The navigation/fish lock with a chamber 6.6m wide and 30m long revealed various kinds of fishes passing through it. Similar locks will also be installed in the Saemangeum project.

**Nature reserves**

For the environmental conservation in the tidal area, several types of natural reserves have been designed in the project areas. In Daeho and Gye-hwado Lakes, some shallow parts of the reservoirs have been untouched to provide suitable shelters for migratory birds and fishes.

Various types of vegetations including floating leaved and submerged macrophytes have been growing in the wetland area. Reed is the most dominant plant as the emergent vegetation in the shallow lake area.

Zostera is an emergent vegetation 2 meter long, which grows in the shallow part of near shore in Gogeum seadike located in the southern coast. It provides a good shelter for fishes and accelerates the creation of new tideland as the tidal flow and wave action are much dissipated (Figure 7.30).

A survey carried out by the Ministry of Environment in 1999 revealed 1,070,000 birds migrate to Korea, among which 204,000 stay in Sihwa Lake, 57,000 in Asan and Sapgyo Lakes, and 87,000 in Haenam Lake. All these lakes were formed through tideland reclamation project.

A research project was carried out by the Korean government in conjunction with UNDP in 1998, at the shallow part of Daeho Lake in the western coast to derive sustainable development schemes for future tideland reclamation projects.

**The mild sloped seadike and groin**

Traditionally, quarry stone have been used as closing materials during construction and covering materials to prevent wave attacks during and after the construction of the seadike.
Saemangeum seadike has been designed to prevent the overtopping of waves from western coast as shown in the hydraulic model study (Figure 7.31). It was concluded that the slope of seadike should be 1:9 to prevent the overtopping of design wave whose height is 7.3 meter and for stabilization of the seadike with cover stones. Stones will not only resist waves during storm period but also function as resting area for people and shelters for fishes. In the upstream parts of Saemangeum project area, where several tideland reclamations had been carried out in 1920’s, several groins are found. They prevent scour and accelerate sedimentation in the tideland reclaimed area in the estuaries of Dongjin and Mangyeong river that flow into the Saemangeum projected area. The groin structure contributed not only to stabilize the seadike structure but also accelerated the development of new tidal flat.

Figure 7.32 shows the groin structure installed between Asan and Sapgyo seadikes to prevent wave attacks during the winter season. It not only protected the paddy fields in the reclaimed area but also contributed to the development of new tidal flat in Asan bay.

7.7 Perspective in 21st Century

**Chun Gyeong Yoon and Jin Soo Kim**

The challenges to be solved in the 21st century include high population, food scarcity, and environmental degradation to maintain favorable living condition on earth. The earth currently holds over 6.0 billion people which is increasing by approximately 100 million each year. This progressive increase in population demands increase in food supply for adequate feeding. With limited arable land on the earth surface, more pressures could be put on the farmlands to increase productivity, which can cause environmental problems.

The medium variant projection indicated a mid-21st Century population of 10 billion on earth. Agriculture is responsible for feeding the rapidly increasing population. About 800 million people are suffering from malnutrition, and 11 million children under age 5 are dying each year due to starvation (Radish 1996).

Rice is the principal staple food for half of human population, and Asian people produce and consume 90% of all the rice grown. Rice (*Oryza sativa* L.) is grown during summer in Korea on about 1,100,000 hectares, which is more than half of the total arable farmlands in Korea (MOAF 1999).
Water is one of the most essential prerequisites for sustaining natural ecosystems and human development. Increasing human population and greater economic development require more water, and competition occurs among the water demands of agriculture, residential, and industrial uses. Water stress is critical in the Middle East and North Africa, and also has affected Europe and North America, which are temperate and typically have plentiful resources. Numerous regions in France, Italy, Spain, and the United Kingdom have suffered the negative impacts of successive droughts during the last few years (Lazarova et al. 2000). Furthermore, the available freshwater is not always satisfactory for the intended water uses due to water quality problems associated with increased pollutant discharges.

South Korea is a densely populated country with about 47 million people in 100,000 km² and is classified as a country of water shortage. Several regions suffer water stress even with an average annual precipitation of 1,274 mm nationwide.

Rice production requires a large quantity of water. The fields are flooded before sowing, and the water level is held at 4–6 cm in shallow rice fields and as high as 10 cm in continuous flooding irrigation during the growing season (Rath et al. 2000; Anastacio et al. 2000). In the field operation, a total of about 1,250 mm is required for the rice crop during the growing season, and this water is primarily supplied through irrigation (Chae 1998).

Among the water uses, irrigation for rice culture ranks first, taking over 50% of the total water consumption in South Korea. Not only heavy water use, but also heavy use of fertilizers and pesticides are practiced to increase the rice productivity. Therefore, much concerns are placed on drainage water from paddy field as a potential source of water quality degradation.

### 7.7.1 Population

Korean peninsula had a population of about 14 million in 1911, 25 million in 1945, and increased to about 70 million in 1999. The population of South Korea only was about 20 million in 1949, 31 million in 1970, 47 million in 2000, and is projected at a maximum of about 53 million in 2030. With unification, a total of about 80 million will live in the land limited peninsula. Birth rates are not increasing markedly with the industrialization of the society, but life expectancy has been increasing consistently during the last few decades with enhanced medical services. Overall population projection of Korean peninsula could reach the range of 80 to 90 million.

### 7.7.2 Food

The major problem in Korean peninsula will be to secure adequate food production system. The principal staple food in Korea is rice. Currently, the rice production in South Korea meets the requirement with a slight surplus for trading. However, rice production system is still weak, and the governmental support is limited in the WTO era.

Farm labor consisting of old farmers is a constraint for sustainable rice farming. Furthermore, arable farmland has been decreasing continuously during last decades due to rapid urbanization, road construction, and industrialization. Thus, future prospects on
rice farming in South Korea are deemed to be gloomy unless substantial investments are made.

National effort to maintain sound rice farming system is imperative. Not only the government but also experts in crop science and agricultural engineering fields are desperately seeking a stable farming system in spite of many constraints.

### 7.7.3 Water resources

Korea has a relatively high annual rainfall of 1,274 mm, which is about 1.3 times the world average. However, the average amount of rainfall per capita per annum is about one-ninth of the world average due to high population density. Furthermore, large seasonal and geographical variations in rainfall cause difficulties in water resource management. Therefore, most dam sites were developed to secure water resources.

Water demand in Korea has been increasing continuously during the last several decades, and the major water use is for irrigation. The government has been trying to supply irrigation system, and expects to complete rural water development by 2004 attaining about 95% irrigation to paddy fields.

Water quality is another concern of water use. There are about 18,000 agricultural reservoirs throughout the nation, and about 31% of the monitored reservoirs exceed water quality standards for irrigation.

Quantity and quality aspects of water resources in Korea are not satisfactory at this point, and not expected to be improved in the near future. Even though more water resources are needed, dam construction to secure water receives less support due to environmental and ecological concerns. Pollutants from point sources by rapid urbanization and industrialization and nonpoint sources particularly from live stock areas cause rise in water pollution problems in rivers and reservoirs.

Efficient water resource management cannot be achieved through government efforts alone. Nationwide, particularly farmers’ participation and proper public education are needed.

### 7.7.4 Water quality in paddy fields

**Overview**

In South Korea, paddy fields of 1.10 million hectares amounts to about 60% of agricultural land. Therefore pollutant loads from paddy fields may significantly affect the quality of surface water. The paddy fields as artificial wetlands have beneficial features as follows: flood control, erosion reduction, groundwater recharge, and water purification. In contrast, runoff water from paddy fields almost always contains sediment and nutrients and can degrade downstream water quality.

