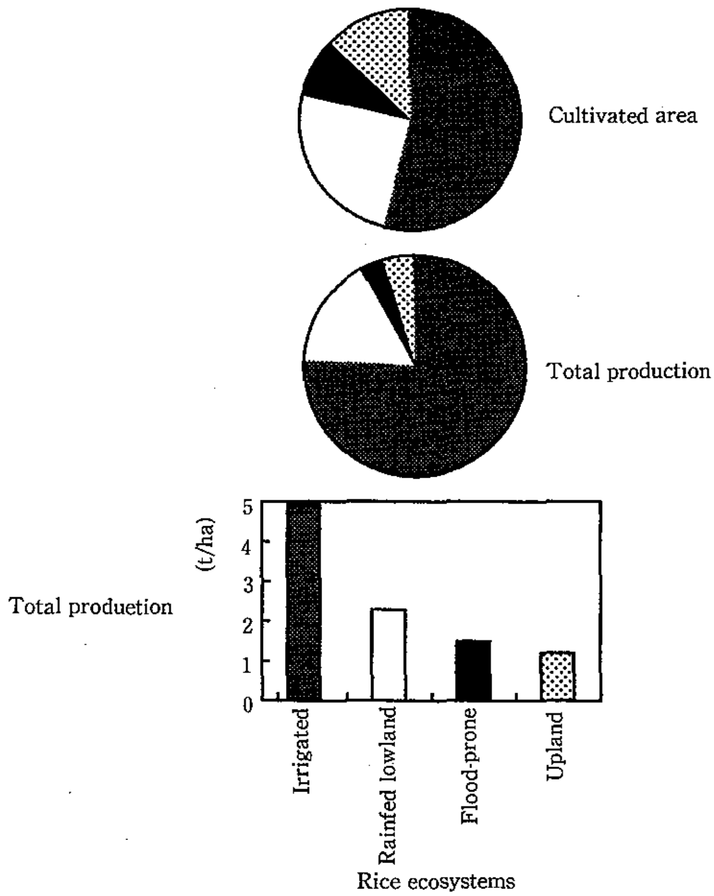

Fig. 1 Distribution of cultivated area, total production, and productivity of rice in the four rice ecosystems

negligible in terms of both area and production (Fig. 3). The productivity is generally higher in the warm subtropics (AEZs 5, 6, and 7) than in the warm tropics (AEZs 1, 2 and 3) mainly due to the well-developed irrigation system (Fig. 4). In AEZs 2 and 3, to which most of the Southeast Asian countries belong, the proportion of irrigated ecosystem is considerably low compared with other AEZs, especially a large part of AEZ 2 which is still kept rainfed. To increase rice production in this region, research should be based on a well-defined characterization of the rice ecosystems and targeted to the particular ecosystem.

IRRI's research structure

The problems associated with rice production are becoming increasingly complicated. Yield increase cannot be the only goal for research in the present time, but conservation of resources, sustainability of the environments, and other issues should also be addressed. To achieve this difficult objective, IRRI shifted its research organizational structure from the hierarchical top-down system to a matrix system which allows the scientists to have more

