

# Sustainable Agriculture and Strategies in Rice Breeding

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Two topics are taken up on the basis of the author's experience in rice research. The first is a renewed understanding of rice farming as a type of sustainable agriculture, a summary of many preceding views. The second is a discussion of strategies in rice breeding. In this part some of the author's immediate experiences are cited.

## Rice Cultivation as a Model for Sustainable Agriculture

### *Ecological Stability of Irrigated Rice Farming*

Among prevailing agricultural systems, rice cultivation is predominant for densely populated areas with the Monsoon climate. Rice is a unique crop for flooded soils. Submergence of soil makes it possible to cultivate rice every year without any fallow land, because many pathogenic fungi do not survive the anaerobic condition. Light power is enough for cultivation. Because the weight of the soil block is decreased in water, a single cattle power, usually a water buffalo, can easily plow and paddle the soil, which is otherwise very heavy. Levees keep irrigation water in terraced farms; thus, rice cultivation is protected against soil erosion.

Electrochemical changes that occur in submerged soils were earlier discussed in detail by Ponnampertuma.<sup>1</sup> According to his paper, in normal tropical soils a set of soil conditions are achieved by submergence, where availability of nitrogen, phosphorus, potassium, calcium, magnesium, iron, manganese and silicon is high, while the supply of copper, zinc and

molybdenum is adequate. The decrease in redox potential (Eh) increases pH of acid soils and decreases pH of alkaline soils.

Soil fertility can be conserved better under anaerobic conditions, because ammonium in soil from crop residues or other organic matter is not easily oxidized into nitrate compounds which are carried away by water or volatilized into air. Mineral nutrition for rice is also supplied through irrigation water. This is the reason for the traditional no-input rice farming, which consistently yields about 1.5-2.0 tons per hectare (t/ha). Nitrogen can be supplied through fixation by algae and other microorganisms.

Weeds are controlled by irrigation, because many kinds are not adapted to submergence. No other crop is planted to flooded soil except rice. Besides, there are some additional merits in irrigated rice farming. Cattle can be fed with the weeds on levees. Fish culture in canals or swamps provides protein resources. The nutritional balance of rice proteins is one of the best among the staple cereals. Farms in arid regions are desalinized by a regular rotation of rice planting.

For introduction of rice cultivation to new areas where rice has not been cultivated, there are a set of problems. Supply of water is a limiting factor. Accumulation of salts can be a problem in arid areas, where salts are carried from underground to the surface and water evaporates, leaving salts.

The advantages of rice farming can be better understood in contrast with other farming systems like those in Europe, which

are characterized by the need of fallow land. No crop can be planted in consecutive years in a field plot, due to disease buildup; therefore, fallow land, pasture or rotation of crops is essential. In European types of agriculture, a major part of the nutritional proteins are supplied through animal husbandry, which requires forage crops. Uptake of proteins through animal products is estimated to require seven times more land area than relying on proteins of plant products. There is also potential soil erosion through overgrazing and rainfall. Similar problems can be seen in dryland farming, and also in nomad agriculture.

In conclusion, the ecological stability of rice farming is excellent, being comparable only to some plantation agriculture of perennial plants such as tea, coconut, oil palm, rubber tree, cacao bean and so forth. Rice farming will be one of the best models for agricultural systems in the future.

### ***Socio-Economic Aspects of Traditional Agricultural Systems in Asia***

Stability of farming through each production cycle has been guaranteed in rice farming. But, this system has been a subsistence farming without a marginal surplus that could have been invested for other local industries. Feudalistic land systems used to abide with the farming system. Villages provide a pool of landless farm laborers and unemployed laborers from city areas. There has been always a kind of vicious cycle: Without local industries people flow into cities to get employment; for them, food prices should be kept at a minimum; but, then there is little opportunity for villages to develop new industries. The green revolution was one of the attempts to improve such stagnant rural structures in Asia.

## **Green Revolution**

### ***Its Start and Impacts***

After World War II most of the Asian countries attained independence from colonialism. At the same time, the limit for extension of farming was evident, due to population increase, particularly in Indonesia, the Philippines and Thailand. In the pre-green revolution years,

there were some experiences in varietal improvement in many countries in Asia. There was a strong motivation for intensive agriculture following the model of the countries in the Far East, where land reform was successful and recovered heavy industries were able to provide sufficient chemical fertilizers.