Paddy fields generally are ponded and also drain water. There are input and output loads for pollutants with water flow in paddy fields. Input loads consist of irrigation water and rainfall loads, and output loads consist of surface outflow and percolated water.
loads. Two types of paddy fields exist according to the input-output budget (Tabuchi and Takamura 1985): a source type, where the output load is larger than the input load, and a sink type, where the output load is smaller than the input load.

Irrigation and fertilization play very important roles in rice production and have significant impacts on the stream water quality. There are many unanswered questions regarding rice production and its impact on water quality. Further researches on the water quality issues in paddy fields are needed.

**Further tasks**

The followings are tasks required for maintaining water quality in paddy fields during the 21st century:

1. **Monitoring and modeling of water quality**
   - Characteristics of the water quality in paddy fields significantly vary according to seasons, flow rates, and types of nutrients. Most nitrogen is transported from fields into receiving water bodies via drainage. In contrast, phosphorous, in combination with soil erosion, tends to enter surface waters during high-intensity but low-frequency storm events. The runoff pattern of pollutants in storm water from irrigated paddy field areas depends on the rainfall intensity, antecedent rainfall, fertilizer application rate, and irrigation management (Kim et al. 2000).

   Collection of statistically sound data on water quality in paddy fields may be costly and would require several years of field monitoring. In addition, more extensive data for different paddy fields and hydrologic conditions are needed.

   Water quality model on paddy fields, based on extensive data, should be developed. It can be used to evaluate the variable loadings of nutrients from paddy fields under different geologic, hydrologic, and management scenarios.

2. **Water management**
   - High volume of irrigation water causes high volume of drainage water and output loads. Runoff loads are reduced by water management techniques that result in low drainage volumes. Surface drainage should be reduced since it directly outflows nutrients in the ponded water into streams at times of puddling, transplanting, and fertilizer application. Physical improvements of paddy soils such as puddling and compacting sub-surface soil can reduce leaching loads due to excessive percolation. Reusing of tailwater and runoff can reduce output loads. With tailwater reuse, a portion of the sediment and nutrients can be recycled back into the fields.

3. **Fertilizer management**
   - The most efficient method of using fertilizer and minimizing its loss is by supplying it when needed by the crops. Accordingly, fertilizer applications at recommended rates and proper timing reduce nutrient loss in surface outflow. Use of slow release fertilizer can also reduce nutrient outflows by regulating the fertilizer particles at the time of melting to fit the assimilation of rice plant.
(4) Structural strategy

Automatic water supply system for paddy fields can save water use and therefore reduce output loads. Real-time monitoring systems for on-site water quality are also important for water quality control in paddy fields. Tailwater pit or sediment detention basin can be used to trap nutrients and keep them from entering the streams. Sediment basins require periodical excavation and removal of trapped solids.

(5) Incentive and regulatory policies

Incentive and regulatory policies are needed to abate non-point source pollution including agricultural pollution. Reliance on purely voluntary approaches is ineffective and results in very low participation of farmers in the abatement program. In 2001, the Ministry of Agriculture adopted a direct payment on rice agriculture, in which a subsidy of 200 to 250 thousand Won (about US $ 2,000) per ha is given to farmers who maintain ponding functions of paddy fields and apply fertilizers and pesticides at recommended rates.

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8 Special Rice Culture In Asia

8.1 Rice culture in Heihe of Heilongjiang province in China

*Jeong Hoon Kim and Hae Chune Choi*

Heihe located at 50° 15' North Latitude is the highest northern-limit of rice culturing region in the world. During the early 1960's, an experimental rice culture in Mohe located further north of Heihe at 53° 29' North Latitude was successfully cultivated. However, suitable rice cultivation could not be undertaken due to economical disadvantages and environmental unstableness.

The rice culture in Heihe was successfully performed in 1922, but the area was very small. By 1949, the rice cultivation area increased to 306 hectares and the average rough rice yield per hectare was about 1,305 kg. The rice cultivation area in 1971 reached to 3,251 hectares through extensive development of paddy fields during 1960-70's, and the rough rice yield per hectare also increased to 2,535 kg. Presently, the mean rough rice yield per hectare is 5 tons with some small-scale high-yielding rice farms showing about 6~7.5 tons per hectare in rough rice. In addition, the cultural technology for high rice production in high-latitude cold area was established.

8.1.1 Climate and soil

Heihe region is strongly influenced by seasonal atmospheric circulation since it is located in the continental climate zone. The rise in air temperature during early spring is very slow, and the radiation intensity of sunshine during summer is very strong, although the annual mean air temperature is about 1°C. In particular, the solar radiation from May to August is about 23.0 x 10⁸ J/m² amounting to 51.8% of annual total solar radiation. While the effective solar radiation for photosynthesis during the period with temperature above 5°C is about 62.5% of annual total solar radiation, the total amount of solar radiation for photosynthesis during the period with temperature above 10°C is only 10.6 x 10⁸ J/m².

The accumulated temperature during rice growing period is about 2,000~2,200°C and the security ratio of optimum temperature for rice growing during this time is about 78.1%. The mean air temperatures of June, July and August in this district are about 17.8, 20.4, and 18.0°C, respectively. The total sunshine hour during May~September is about 1,205.7 hours and the annual total precipitation ranges from 500 to 600 mm concentrated during June-August. The drop in air temperature during autumn is very quick, and temperature difference between day and night is very large. Because the first frost occurs in mid-September, the frost-free duration in this region is about 120 days.

The soil in Heihe region is very rich, and there are large areas available for rice cultivation. The paddy soil has thick black-colored layer, high content of organic matter, high
water-holding capacity, and relatively high contents of nitrogen, phosphorus, and potassium, with soil pH of 5.5–6.5.

8.1.2 Rice cultivars

The very early-maturing rice cultivars can only be grown in the Heihe region, which has 95–100 days of growth duration and 9–10 leaves emergence in the main stem. The rice varieties cultivated mainly in this district were Heikeng 2 and Heikeng 5 developed by Heihe Agricultural Science Institute. At present Heikeng 7 with high grain quality and high-yielding performance of 7.5 t/ha in rough rice is popularly grown in this region. The general agronomic characteristics of Heikeng rice cultivars are strong cold tolerance and high germination ability under low temperature. The lowest germination temperature of these varieties is about 8°C. The Heikeng rice varieties generally are 80 cm in height, and have 9–10 leaves in the main stem and 60–100 spikelets per panicle. They also have 110–120 days of growth duration and are weakly photosensitive and considerably thermostressive. The accumulated mean temperature for full ripening is at least 634°C in this region. The rice cultivars grown in this district show high productiveness and less tillers, overlap of vegetative and reproductive growth periods, dark green leaves, short period of heading initiation till full heading, and high grain fertility.

8.1.3 Cultural practice

Since Heihe region is located in high latitude cold zone, which has a very short frost-free period and low temperature, the farmers exert all possible efforts to accelerate the rice growth during the high temperature period and to protect from cold damages. The conventional rice culture system in Heihe region at present is hand transplanting using about 25 days old rice seedlings raised in protected upland vinyl tunnel nursery.

**Germination and sprouting** Fully ripe rice seeds are selected through salt water with 1.13 specific gravity, washed several times with clear tap water, and treated in seed disinfectant solution. The seeds were then soaked in cold water for 7–10 days and were subjected to forced sprouting for two days at 30°C.