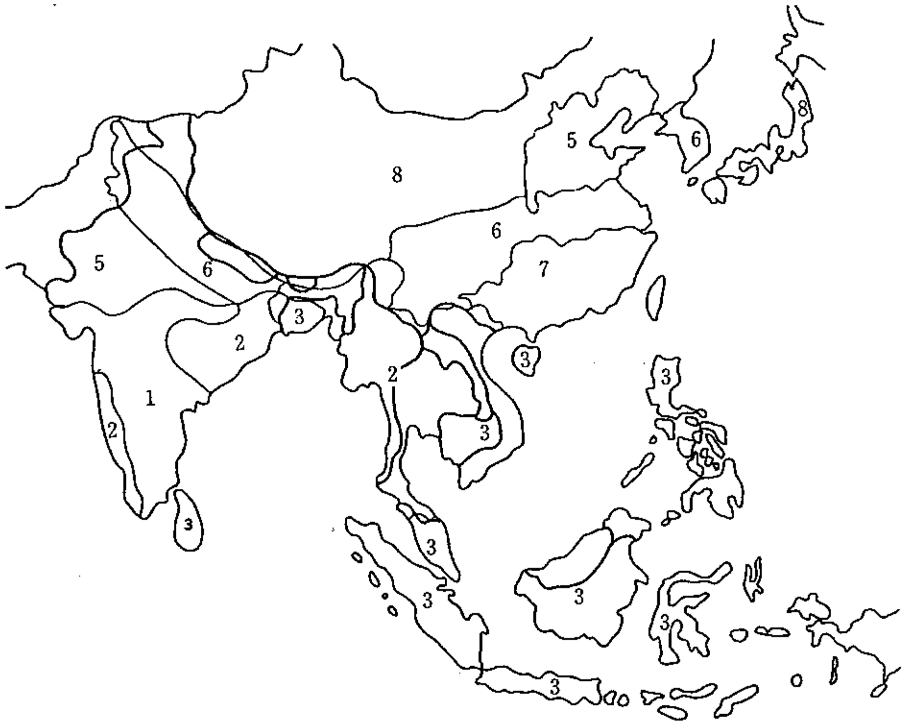

Fig. 2 Agroecological zones (AEZs) in South, Southeast and East Asia
AEZ 1: warm semiarid tropics, AEZ 2: warm subhumid tropics, AEZ 3: warm humid tropics, AEZ 5: warm arid and semiarid subtropics with summer rainfall, AEZ 6: warm subhumid subtropics with summer rainfall, AEZ 7: warm cool humid subtropics, and AEZ 8: cool subtropics with summer rainfall.

interdisciplinary and focused approach toward the goals. The research projects at IRRI are now implemented through a matrix with the programs on one axis and the divisions on the other. The programs are divided on the basis of the four rice ecosystems mentioned above, adding the cross-ecosystem as a separate program to deal with either fundamental or global research agenda which is common across the ecosystems. The divisions consist of six discipline-based units; Agricultural Engineering; Agronomy, Plant Physiology and Agroecology; Entomology and Plant Pathology; Plant Breeding, Genetics and Biochemistry; Soil and Water Sciences; and Social Sciences.

With this new structure, any core research agenda is subjected to open discussion from the time of priority setting and to final planning stages not only within the institute, but also within the research communities including the NARS and the ARI. The close partnership with these organizations enables IRRI to expand its capabilities.

Crop intensification and yield stagnation

The release of IR 8 and the subsequent HYVs, which are resistant to various biotic and