Under such situations, international collaborative approaches were initiated for attaining higher yields of rice. The first model of a high yielding variety, Taichung Native 1 and several similar varieties were entered in cooperative trials sponsored by The International Rice Committee (IRC) of the Food and Agriculture Organization (FAO) for 1961-1963 in several countries.<sup>2</sup> The first crosses using such varieties were made in 1962 at the International Rice Research Institute (IRRI) in the Philippines. International collaborative approaches by scientists became easier by development of transport and communication. A new plant type of rice was identified in such a network of international testing.

Then, the new plant type was further improved through breeding programs into the release of IR 8 from IRRI in 1967. The improved type was characterized by a single gene for semi-dwarfism, *sd-1*, which is a basis for the short stature and improved response to increased fertilizer application. This type performed best with a combination of increased fertilizers under irrigation. Similar approaches were adopted in other crops like wheat.

The new technologies were adopted through the 1970s, and led to self-sufficiency of rice in chronically deficient areas. New areas for rice cultivation were explored, because sufficient return on investments for irrigation and related infrastructures was predictable. Research at national centers was also strongly supported. The intensified rice farming was further developed in Japan, Taiwan, Korea, Egypt and China.

### ***Associated Breeding Works with the Green Revolution***

To stabilize the initial success, there were some immediate tasks in intensive farming, as well as new attempts to improve rice in marginal areas.

First, breeding for resistance to diseases and insect pests was urgent, because the adoption of intensive rice farming, particularly of rice cultivation in the dry season, provoked an outbreak of pests and diseases which had been only minor problems in traditional systems. Breeding for resistance has been successful in wide areas, and by and large it has protected the gains from the improved plant type.

Second, some resources were allocated to genetic improvement of varieties in marginal areas, which the green revolution had bypassed due to deep water, adverse soils or drought. The author was once assigned to such areas of breeding as tolerance to adverse soils, resistance to blast disease and deep water rice. But progress in these areas was not significant due to limited time, lack of scientific means and social structures, which can still be seen in the northeastern states of India. Often, the target environments are too variable to set any clear focus. Any gain expected is assumed to be marginal, even if some success is achieved.

Third, improvement of grain quality is another area where steady progress has been attained. But there is a tendency for the market pressure for high quality to constrain breeders' effort toward a higher level of yield. A decline in productivity of rice is indicated in some areas of intensive rice production. The reason for this still remains for scientific analysis. A part of this decline may be attributed to the grain quality issue. For instance, Basmati 370 and Khaw dawk mali 105, reputed varieties for high market price but with low yielding capacity, have extensively been planted to wide areas in Myanmar, Thailand and other countries.

## Problems and Tasks in the Post Green Revolution Era

### *New Problems Which Were Outside of Targets of the Green Revolution*

As mentioned above, the technological plateau of yield has been attained, with an emphasis on grain quality. Budget cuts have been serious for cereal production and related research. Concerns for ecological stability of agriculture and rice cultivation have been raised in light of a new concept for evaluating agricultural systems, the issue of Low Input

Sustainable Agriculture (LISA). The emission of methane and 'green house effects', as well as salt accumulation in arid regions, are indicated as adverse factors from rice cultivation, although these aspects are not adequately studied. Fear of pollution by spraying insecticides, fungicides or herbicides has led a series of new ideas, such as organic farming, to the forefront.

### *Socio-Economic Aspects*

In the post-green revolution era, a new series of socioeconomic problems have emerged with self-sufficiency of rice. The new trend of industrialization caused domestic competition for land use, labor, etc. Fragile infrastructures for grain storage, transportation and sales became clear in rural industries. There has been criticism from the point of social equity to the outcomes of the green revolution. There are also clashes between subsistence farming versus profit-seeking international agricultural business under the GATT (WTO) agreement. Fledgling industries, mature societies with family farming, and workers in the middle classes are likely to be affected as well as small farmers. Those are far beyond the scope of any review by a rice breeder.

### *Strategies for Enhanced Yield Level*

#### *Prediction of Supply and Demand*

While self-sufficiency in rice has been achieved in major rice-producing countries in Asia, the demand for rice is estimated to be increasing beyond the capacity of production. According to an estimate of attainable rice yield, out of eight countries surveyed, only Thailand and Myanmar will be in a comfortable position for meeting the rice needs of their populations.<sup>3</sup> Vietnam and India will be in a tight situation, even if they can exploit the full potential of the technologies. China, Indonesia, the Philippines and Bangladesh are likely to face severe shortages, unless there is further investment in transforming the rice area from unfavorable to favorable ecosystems and technological breakthroughs.