**Seeding and seedling raising** In general, seeding period is the last ten days of April, when the mean temperature is above 5°C. Nursery bed should be made on selected upland, which is fertile, flat, and can be easily drained. Acidity of the upland soil is adjusted and disinfected for the protection from seedling blight. The soil acidity can be adjusted using dilute sulfuric acid (H₂SO₄) or sulfur powder to attain an optimum pH of 5.5, and the soil is disinfected against seedling blight. Presently, the control of soil acidity and disinfection can be easily done using the newly developed mixture products enabling simultaneous acidity control and disinfection. In addition because the mixture products contain nitrogen, phosphate, and potassium, among others, separate application of basal fertilizer is not required. Subsequently, the nursery soil should be sufficiently moistened to maintain soil moisture until seedling emergence.

The optimum amount of seeding is about 300–350 g of sprouted rice seeds per m² nursery bed in order to grow healthy rice seedlings. After seeding and soil covering, herbicide should be applied to prevent the occurrence of barnyard grass. The nursery bed is then
doubly covered with vinyl film under vinyl tunnel for protection against low temperature and to ensure good seedling emergence. The vinyl covering also helps to maintain the soil moisture and increase the soil temperature. Furthermore, to ensure a higher seedling emergence rate, nursery bed can be set up in a vinyl house. When the air temperature rises, the vinyl cover is removed after the emergence and growth of enough seedlings. When the rice seedling shows 1.5 leaves, the nursery bed is treated again with a chemical mixture for soil acidity control and disinfection. The rice seedlings are grown for about 25 days, at which time show about 3.5 leaves and are 13~14 cm in height.

**Transplanting** Generally, transplanting time is on May 25th, when the mean air temperature reaches above 13°C. Currently, most farmers transplant rice seedlings by hand. The planting density is 3~4 seedlings per hill with 26 cm x 13 cm space. Because this region is located in high latitude, cool zone, establishing enough hills and panicles is extremely important for high yield.

**Fertilizer application** Fifteen tons of organic fertilizer per hectare is applied as basal before plowing. The chemical fertilizer generally is applied at a rate of 1 : 0.5 : 0.5 of N : P2O5 : K2O. The application amount at present is 105 kg of nitrogen (N) and 52.5 kg each of phosphate (P2O5) and potassium (K2O) per hectare. The nitrogen fertilizer is applied with 40% as basal, 30% as topdressing at tillering stage (after enough rooting), 20% as topdressing at panicle initiation stage, and 10% as topdressing at heading stage. The phosphate fertilizer is applied with 50% as basal and 50% as topdressing at panicle initiation stage. After heading K2HPO4 solution can be used for foliar application to increase the ripening ratio.

**Water management** The depth of irrigation water is maintained at 2/3 level of seedling height after transplanting until rooting, then as shallowly as possible from tillering till heading stage, and intermittently during grain filling period.

**8.1.4 Harvest, drying and storing**

Since the Heihe region has a very short frost-free period with needs of high grain production, the rice harvest usually starts after the first frost, which usually occurs between 12th to 15th September. Accordingly, the harvest is undertaken not at the yellow ripe stage but at dead ripe stage. At present a few farmers harvest using small combine harvesters, but most farmers still harvest by hand with sickle and dry naturally in the field. 

Since the autumn season is dry with sufficient amount of sunlight, the moisture content of rice grain is maintained at 18~20%. After natural drying the moisture content of rice grain becomes about 16~17%. Due to the cold temperature in October artificial drying is not needed and the grain quality can be maintained. The harvested rice is threshed using a thresher after about one month of natural drying in the paddy fields and stored with rough rice in storehouses. Since most farmers sell the rice soon after threshing and milling, very little of the rice is stored.

The moisture content of stored rice after winter through spring decreases to 15%. The cold winter allows the natural storage of rice grains without any deterioration in the grain quality.
8.2 Hybrid rice culture in China

_Huhn Pal Moon_

China is the first country in the world to put hybrid rice, a typical self-pollinated crop, into commercial use in 1976. Hybrid rice research work in China was initiated in 1964, and a set of WA-type cytoplasmic male sterile (CMS) system was developed in 1972 through backcrossing to transfer the CMS traits from wild rice population of *Oryza sativa f. spontanea*. Encouraged by the developments achieved by China, more than 16 countries and two international research institutes (IRRI and IRAT) are currently involved in the development of hybrid rice technology. However, the pace of development of hybrid rice technology outside China has been slow because most countries did not commit and invest wholeheartedly in this research endeavor (Virmami 1994). From 1976 to 1995, hybrid rice helped China to increase rice production from 129 to 200 million tons annually. Hybrid rice varieties yield on the average 6.6 t/ha (Yuan 1994) compared with 5 t/ha for the inbred rice varieties. More than 80 percent of the hybrid rice cultivated area is covered under two hybrids viz, Shan you 63 (65%) and V you 64 (18%). At the beginning, V20 A and Zhen Shan 97 A were extensively used for CMS lines. Recently, however, CMS lines with much higher outcrossing rates such as Bo A and U 1 A are being utilized. Use of these CMS lines has helped to increase the average seed yields in China from 2.0 t/ha to almost 2.8 t/ha. Hybrid rice is cultivated mainly in southern and central China.

Researchers are now experimenting with a new method of hybrid rice production called “environment-sensitive genetic male sterility”, which uses either photoperiod-sensitive genetic male sterility (PGMS) or thermo-sensitive genetic male sterility (TGMS). PGMS lines are sterile lines that regain fertility with daylight fluctuations. TGMS lines regain fertility when the temperature fluctuates, which means they can be used in the highlands of the tropics.

Though effective, the three-line system is cumbersome and tedious especially in seed production. The two-line system involving PGMS and TGMS lines has several advantages, such as wider choice of male parents, simplified seed production system, absence of negative effect of sterility-inducing cytoplasm, among others. Recently, two-line hybrids have been developed in China. The area under two-line hybrids is estimated to be around 0.3 million hectare.

To further increase the magnitude of heterosis, indica x tropical japonica hybrids are being developed. These hybrids have exhibited 10~15% higher heterosis than the indica x indica hybrids. However, they also have negative effects such as semi-sterility in the hybrids, unacceptable grain quality, and tallness. The problem of semi-sterility can be overcome by utilizing wide-compatible genes, and height and quality problems can be solved through careful choosing of the parental lines.
8.2.1 Current status of hybrid rice in China

In 1994, hybrid rice covered 15.7 million hectares, 50% of the total rice area, and hybrid rice production was 57% of the total rice output in China (Figure 8.1). The largest hybrid rice-growing province is Sichuan, where 3 million hectares (95% of the rice area) are covered by hybrids and the average yield has remained at 7.5 t/ha for years. Hunan is the second-largest hybrid rice-growing province, where the average yield of the second crop grown on 2 million hectares is 6.8 t/ha.

In 1998, China’s super hybrid rice - 64S/E32 and 64S/911- production hit a new world record reaching 17 t/ha. In 1999, the “super rice” grown on 6.7 hectares of land in 14 areas and on a 66.7 hectares plot in Jingsu and Hunan provinces resulted in as much as 10.5 t/ha. Yunnan cultivated 24.2 ares short-stalk 64S/E32 rice, reaping 16.5 t/ha, of which a single spot of 7.2 ares yielded 15.8 t/ha of rice. The yield of rice on 6.7 hectares plots of land in 12 areas and 66.7 hectares plots in 3 areas of Hunan exceeded 10.5 t/ha, while the 0.7 ares yield in Xinyang, Henan province resulted in 10.6 t/ha. Yuan stated that if 13.3 million hectares of paddy field is planted with super hybrid rice, an extra 30 billion kg of rice will be produced annually, feeding more than 70 million people.