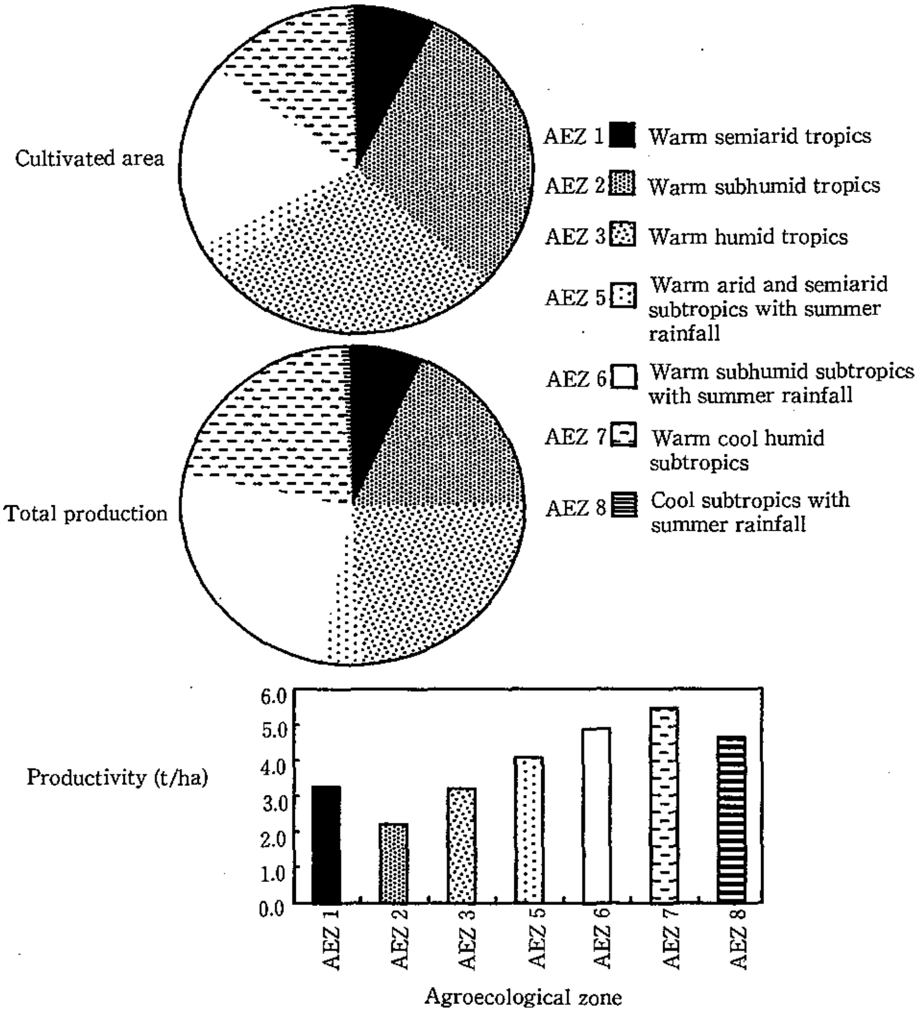

Fig. 3 Distribution of cultivated area total production, and productivity of rice, by agroecological zone

abiotic stresses, was important not only for increasing the yield level but also for changing the rice-based cropping patterns. The reduction in the growth period by 20–30 days enabled the farmers to grow one or two more rice crops in irrigated areas and other upland crops, such as cereals and grain legumes, which are planted before the end of the rainy season and grown with residual moisture. The intensification of rice-based cropping took place in many parts of Asia and gave farmers additional income. Although crop intensification definitely gave a positive impact on the farm communities, its long-term effects on the natural resources have not yet been well-investigated. In tropical irrigated areas, double or even triple rice cropping is possible, which has never been practiced in the temperate region like Japan, and consequently receiving little scientific attention in this region. This type of intensification likely gives a heavy load to soil resources. Under long-lasting submerged conditions, soil chemical reactions continue without sufficient oxygen supply and may result in the formation