Substantial yield loss is predicted due to various technical constraints.<sup>3</sup> For the irrigated ecosystem, yield loss due to all technical

constraints is 962 kg/ha, i.e., about 20%. For rain-fed lowland and flood-prone ecosystems, such a loss is estimated to be about 33% and 40%, respectively. Yield loss due to submergence, drought and cold is estimated to be 20% and 28 %, respectively, for upland and flood-prone ecosystems. Yield loss due to insects and diseases is also predicted to be severe, particularly in the rain-fed ecosystem.

### **Strategies in Rice Breeding**

Improvement for yield level will still be the target of first priority in the coming century. According to the report of IRC of FAO in 1994, the yield of modern varieties has become stagnant. Hybrid rice is the only technology presently available to overstep these yield barriers.<sup>4</sup> Having been in a position to review the hybrid rice technologies, I would like to discuss the potential of this technology.

Doubtlessly, hybrid rice using cytoplasmic male sterility (CMS) is one of the most significant achievements after the introduction of semi-dwarf high yielding varieties. The yield increase is estimated to be 15-20 % over the ordinary varieties. It is reported that this hybrid rice covered nearly half of the total rice areas in China. But the initial gains by hybrid rice have not been improved in China, perhaps due to the difficulty in breeding stable CMS lines and shifted emphasis on grain quality. Since the 1990s hybrid rice breeding has been one of the first priority programs in India, where hybrid rice is being increased from the initial adoption of 50,000 ha in the mid-1990s.

What is interesting in hybrid rice breeding is a series of unique innovations in the technology. After the success of the CMS system, hybrid seed production along the idea of two line hybrids has been a fascinating target. With the use of environment-dependent genic male sterility (EGMS), fertile plants can be propagated by self-pollination under one set of conditions, while the same genotype can be male sterile and be hybridized with any other variety. When the new type of hybrid was first proposed in China, few scientists were confident in it. But it is now a reality showing further yield increase. Hybrid rice technology will be improved further by the further study of EGMS.

Another idea is to overcome hybrid sterility between different groups of rice varieties (Table 5.1). Partial sterility is commonly found in the panicles of F1 hybrids between Indica and Japonica groups in rice. It is known as a barrier in the use of pronounced heterosis of Indica-Japonica hybrids. I started a genetic study in the early 1980s, and found that the panicle sterility in Indica-Japonica hybrids is caused by an allelic interaction at locus S-5 on chromosome 6, where Indica and Japonica varieties have S-5<sup>i</sup> and S-5<sup>j</sup>, respectively (Fig. 5.1). The heterozygote S-5<sup>i</sup>/S-5<sup>j</sup> produces semi-sterile panicles because of the partial abortion of the female gametes carrying S-5<sup>j</sup>. Some varieties such as Ketan Nangka (KN) and Dular, have a neutral allele S-5<sup>n</sup>, and the genotype S-5<sup>i</sup>/S-5<sup>n</sup> and S-5<sup>j</sup>/S-5<sup>n</sup> produce fertile panicles. S-5<sup>n</sup> is called the wide compatibility gene (WCG), and has been incorporated into Indica or Japonica varieties to overcome the sterility in Indica-Japonica hybrids.<sup>5</sup> In the past decade, several Indica-Japonica hybrids which have the neutral allele S-5<sup>n</sup> have been developed to determine the yield potential in China. Such hybrids showed strong heterosis, but their seed set were unstable under some environments. One way to solve the problem is to use Javanica varieties instead of Japonica. This idea has been utilized for the new generation of hybrids, inter-subspecific two line hybrids, which showed increased yield and were planted to 0.7 million ha in 1996 in China.

An ultimate technology in hybrid rice breeding will be the use of apomixis, which functions in some plant species to produce genetically the same progeny via seed. In this way hybrid plants may produce hybrid seed without any artificial crossing. So far there is no basis on which further progress can be seen in rice breeding.

### **A New Plant Type**

Yield gains of 25% is envisaged by improving plant type on another front. Promising new lines with big panicles and a few thick stems are being developed at IRRI.<sup>6</sup> So far the performance of the new types are not yet widely available. This approach reminds us of the project for 'super high-yielding rice' in the 1980s in Japan. A series of high-yielding lines were actually produced through this project.