The technology of hybrid rice seed production has been well developed. Nationwide average seed yield is 2.4 t/ha (Table 8.1). Several new cytoplasmic male sterile (CMS) lines with a high outcrossing rate and good grain quality have been developed recently. Furthermore, new rice hybrids with good grain quality and multiple resistance have been released to farmers. The field area ratio of A-line multiplication, hybrid seed production, and F₁ commercial cultivation was 1:30:1,000 during the late 1970’s. This has been increased to about 1:50:6,000 recently. The highest hybrid seed yield recorded (7.4 t/ha) was obtained in 1993 by the Zixing Seed Company of Hunan Province on a small plot (0.2 hectare).

<table>
<thead>
<tr>
<th>Year</th>
<th>Area (1,000 ha)</th>
<th>Yield (kg/ ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1986</td>
<td>100.5</td>
<td>1.995</td>
</tr>
<tr>
<td>1987</td>
<td>154.1</td>
<td>2.010</td>
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<td>1988</td>
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<td>146.6</td>
<td>2.438</td>
</tr>
<tr>
<td>1993</td>
<td>105.9</td>
<td>2.214</td>
</tr>
</tbody>
</table>

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**Figure 8.1**  Area and yield of hybrid rice in China
The seed production cost also decreased gradually and steadily (Table 8.2). Compared with its cost in 1976 and 1985, the seed cost in 1995 was 87 and 25% lower, respectively. The cost of F1 hybrid seed in 1995 was estimated at US$ 0.80 per kg (Table 8.3).

### 8.2.2 Constraints and challenges

Researches on the commercial use of heterosis in rice have made tremendous achievements during the past 20 years, although still in the juvenile stage, from a strategic point of view, because the high yield potential of hybrid rice has not yet been fully tapped. Hybrid rice breeding still has a bright future. Based on our studies, to derive full benefits from hybrid rice breeding, future developments may involve intensifying research on breeding methods and increasing the degree of heterosis. Three approaches are involved:

1. Three-line method using CMS system.
2. Two-line method using the photoperiod-sensitive genic male sterility (PGMS) or thermosensitive genic male sterility (TGMS) system.
3. One-line method using the apomixis system.

The rice hybrids used in commercial production belong to the category of inter-varietal hybrids based on the CMS system. Many years of practice and experience have proved that CMS system or three-line method is an effective way to develop rice hybrids and will continue to play an important role for the time. But this system has some constraints and problems.
In all rice hybrids developed so far, the harvest yield level has stagnated for years, an indication that yield plateau has already been reached for rice hybrids. It would be difficult to increase the yield potential further in new rice hybrids if no new methods and materials are invented and adopted.

Sources of male sterility-inducing cytoplasm that can be used to develop better CMS lines are poor. Currently, about 85% of the male sterile (A) lines used in commercial production still belong to the wild abortive (WA) type. The dominant cytosterility situation of the WA type could produce a crisis in the long run, which could make hybrid rice susceptible to pests.

The heterosis level in japonica hybrids is not as good as that in indica hybrids. In addition, the currently used CMS lines (BT type) in japonica are not stable enough to produce pure F₁ seeds. The planting area of japonica hybrids has not only been limited to about 0.1 million hectares for many years, it is declining.

A limited number of very early maturing hybrid combinations with high heterosis are grown for the first cropping in the double-cropping regions of rice, which is one of the major reasons why the area of hybrid rice is not able to increase.

To increase the yield potential of hybrid rice, the magnitude of heterosis must be increased by adopting intersubspecific and/or intergeneric hybrids. In each of these phases, if the objectives are achieved, it will be marked as a new break-through in rice breeding and result in a large yield increase.

### 8.2.3 Strategies for 21st century

#### Development of two-line hybrids

Taking the long-range strategy of rice heterosis breeding into account, several Chinese rice scientists have been exploring new technological approaches to replace the CMS system. So far, the most successful outcome is the development of two-line hybrids. This method is based on two new types of rice genetic tools, photoperiod-sensitive genic male sterile (PGMS) lines and/or thermo-sensitive genic male sterile (TGMS) lines that recently have been successfully developed in China. Their male sterility is mainly controlled by one or two pairs of recessive nuclear genes, and has no relation to cytoplasm. Exploitation of these P(T)GMS lines to develop rice hybrids has the following advantages over the classical three-line or CMS system:

- The maintainer line is avoided. PGMS lines under longer day length or the TGMS lines under higher temperature show complete pollen sterility; therefore, they can be used for hybrid seed production under these conditions. Under shorter day length or moderate temperature conditions, they show almost normal fertility and can thus multiply through selfing.

- The choice of parents in developing heterotic hybrids is greatly expanded. Studies show that more than 95% of varieties tested (within the same sub-species) can restore such GMS lines. In addition, PGMS and TGMS genes can be easily transferred into almost any rice lines with desirable characteristics.
No negative effects are caused by sterile cytoplasm and the dominant cytoplasm situation of WA will be avoided.

Several achievements in this research area have been made.

Another advantage of the two-line system over the three-line system is that the yield area ratio of P(T)GMS line multiplication, seed production, and commercial use of F1 is 1:100:12,000-15,000. The expansion of this ratio can reduce seed cost.

The temperature-sensitive stage ranged from the differentiating stage of the pollen mother cell to the early ripe stage of pollen. Critical temperature points (CTP) of fertility alteration varied in different TGMS lines: 26.5°C (daily mean) for W6154S, W6184S, W6111S, W6417S, and W8103S; 25.5°C for W9046S and W9056S; and 24°C for W91607S. The fertility expression of PGMS lines was controlled simultaneously by photo-period and temperature. PGMS line W7415S had a CTP of 26°C and a critical photoperiod point (CPP) of 13.5 h. The CTP and CPP for W9451S and W9461S were 24°C and 14.0 h, and for W9593S were 24°C and 13.0 h, respectively. A practical and effective procedure for breeding PGMS, TGMS and TGMS lines has been established.

To develop two-line rice hybrids, several types of PGMS and TGMS lines exist, which pose no restrictions for the restorer-maintainer relationship as in the case of CMS lines. It is, therefore, relatively easier to develop desirable new two-line rice hybrids than three-line rice hybrids. In an early work on the breeding of two-line rice hybrids, Chinese breeders generally used the newest restorers, such as Minhui 63, Wanhu 9, and 6078, from the three-line breeding program, and the newest cultivars, such as Teqing, Shanqing 11, Te-san-ai, and 77 Zhan, from the inbred breeding program as two-line system restorers. A number of new two-line hybrid rice combinations with a yield increase of 5-10% over the three-line combinations (Table 8.4) have been developed and commercialized (Wang and Li 1992, Luo et al. 1994, Wang et al. 1995, Chen et al. 1996). It is believed that two-line hybrids will replace 70% of the three-line hybrids during the first decade of the 21st century.