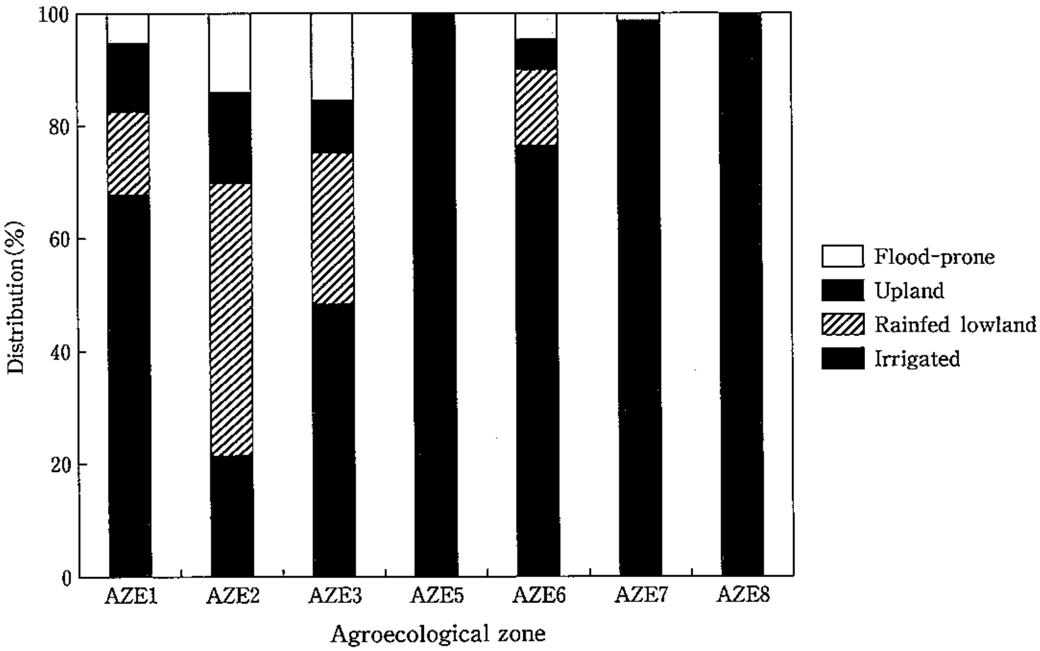

Fig. 4 Distribution of rice ecosystems in each agroecological zone
(See Figs. 2 & 3 for classification of agroecological zones).

of soil organic materials which are different from those produced under aerobic conditions.

There was no clear evidence to show the negative effect of crop intensification on rice production, but one emerging sign in relation to this is that growth rates in rice yield have declined sharply since the 1980s. For Asia as a whole, yield growth rates decreased from 2.6% per annum in the 1970s to 1.5% from 1981-88 (Hossain, 1996). Looking at trends at the national level, for example in Indonesia, total production and average productivity of rice increased steadily from 1976 to the early 1980s and then both seemed to reach a plateau. Although N fertilizer use on rice increased by 440% during this period, the partial factor productivity for N fertilizer increased sharply up to 1979 but steadily decreased afterwards. The current level is below 30 kg of grain output per kg applied N. This is mainly caused by an overdose of fertilizer brought about by subsidies from the government. Even at the farm level, for example in Ludhiana, Punjab, India, where an intensive rice-wheat double crop system has been practiced, average rice yields rose from 1.8 t/ha in 1970 to 4.0 t/ha by 1980 and have remained relatively constant since. A similar stagnating trend in rice production can be observed in eight out of ten long-term experimental fields established before 1975 in the Philippines and India (Cassman and Pingali, 1995).

A long-term trial has been conducted in IRRI's experimental field with three crops a year since 1963. Various yield constraints such as viral diseases, bacterial leaf blight, leaf streak, stem rot, sheath blight, and zinc deficiency were identified. Efforts were made to minimize these constraints during the course of the trial by introducing the best possible HYVs which are resistant to the diseases and by applying fertilizers. Nevertheless, the yield in this trial showed a steady declining trend during more than a 30-year period. Extensive research has been carried out to identify the major cause of yield decline. As far as the experimental field where socioeconomic and some external factors can be excluded is concerned, changes in the chemical structure of soil organic compounds may alter the capacity and pattern of nitrogen supply of native soils (Olk *et al.*, 1996). Nitrogen can no longer be supplied from the soils in the same way as before probably due to the continuous flooding. More nitrogen applied at the proper time is required to attain previous yield levels. Based on experience and data obtained from the trial, scientists in IRRI and their partners in NARSS have started addressing the yield stagnation problem at the farm and regional levels.

A trend analysis of rice production over the years should be carefully performed. The possible causes of yield stagnation varied and may differ from one site to another. The solutions applicable in an experimental field may not be applicable at the farm and regional levels but it remains imperative that a solution be found at the global level in order to feed the rice consumers who will be added to the Asian region with a 50% increase during the next 25 years (Pinstrup-Anderson, 1994). The increase in rice production should be achieved with less land, less water, and less labor. This situation is very different from what we faced a few decades ago and poses a tremendous challenge to us.