**Table 5.1. Loci for hybrid sterility**

Locus	Chromosome	Marker genes in order	Crosses
S-5	6	<i>C, S-5, Amp-3; Est-2, Pgi-2, RG213, alk</i>	indica x japonica
S-7	7	<i>Rc, S-7, Est-9, rfs, ga-11, Acp-4</i>	Aus x javanica
S-8	6	<i>Cat-1, Pox-5, S-8</i>	IR2061-481 x javanica
S-9	4	<i>Ph, 1g, Mal-1, Est-1, S-9</i>	Aus x javanica
S-15	12	<i>Acp-1, Pox-2, S-15, Sdh-1</i>	IR2061-628 x Dular (Aus)
S-16	1	<i>Est-5</i>	China Native Rice x javanica
S-17(t)	12	<i>Pox-2, S-15, Sdh-1, S-17(t)</i>	P.B. II x japonica

Revised from Wan and Ikehashi 1996.<sup>16</sup>

In any breeding program, if the yield level is emphasized by ignoring other traits, there will be potential for a higher level of yield.

### **Extension of Elite Breeding Lines Through International Networks**

A more routine approach, though no less important than those mentioned above, is systematic exchange and tests of promising lines through an international network (INGER). Further support to such a system is important. The preceding program, the international rice testing program, had enormously promoted exchanges of better lines, as well as experience among breeders in each of the national programs. Such a program, if supported adequately, would contribute significantly to food security.

### **Application of Molecular Biology to Rice Breeding**

For those plant breeders who were assigned, with conventional tools, in the 1970s to some areas of rice breeding such as tolerance to adverse soils and host resistance to blast disease, the set of new tools based on molecular

biology seems to be powerful and attractive. The following are some new challenges from our laboratory to such tasks with a renewed set of weapons.

### **Development of Molecular Markers in the Breeding for Tolerance**

Of environmental stresses in rice production, tolerance to excess of soluble iron is known to show a clear genetic difference. The severest abiotic stress in the lowlands is iron toxicity in west Africa's lateritic soils. It has been shown that genetic tolerance to iron toxicity can contribute significantly to rice production in toxic soils.<sup>6</sup> We started a program to search for genetic markers for this tolerance. Initially, the testing method had to be improved. An improved screening method was developed on the basis of solution culture. Then, a search for RAPD markers which might be linked to the tolerance was started. To obtain stable PCR products as selection markers, the sequence of RAPD markers had to be determined as site-tagged sequences (STS), for which a set of new primers could be developed. This approach enabled us to identify, with a