Table 8.4  Two-line hybrid rice combinations in commercial production and regional trials in China

<table>
<thead>
<tr>
<th>Combination</th>
<th>Cross</th>
<th>Subspecies</th>
<th>Place developed</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>70 You 9</td>
<td>7001S/ Wanhu 9</td>
<td>Japonica</td>
<td>Anhui AAS</td>
<td>Commercialized</td>
</tr>
<tr>
<td>E-Jing-Za No. 1</td>
<td>N5088S/R187</td>
<td>Japonica</td>
<td>Hubei AAS</td>
<td>Commercialized</td>
</tr>
<tr>
<td>Hua-Jing-Za No. 1</td>
<td>N5088S/1514</td>
<td>Japonica</td>
<td>Huazhong Agric. Univ.</td>
<td>Commercialized</td>
</tr>
<tr>
<td>Liang-You-Pei-Te</td>
<td>Pei 64S/ Teqing</td>
<td>Indica</td>
<td>Hunan HRRC</td>
<td>Commercialized</td>
</tr>
<tr>
<td>Pei-Za-Shan-Qing</td>
<td>Pei 64S/</td>
<td>Indica</td>
<td>Hua Mao Company, Guangdong Province</td>
<td>Commercialized</td>
</tr>
<tr>
<td></td>
<td>Shanqing 11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pei-Uang-You 288</td>
<td>Pei 64S/288</td>
<td>Indica</td>
<td>Hunan Univ.</td>
<td>Commercialized</td>
</tr>
<tr>
<td>Pei-Za 77</td>
<td>Pei 64S/77 Zhan</td>
<td>Indica</td>
<td>Guangdong AAS</td>
<td>Regional trial</td>
</tr>
<tr>
<td>Liang-You 681</td>
<td>Shuguang 612S/881</td>
<td>Indica</td>
<td>Sichuan Univ</td>
<td>Regional trial</td>
</tr>
</tbody>
</table>

*AAS = Academy of Agricultural Sciences, HRRC = Hybrid Rice Research Center*
Development of intersubspecific hybrids

Studies have indicated that the degree of heterosis in different types of rice hybrids shows the following general trend: indica / japonica > indica / javanica > japonica / javanica > indica / indica > japonica / japonica (Yuan 1994). The first three types are intersubspecific hybrids and the latter two are intervarietal hybrids. Indica/japonica hybrids possess the highest yield potential considering their sink and source. Their theoretical yield may be 30% higher than those of the existing intervarietal hybrids (Yuan 1994). Exploiting the strong heterosis in indica/japonica hybrids has been the major goal of our two-line system hybrid breeding program. To achieve this, however, five barriers commonly found in such F₁ hybrids must be overcome: the low rate of seed set, very tall plant-height, very long growth duration, many poorly filled grains, and poor grain quality.

Using wide compatibility (WC) genes, the low seed-setting rate caused by semi-sterility from incompatibility between indica and japonica lines can be raised to nearly normal level. A large number of japonica lines and several indica TGMS lines possessing WC genes have been developed recently.

Transferring an allelic dwarf gene (Sd₁) into the male and female parents can lower the plant height of indica/japonica hybrids to semi-dwarf level, and still allow the hybrids to express strong heterosis. By crossing parental lines of different growth duration, except photosensitive late varieties, indica/japonica hybrids with medium and even shorter growth duration can be obtained.

Efforts are now focused on solving the last two problems, the low grain filling and poor grain quality. Within a year or two, revised breeding strategies are expected to help overcome these barriers. The new strategies put emphasis on developing indica/javanica hybrids rather than typical indica/japonica hybrids in the indica rice-growing region and japonica/javanica hybrids in the japonica rice-growing region. The superiority of this strategic change involves:

- Fewer fertility problems.
- Ecological adaptability, which will solve the problem of poor grain filling.
- Indica/javanica hybrids have similar or improved grain quality compared with that of indica rice; the japonica/javanica hybrids also have similar or better grain quality.

Several combinations that performed well in the experimental field in 1995 underwent regional trials in 1996. The intersubspecific hybrids with super high yield potential (100 kg/ha/d) are expected to be released to farmers by the end of this century. These hybrids will play a major role in increasing rice yield during the 21st century.

Development of the one-line system of hybrid rice

Theoretically, there could be several approaches to fixing heterosis; among these, the use of apomixis to develop true-breeding F₁ hybrids appears to hold promise. Although this research program began during the late 1980’s, it is still tentative. After extensive screening, some apomictic rice lines with a low frequency of apomixes (adventitious embryo and apospory) were found, but their frequency is too low (only 1~5%) for practical use. Transferring the obligate apomixis gene from wild grasses (such as Pennisetum) via genetic engineering combined with conventional breeding should be an effective way
to develop the one-line system of rice hybrids. This could be achieved during the 21st century.

Using distant genes to raise the heterosis level
To attain stronger heterosis observed in distant crosses, a marker-assisted advanced breeding strategy can be used to rapidly discover and transfer valuable novel genes for high yield potential and grain quality from wild species into elite combinations of hybrid rice. Based on careful evaluation in the experimental field and with the help of molecular markers, we discovered two important quantitative trait loci (QTL) from a wild rice in 1995 (Xiao et al. 1996). The two genes are located on chromosomes 1 and 2, each bringing about an increase in grain yield of 20% compared with the control hybrid. China has just started to use new strategy to exploit heterosis of distant hybrids. It is expected that the skillful combining of conventional breeding methods with molecular techniques could lead to another breakthrough in hybrid rice breeding during the first decade of the 21st century.

8.3 Rice culture in Punjab saline soil area of India

Kyu-Seong Lee

Rice is the staple food for most of the Indian population and particularly for Southern and eastern Indians. In Punjab, one of the smaller state of India, a giant leap in rice productivity and production was observed after launching of the first five-year-plan in 1950-1951 and the introduction of high yielding, short duration and photo-insensitive varieties in 1970’s. The increases were mostly due to the increased area of rice cultivation, rapid spread of the high-yielding varieties, well established irrigation system, improved production technologies, and the enthusiasm of rice farmers in the Punjab state (Kanchan 1982).

The success in rice production at present, however, has been made through great efforts to overcome the challenges that give unstable yield production due mainly to the soil problems in the state. In India, saline and sodic soils occur in some 10 million hectares of lands. Out of this area nearly 40 percent occurs in the Indo-Gangetic alluvial plains of the Punjab, Haryana, Uttar Pradesh, Delhi, and parts of Bihar and Rajasthan (Jawahar 1973). In the Punjab state alone, 0.75 million hectares is salt-affected, and this area is spread out in the arid and semi-arid regions of the state. In the salt-affected area, it appears that, even in area with deepwater tables, the water tables rise close to the surface during wet periods. The rise in water-table, the use of brackish water for irrigation, poor internal drainage, and, sometimes, excess surface drainage have contributed to the accumulation of salts in the Punjab soils.

Here discusses understanding of technical constraints to rice production during decades in Punjab state, which requires knowledge of some factors affecting rice production such as soils, climate, pest, fertilizers, soil management, and cultural practices. It is important to identify the constraints, which operates to keep rice yields significantly below their
Potential maximum, and to channel efforts to increasing yields by solving the problems existing in the state.

8.3.1 Environment of rice culture in Punjab

Geographical situation
Punjab is situated in the Northwestern corner of the country. It is bounded on the north by the Indian states of Jammu and Kashmir, on the east by Himachal Pradesh and the Union territory of Chandigarh, on the south by Haryana and Rajasthan, and on the west by Pakistan. The state, covering an area of 5.04 million hectares lies between the 29° 33’~ 32° 31’N and 73° 53’~ 76° 55’E. The land utilization pattern of the state is shown in Table 8.5.

Climate
The climate of Punjab is mostly influenced by the Himalayas in the north and the “Tharai” desert in the south and southwest. The mean annual rainfall varies from less than 300~500mm in south to middle parts to about 750~1,400 mm in northern parts (Figure 8.3). A major portion (70%) of rain is received during monsoon (July to September). The mean annual temperature varies from 23.3 to 25.8°C. The mean monthly minimum temperature (January) is as low as 4.7°C and the mean monthly maximum temperature (June) is as high as 42°C. The area qualifies for hyperthermic to thermic temperature regimes.