Direct seeding

The shift from transplanting to direct seeding will be one way of coping with the new situation of rice production. The direct seeding method can be broadly divided into wet seeding and dry seeding. In dry seeding, seeds are broadcast on dry soil or on soil with the moisture content corresponding to the field capacity. Wet seeding can be further divided into aerobic wet seeding (where sprouted seeds are broadcast on puddled soil surface), anaerobic wet seeding (where dry seeds are broadcast and covered with a thin layer of settling mud), and water seeding (where dry seeds are broadcast on water). Wet seeding is more popular than dry seeding and has a great potential to be widely accepted by farmers in the irrigated and rainfed rice ecosystems. The labor input can be markedly reduced by direct seeding for example 20 person-d/ha for transplanting versus 1-2 person-d/ha for wet seeding (Pandey, 1995). Wet seeding outperformed transplanting in farmers' field in terms of water economy, drought tolerance, and economic return mainly due to less expenditure on labor (Bhuiyan *et al.*, 1995 a, b). The production cost in the wet seeding system as practiced in Thailand is significantly lower than that in transplanting (De Datta and Nantasomasaran, 1991). Although great care should be taken to manage weeds in direct seeding, the labor cost advantage compensates for the increase in expenditure for weed management.

Sri Lanka has a long history of direct seeding. The cultivated area under direct seeding occupies nearly 80% of total riceland in the country (Pathinayake *et al.*, 1991). In peninsular Malaysia, direct seeding was seldom practiced before 1980, and since then it has been increasingly applied accounting for 80% of total riceland in 1993 (Supaad and Cheong, 1995). The rapid industrialization which took place in many Asian countries in recent years caused the migration of labor from rural to urban areas, resulting in increased labor cost and shortage of labor. In addition, water utilization has now shifted from agriculture to industry, which implies that the agricultural sector can no longer enjoy an abundant supply of water, especially during land preparation. To compete with industrial development, rice cultivation should be directed toward more mechanization and less dependence on labor. The direct seeding method meets these requirements.

1 Crop improvement in direct seeding

In direct seeding, the rice plants inevitably compete with weeds because they both germinate and grow at the same time. Since weeds display a much stronger early growth vigor than rice, they become a major biotic threat in direct seeding. One way to alleviate weed proliferation is to increase the seeding rate and to close the canopy as early as possible to limit light penetration onto the weeds. When HYVs are used, however, higher yield is not achieved in many cases, and reduced yield occurs due to the increased proportion of unproductive tillers and reduced spikelet number per panicle. This fact clearly indicates the need to develop varieties that fit well into direct seeding. Different ideotypes from HYVs must be bred as well.

In the early 1980s, IRRI scientists already started looking for a set of physiological traits that would enable to break the yield barrier and would be suitable for the emerging rice cultivation systems (Vergara *et al.*, 1991 ; Dingkuhn *et al.*, 1991, 1993). This project to develop a new plant type was started in 1989 (Khush 1996 ; Peng *et al.*, 1994). The new plant type has readily distinguishable features. It is characterized by a low tillering capacity (three to four tillers when direct seeding is applied) without unproductive tillers. Low tillering is usually associated with larger tillers resulting in a higher sink-source ratio and consequently higher spikelet number per panicle (200–250 in case of the new plant type). The new plant type has very sturdy stems and dark green, thick and erect leaves. Donors for these physiological traits originate from germplasm classified as bulu or javanicas from Indonesia. Javanicas belong to the same varietal group as japonicas based on allelic constitution at 15 isozyme loci, and are referred to as tropical japonicas. Crosses between tropical and temperate japonicas are fully fertile. Additional donors of tropical japonicas were identified in Malaysia, Thailand, Myanmar, Laos, Vietnam, and the Philippines. A large volume of hybridization work was carried out within the tropical japonica germplasm with selective introduction of genes from temperate japonicas and indicas.

The yield level achieved by the new plant type so far is still within the range of potential yield of HYVs. The current limitation of the new plant type is the low percentage of ripened grains. A detailed investigation is underway using a system analysis approach in order to achieve the targeted yield level, 12 t/ha.