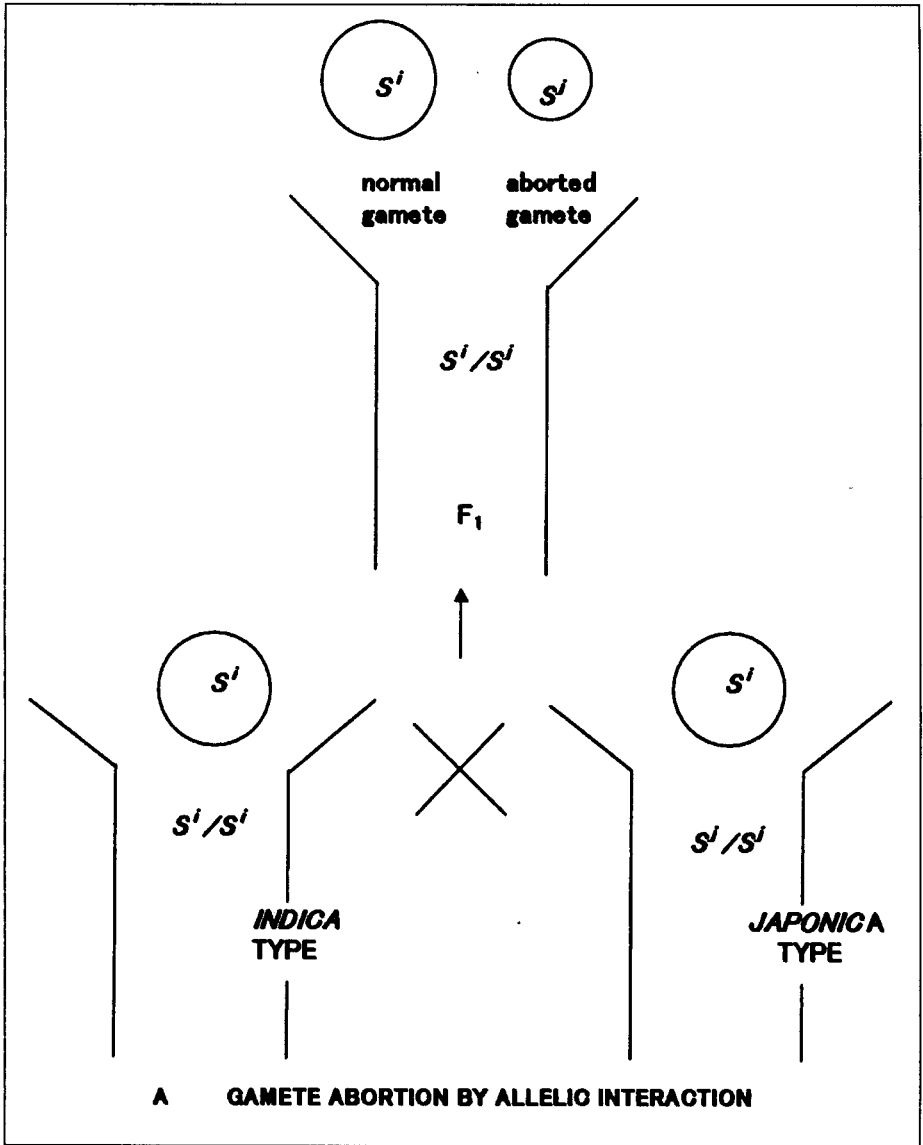


Fig. 5.1. Two types of allelic interaction at a hybrid sterility gene locus  $S^i$  gametes are abortion in the sporophyte genotype  $S^i/S^i$ .

high level of precision and reproducibility, a monogenic segregation in the tolerance, and can be a standard in any selection for highly variable tolerance to environmental stress.

### ***Search for Antifungal Proteins as New Resources of Host Resistance***

Incorporation of exotic resistance genes had been a major means in the breeding to rice blast (*Pyricularia oryzae*) resistance. But such new resistances break down sooner or later.

**Table 5.2. Pathogenesis-related proteins found in floral organs**

Proteins	Plants	Organs	Reference
RNases	Rosaceae	Pistil	Sassa et al 1993. <sup>8</sup>
PR-1	Camellia	Pistil	Tomimoto et al 1999. <sup>13</sup>
Chitinase	Rice	Husk	Nakazaki et al 1997. <sup>12</sup>
Chitinase	Rice	Pistil	Takei et al 1998. <sup>14</sup>
Thaumatococin	Rosaceae	Pistil	Sassa et al 1998. <sup>15</sup>

In early 1990s, we have initiated a minor study to identify self-incompatibility genes of fruit trees in Rosaceae, and identified a series of pistil-specific RNases which corresponded to the self-incompatibility genes.<sup>8</sup> That work suggested that plants may contain a variety of proteins against disease infection, and that such proteins may be utilized in breeding for host resistance. The proteins for self-incompatibility might be recruited from one of the antifungal proteins in floral organs, which seem to be most vulnerable to fungal infection.<sup>9</sup>

In the light of recent work to isolate host resistance genes of tomato and rice against bacterial diseases, the host resistance genes seem to function in signal transduction and do not seem to be antifungal agents for invading organisms. At the end of such responses there seem to be a set of proteins which are called pathogenesis-related proteins (PR proteins). They are initially defined as those induced by viral or fungal infection or by some chemicals like salicylic acid and benzothiadiazole.<sup>10</sup> They can be involved as antiviral or antifungal agents in a systemic acquired resistance, because such proteins directly inhibit propagation of pathogens.<sup>11</sup> What, then, can be seen if such proteins are incorporated and constitutively expressed in plants? In fact, the antifungal function of chitinases and PR-1 have been proved by gene transformation or in vitro testing.

In our preliminary search for PR-like proteins, some genes which encode novel PR-1 or chitinases were isolated (Table 5.2).<sup>12,13</sup> They are basic types and endogenously induced

in the course of development. So, their functions may be different from those expressed by other PR-I proteins, but the isolation of such types of PR proteins, and their subsequent incorporation into rice plants, are expected to reveal a new aspect of host resistance.

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