Extent of problem soils
Saline and sodic soils are occupying an area of about 0.7 million hectares in the arid and semi-arid zones of Punjab. Redistribution of salts occurs in the profile due to fluctuation of ground water table, prolonged use of poor quality irrigation water, and improper soils. Besides alkali and salt-affected soils (Figure 8.3, Table 8.6), water and wind erosions, waterlogging, and poor soil physical conditions are some of the critical important factors contributing to the problem.

<table>
<thead>
<tr>
<th>Designation</th>
<th>Area of land (Million ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total geographical area</td>
<td>5.04</td>
</tr>
<tr>
<td>Reporting area for land utilization statistics</td>
<td>5.03</td>
</tr>
<tr>
<td>Forest</td>
<td>0.22</td>
</tr>
<tr>
<td>Not available for cultivation</td>
<td>0.52</td>
</tr>
<tr>
<td>Other uncultivated land excluding fallow land</td>
<td>0.05</td>
</tr>
<tr>
<td>Fallow land</td>
<td>0.04</td>
</tr>
<tr>
<td>Net area sown</td>
<td>4.21</td>
</tr>
<tr>
<td>Area sown more than once</td>
<td>2.72</td>
</tr>
<tr>
<td>Total cropped area</td>
<td>6.93</td>
</tr>
</tbody>
</table>

* Source: Sehgal, 1985
Irrigation and cropping pattern

Salinity control is frequently a major concern of irrigation management, even though the primary objective of irrigation is to maintain soil water in a range suitable for optimum rice yield. About 5.96 million hectares in Punjab is under irrigation, which constitutes about 86 percent of the total gross cropped area. Wheat, rice, maize, and cotton are the crops that share the major area under irrigation. Irrigation is a component of agricultural transformation, changing in the patterns of land use, and can be viewed as a land-augmenting technology such as adopting high yielding varieties and chemical fertilizers, that results in an increase in the effective amount of land availability through changes in the land use intensity.

In general, the main cropping systems followed are rice-wheat in the central Punjab. This system, however, has been changing in favor of rice in this area when the irrigation system has been built up from canal and tubewell irrigation after 1970’s in Punjab.

Table 8.6 Distribution of alkali- and salt-affected soils in different states, India

<table>
<thead>
<tr>
<th>State/Union territory</th>
<th>Alkali-affected (thousand ha)</th>
<th>Salt-affected (thousand ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uttar Pradesh</td>
<td>1,900</td>
<td>2,375</td>
</tr>
<tr>
<td>Gujarat</td>
<td>2,65</td>
<td>1,334</td>
</tr>
<tr>
<td>West Bengal</td>
<td>-</td>
<td>1,150</td>
</tr>
<tr>
<td>Rajasthan</td>
<td>2,80</td>
<td>958</td>
</tr>
<tr>
<td>Punjab</td>
<td>2,98</td>
<td>749</td>
</tr>
<tr>
<td>Maharashtra</td>
<td>1,24</td>
<td>14</td>
</tr>
<tr>
<td>Haryana</td>
<td>2,55</td>
<td>636</td>
</tr>
<tr>
<td>Orissa</td>
<td>-</td>
<td>404</td>
</tr>
<tr>
<td>Karnataka</td>
<td>1,23</td>
<td>614</td>
</tr>
<tr>
<td>Madhya Pradesh</td>
<td>68</td>
<td>224</td>
</tr>
<tr>
<td>Andhra Pradesh</td>
<td>1,19</td>
<td>396</td>
</tr>
<tr>
<td>Bihar</td>
<td>62</td>
<td>155</td>
</tr>
<tr>
<td>Jammu and Kashmir</td>
<td>40</td>
<td>80</td>
</tr>
<tr>
<td>Others</td>
<td>66</td>
<td>137</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3.6 million ha</strong></td>
<td><strong>9,826 or 10 million ha</strong></td>
</tr>
</tbody>
</table>

* Source: Bhargaya, 1989
8.3.2 Rice production in Punjab

The percentage of rice culture among cropped areas has increased from 5.5 percent in 1967 to 23.7 percent in 1986 (Table 8.7). The rice production and productivity in the state are respectively 5.6 million tons and 3.2 tons per hectare in 1988 (present data is not available). It has dramatically increased during the last decade due to several factors affecting the rice production in Punjab such as high yielding cultivars, techniques for rice cultivation, irrigation system, and greater efforts by farmers for rice production.

Sharma (1988) reported that the Ludhiana district registered the highest growth rate of 40.45 percent in production of rice, mainly due to an increase in farming area. In Bhatinda, Sangrur, and Jalandhar districts, the growth rate of production varied from 25 to 30 percent per annum. Yield was the dominant factor of growth in Hoshiarpur and Gurdaspur districts, while the contribution of farming area was relatively higher in Amristar and Kapurthala districts.

The increase in paddy fields in all districts of the state has resulted in an intensive exploitation of underground water resources through the installation of tubewells. This has led to the lowering of water table in a large part of the central state zone, where water table is receding at an estimated rate of one and a half feet every year. This virtually amounts to undermining the ground water resources of the State.

<table>
<thead>
<tr>
<th>Year</th>
<th>Wheat</th>
<th>Rice</th>
<th>Maize</th>
<th>Gram</th>
<th>Rapeseed</th>
<th>Groundnut</th>
<th>Sugarcane</th>
<th>Cotton</th>
</tr>
</thead>
<tbody>
<tr>
<td>1967</td>
<td>31.09</td>
<td>5.50</td>
<td>8.59</td>
<td>12.26</td>
<td>2.30</td>
<td>3.46</td>
<td>3.20</td>
<td>8.41</td>
</tr>
<tr>
<td>1975</td>
<td>37.38</td>
<td>9.63</td>
<td>8.81</td>
<td>4.51</td>
<td>3.03</td>
<td>2.78</td>
<td>2.08</td>
<td>9.26</td>
</tr>
<tr>
<td>1980</td>
<td>43.04</td>
<td>17.93</td>
<td>6.01</td>
<td>3.61</td>
<td>1.35</td>
<td>1.39</td>
<td>1.18</td>
<td>9.64</td>
</tr>
<tr>
<td>1985</td>
<td>44.15</td>
<td>23.44</td>
<td>4.33</td>
<td>1.48</td>
<td>1.87</td>
<td>0.64</td>
<td>1.27</td>
<td>6.70</td>
</tr>
<tr>
<td>1990</td>
<td>43.90</td>
<td>23.73</td>
<td>3.62</td>
<td>1.39</td>
<td>2.09</td>
<td>0.64</td>
<td>1.32</td>
<td>7.78</td>
</tr>
</tbody>
</table>

Technical constraints

Constraints on rice production for district-basis in Punjab have been studied extensively. Technical constraints encompass biotic and abiotic factors that limit rice yields and are distinct from socio-economic constraints in that many are potentially solvable through genetic improvement of rice. Technical constraints in Punjab can be characterized on the basis of:

**Physical**
- Widespread nitrogen and phosphorus deficiencies in all districts
- Wide spread zinc deficiency especially in areas of high fertilizer consumption.
- Poor underground water quality, particularly with high soluble boron in Bhatinda and salinity in many parts of the state.

**Input-related**
- Imbalance use of fertilizers
- Very limited availability of good seeds; use of certified seeds of the high-yielding
varieties.
- Poor attention to weed control, which leads to loss of fertilizer nutrients and water
- Non-availability of weedicides on time

**Pests and diseases**
- Insect pests such as stem borer, lea folder, white-backed planthopper, army worm
- Disease such as sheath blight, false smut, brown spot, and blast

**Technology recommended for maximising rice productivity**

**Variety**  High yielding modern varieties require greater management than traditionally grown varieties in most aspects of production including water, insects, diseases, weeds, and soil fertility. Therefore, the high yielding variety covers 97.3% of the total rice-planting area of Punjab such as PR 106, PR103, PR108, PR 109, etc. bred by rice institution of the state.