2 Weed management in direct seeding

Manual weeding is extremely difficult when seeds are broadcast and cannot be applied in large-scale rice farming. Therefore, the main focus of weed management in direct seeding is on how to reduce weed proliferation with less labor and less time. The number of weed species usually increases by the shift from transplanting to direct seeding. Twenty-one weed species belonging to 13 families were identified before the direct seeding system was introduced in the late 1970s in the Muda area in Malaysia. In the first season in 1989, when 82%

of the area was direct-seeded, 57 weed species belonging to 20 families were recorded (Moody, 1996). The use of herbicides is highly attractive to farmers who practice direct seeding and to chemical industries which sell them. The over-dependence on herbicides results in low species diversity and allows new problematical weeds to appear in the agroecosystem. An agroecological approach is required to control weeds in direct seeding instead of relying heavily on chemical control methods. The shift of weed species and emergence of tolerant weeds can be avoided by rotation of chemicals and crops. Integrated weed management (IWM) was developed for the direct seeding system in the Muda Agricultural Development Authority. This includes: using two rounds of dry rototilling and land leveling, using weed-free, clean seeds, filling vacant areas in the field with healthy seedlings, applying direct weed control measures, using herbicides and hand weeding, and closely adhering to irrigation schedules (De Datta and Baltazar, 1996).

Weed control by flooding water is the most important component of IWM. For this, thorough land preparation and an irrigation scheme on schedule are necessary, which cannot be achieved by an individual farmer and which requires community cooperation. The growth and development of weeds can be suppressed by flooding during the early growth stages. Once weeds are established, flooding is less effective and deeper flooding is needed to suppress them (Moody, 1994). Not only is the intensity of weed proliferation markedly changed by the depth of flooded water but weed composition as well. Flooding causes oxygen deficiency which severely affects the germination and development of seeds of both rice and weeds. However, rice is generally more tolerant of oxygen deficiency than weeds. Rice cultivars tolerant of anaerobiosis were identified from *aus* and deepwater rices, improved semidwarf irrigated rice, *Oryza glaberrima*, and Fl hybrids (Yamauchi *et al.*, 1993). Direct seeding of anaerobic cultivars will be a promising way to reduce weed damage in combination with other weed management options.

The introduction of resistance genes to herbicide into rice would eliminate problems of herbicide selectivity. Transgenic rice plants resistant to certain herbicides have been developed. With transgenic rice, herbicide application can be performed at the most vulnerable growth stage of the weeds with less consideration for the rice plant itself. The herbicide-resistant rice plant raises issues related to risks due to increases in herbicide spray, harmful environmental and toxicological effects, and introgression of genetically engineered rice and related weed species (Moody, 1996). The herbicide-resistant rice attracts the attention of the private sector not only for selling the seeds and the herbicide itself, but also for providing a package of technologies including planting methods, herbicide spray, and so on. This will become a major agri-business venture in the near future. The active involvement of the private business sector has already started for other crops.

In terms of environmental safety and target selectivity, the biological control of weeds is a highly promising way to partly replace chemical herbicides. Fungi would seem to have the greatest potential as bioherbicides (mycoherbicides) because they offer a wide range of virulence, reproductive capacity, specificity, and stability. *Mimosa invisa* Mart. and *Sphenoclea zeylanica* Gaertn. have been controlled (100% mortality) by virulent pathogens in field trials at IRRI (Watson, 1994). Of 61 species listed as major weeds of rice, however, only six were identified as likely targets for classical biological control (De Datta and Baltazar, 1996). Bioherbicides often underperform under field conditions compared with laboratory conditions and more research on their formulation and application (Moody, 1996) is needed.

Concluding remarks

Since the development of new technology can only be achieved by the participation of a group of scientists from a wide range of disciplines and by using a considerable time span, the forecast of agricultural status at the planning stage of the project is a crucial factor for success. The research project relating to the direct seeding system is a good example. The importance of this technology has been recognized for a long time. Several research components have been incorporated into the project and synthesized resulting in a form of management options. Continuous efforts have been made and are still underway. The new plant type should be further improved. Details of the integrated management options should be indicated for nutrients, insects/pests, and weeds. Breaking the yield barrier with the new technology should be within our reach in the foreseeable future.

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