**Soil, water and nutrient management**
- Ameliorate soil salinity or alkalinity through application of gypsum and green manure, and proper drainage.
- Ensure adequate irrigation at critical crop growth stages such as panicle initiation to flowering.
- For good water management, level the fields and maintain 3~5 cm of water until the beginning of the ripening phase.

**Optimum cultural management**
- Timely transplant, preferably by the first week of July.
- Adopt closer spacing of 20 x 10 cm with 2~3 seedlings per hill to ensure optimum plant population.
- Transplant seedlings of optimum age (25~30 days old) at shallow depth of 3~4 cm.
- In case of late transplanting, adopt bunch planting (5~7 seedlings/hill) with 40~45 days old seedlings at closer spacing of 15 x 10 cm.

**8.3.3 Research priorities and prospects**

The Punjab alone contributed about 50 percent of rice to the central pool during the 1994~95, despite the fact that it comprises only 1.53 percent of the area in the country. This is due to several factors such as rapid adapted high-yielding varieties, improved technology of rice culture, well-organized irrigation system, farmers’ efforts, and agricultural policy of the state government. However, some constraints to rice production are still existing such as the continuous management of problem soils, salinity, alkalinity, water-logging, and farm mechanization. Generic resistance to insects and pests, and conservations of irrigating systems must also be improved in the whole rice cropping area. Soils are important constraint, for which there are some conventional solutions, but these methods can be very costly and time-consuming. Biotechnology embraces a wider range of technical possibilities, the future potential of which is still being hypothesized. It is currently unknown how biotechnology may help ameliorate yield losses associated with adverse soil complexes. However, basic research is progressing at a rapid rate and transfer of genes for tolerance to alkaline and saline soils into rice seeds is a distinct possibility.
8.4 Double transplanting and irrigated rice in East India

Jae Duk Kim and Benito S. Vergara

Rice is the most important food crop of the world, if one considers the area under rice cultivation and the number of people depending on the crop. Although rice is the main agricultural crop in most tropical countries, national average yields per hectare have been considerably below the average yield obtained in temperate zone countries. The low yields common throughout the tropics is probably the net result of many factors. These include high day and night temperatures, high rainfall and low light intensity during the monsoon season, and drought during the dry season.

The fundamental environmental factor that differentiates rice cultural types that are not upland or irrigated is the depth and duration of flooding. Rice scientists recognize five major rice growth environments: irrigated, rain-fed lowland, deepwater, upland, and tidal wetlands. This useful and tidy classification goes a long way in clarifying many confusing concept and terminologies of the rice environment, but there remain considerable overlaps between categories.

In Southeast Asia, rice is cultivated using broadcasting, double-transplanting or single-transplanting methods. Although the double-transplanted rice area includes such areas where the practice has been replaced by double cropping, many areas still continue the double-transplanting traditional cropping practices. Double transplanting is practiced in India, Bangladesh, Thailand, Indonesia, and even in Ecuador with variations.

8.4.1 Process of double transplanting

Double transplanting is the practice of transplanting twice the same original seedlings during the main (wet) season. This is mainly to insure the survival of the seedlings.

First nursery Seedlings for the first transplanting are grown early in May. The nursery is usually located at places near a water source so that it can be conveniently watered by hand. The nursery is prepared first by clearing a land area of approximately 200 sq. m for a final transplanting of one hectare. Holes of 5 to 7 cm in diameter and about 3 cm deep are made 10 cm apart throughout the area. Each hole may first be covered with half-burnt rice hull in the bottom, then with a handful of pregerminated seeds. Finally the whole field is covered with large rice straw mulch. Watering by hand is carried out several times a day depending on the weather. Straw mulch is removed after seedlings attain a height of about 5 cm. The nursery is kept non-water-logged until the seedlings are removed for the second nursery in 30~45 days. No tillering takes place in the first nursery.

First transplanting After 30 to 45 days, the seedlings are pulled by simple twisting of each bundle out of its hole. Normally, rainwater accumulates in parts of the field by this time, sufficient for the preparation of the second nursery. Soil puddling is essential for a good production of seedlings in the second nursery. It consists of one plowing and at least two harrowing. Seedlings from each hole of the first nursery are separated for transplanting
into 8 to 10 hills. Spacing between hills is about 30 cm. Rice plants in the second nursery are allowed to grow for about 60 days. During this time, the field is fed with rainwater during the first half, and combined with the river water during the second half period.

**Land preparation for second transplanting**  From July through early August, as more rainwater combined with river water covers the entire field, farmers start preparing for the second transplanting. The tall weeds, predominantly sedges, are chopped off with an extra large scythe and raked out of the field. A few days later but before transplanting, farmers come back to the weed-free field to cut weed stubbles using the same type of scythe. This second cutting is less laborious than the first one. The main objective is to work up the topsoil to a certain extent. The field is thus ready for the second transplanting. There is no plowing or harrowing.

**Preparation of seedlings for second transplanting**  After about 60 days the rice plants in the second nursery are about 70 to 80 cm tall. At this stage, the plants can only be uprooted with the use of machetes. Each hill of rice plants, roots trimmed close to the base, forms a handy bundle of seedlings. The bundles are then stacked in circular pads with their bases in the water. These pads are left floating in the field for 2 to 5 days for new roots to be stimulated by the rising temperature within the stack. Although seedlings are tall, they are never pruned since their natural height is suitable to survive the moderate flood.

**Second transplanting**  The second transplanting, which starts sometime between late August to early September, coincides with the rising flood and increasing intensity of the rainfalls. However, the resulting field water level is influenced by daily tidal flows. When transplanting, farmers separate the tillers from the second nursery, then make a hole in the hard soil beneath the water surface using a specially made wooden dagger, and simultaneously push 3 to 4 large tillers into the hole. Spacing between hills is about 30 to 35 cm. Obviously, such natural daily intermittent irrigation and drainage would remove part of toxic substances produced as a result of the degradation of fresh organic matters in the fields. Normally, weeds are no longer a problem during crop growth; however insects and plant diseases often cause damages.

**Harvest**  Since all double-transplanted rice is seasonal, they mature in time for harvest during the dry months from late December through early February. During the maturity stage, the plants lodge heavily. Total lodging over a large area is not uncommon. Harvested rice is usually threshed in whacking frames, and winnowed by wind. Today home made thresher-cleaners designed by ingenious farmers are gaining popularity. Grain yield of double transplanted rice is variable depending on the pest situation and water regime. On the average the yield is about 2 t/ha, and it may reach 3 t/ha in a good year. A yield is generally expected even in drought years since some water is generally available in these low-lying areas. Any late seasonal variety of rice can be used in double transplanting. But there are indications showing some varieties are more suitable than others.

**8.4.2 Reasons for double transplanting**

**Soil fertility**  Water depth, soil fertility and weeds are the reasons for the double trans-
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The soil rich in organic matter and nitrogen is often considered to be a reason for this peculiar way of rice cultivation. The annual inundation is closely related to the high inherent soil fertility. No fertilizer is used in this area. The double transplanting has an effect of suppressing the excessive vegetative growth caused by the high soil fertility. However, this is not the main rationale for double transplanting. The high soil fertility can result in the rapid growth of weeds. The initial rapid growth of weeds is cut before transplanting.

**Water depth** The practice of double transplanting is mainly related to water depth, broadcasting in the deepest, double transplanting in the medium, and single-transplanting in the shallow flood areas. If one measures the water depth at the peak flood period and examines its relation to the geographical distribution of the three different methods of rice cultivation, a certain correlation may be found between them. However, the correlation does not necessarily mean that the maximum water depth directly determines the different cultivation methods. For example, broadcasting is not directly related to deep inundation. Generally speaking, inundation, deep or shallow, occurs from September to October after the rice plant has well established itself. The critical period for the crop’s success or failure is the first half of the rainy season, during which the crop mainly depends on the rainfall. Therefore, should the water condition at all be related to double transplanting, it should be the water condition before September that is really meaningful. It would be difficult to consider that the maximum water depth in October is directly related to the double transplanting.

In some areas, the rapid rise in water level at the start of the monsoon season makes it impossible to prepare the land and transplant the small seedlings grown under standard conditions. The seedlings would be shorter than the water depth. Double transplanting makes it possible to transplant the tall seedlings in 30 to 50 cm water depth. Special implements are used in many countries for transplanting rice seedlings at this depth.

**Weeds** Some people regard the vigorous growth of weed as a reason for the double transplanting. According to them, the competition between weeds and the rice plant is so severe in double transplanting that an old and big seedling is required. The weeds in some areas consist mainly of the perennial species of scirpus and cyperus. They thrive vigorously during the early half of the rainy season and form dense vegetation, over one-meter high. Just prior to the second transplanting in September, they are cut close to the ground level with a big scythe. Once cut, they take some time to re-establish or they die from submergence. Most broadleaf weeds die during inundation and fast growing rice can grow without much difficulty. In the broadcast seeded rice area bordering the double-transplanting area, some degree of soil desiccation during the growing season may suffer from the weed problem. The weed problem in the double transplanting can be solved by the death of weeds during inundation. Since short seedlings cannot be transplanted in deep water (30~50 cm), special seedlings raised in two stages produce seedlings of 30~70 cm in height. When transplanted, the seedlings are above the water level, with no visible weeds growing.

**Topography and water condition** The topography for double transplanting is quite distinct from these of other areas. It is characterized by bowl-shaped area. Micro-relief is a common feature within farm units. This type of topography is seldom observed outside
the double transplanting area. This suggests that the topography would be one of the important reasons for the practice of double-transplanting method. In the double transplanting, the lowest-lying part of one farmer’s land becomes waterlogged and ready for transplanting at the time of the full moon in mid-August. Thereafter, the acreage of land ready for transplanting gradually increases, and, around the end of September, the last inundated patch is ready. Accordingly, transplanting proceeds from the lower to the higher places within a time span of more than one month. If the seedling is left in the nursery for a long period, it becomes tall and weak. Supposing that a farmer prepares his nursery on the first day of August, the seedlings will be about one month old in early September and two months old in late September. The former might be too young to withstand the deep water and the latter too old to produce a good yield. Therefore, the farmer sometimes makes rice nurseries at different times so that the seedlings of different ages are available at any time in September. In the case of the double-transplanting method, the plant produces numerous tillers while it grows in the second nursery. The longer it is left there, the more tillers it produces. However, if sufficient space is available around the plant, seedling will not become tall and weak. After a certain period in the second nursery, the seedlings are ready to be re-transplanted at any time, a great advantage of the double-transplanting method.

The farmer will transplant from the center, lowest portion, as water becomes available. Transplanting is done as rapidly as possible and even during moonlighted nights. In some cases the rise in water level may be too rapid for farmers to transplant.

The reasons for the double-transplanting method can be summarized as follows. First, because of the water regime that floods the area to a depth of more than 30 cm in a space of 30~40 days, tall seedlings (>30cm) are needed. Second, the very high soil fertility and the moisture regime allows the rapid growth of perennial weeds, while deep flooding eliminates most of the weeds. Late transplanting and hence shorter growth duration is possible through both double and single transplantings. However, due to uneven topography, transplanting has to proceed from the lower to higher places over a short time span. The double-transplanting method, which can provide healthy seedlings for transplanting over a short time span, is more suitable than the single-transplanting in such circumstances.

### 8.4.3 Effect of double transplanting on performance of rice

Effects of seedling age and transplanting date as well as their interactions were statistically significant with regard to yield and yield contributing characteristics. Although no conspicuous increase was observed in the number of productive tillers per unit area with double transplanting, a significant improvement occurred with early transplanting. When transplanting was delayed, direct transplanted seedlings (30-day old) did not bear panicles, whereas double transplanting 50- to 70-day-old seedlings gave a reasonable number of productive tillers. Grain weight per panicle was greatly influenced by both variables. Double transplanting resulted in almost twofold increase in grain weight as compared to direct transplanting. Delay of 15 days in transplanting caused a significant reduction in this yield attribute. The grain weight per panicle with double transplanting over the direct method showed an increasing trend with delay in the transplanting date. Grain yield also exhibited a significant improvement with double transplanting.
The gap between the grain yields of single- and double-transplanted crops widened with delay in transplanting time. Such a response in grain yield could be ascribed to the differential response of these treatments with regard to yield contributing characteristics, i.e. productive tillers and, more particularly, grain weight per panicle. The favorable effectss of double transplanting on yield and yield-contributing characteristics were due to much early maturity of the double-transplanted crop in the main field, which helped the double-transplanted crop to escape damages caused by low temperature. During the process of double-transplanting, some additional costs incurred at early stages in transplanting and irrigation. However, compared to the increase in grain yield, the excess cost is negligible. Besides yield advantage, double transplanting has another advantage that the following crop of rice could be sown earlier than a single transplanting due to early maturity of the double transplanted rice.

8.4.4 Advantage of double transplanting rice

**Saving seed** For single transplanted field each hectare requires at least 40 kg seeds, while only 8 kg seeds are required to produce seedlings for double-transplanting a field of 1 hectare.

**Avoiding water submergence of seedlings** This is true for many areas where water at the time of transplanting is about 40 to 70 cm deep. These depths continue for approximately one month. It is, therefore, impractical to use single transplant rice under this condition, as the seedlings will be completely submerged. In these areas farmers must have seedlings tall enough to survive complete submergence.

**Reducing unfavorable physiological characteristics of traditional rice varieties** Even in higher areas where water level is not a problem, some farmers still double-transplant their rice because single transplanting results in more straw and less grain than double-transplanting. This is a direct adverse result of the longer lag vegetative phase, during which many tillers die before panicle initiation occurs. Double-transplanting can save a considerable amount of potentially productive tillers from being exposed too long in the field before panicle initiation occurs.

**Minimizing the cost of production** Initially, double-transplanting appears to be very costly. However, although labor for pulling seedlings from the first seedbed and uprooting of seedlings from the second seedbed is high, land preparation cost is kept at a minimum. Farmers seldom, or not at all, plow and harrow the fields in case of double transplanting. Although, cutting of weed is necessary before transplanting, most of the weed growth is suppressed through deep inundation. No fertilizer is used, especially on the second transplant field. Insecticide is seldom applied except during the growth of seedlings in the second seedbed.

8.4.5 Irrigated rice production

After the harvest of the double-transplanted rice, additional rice crop production is possible in these areas with sufficient irrigation water and growing season. High grain yields are obtained, to the extent that farmers no longer plant rice during the monsoon season so that the winter rice could be planted. Yields can be 5 to 8 tons from the winter rice com-
pared to 1~2 tons from double-transplanted rice. The constraints for winter rice are availability of water and cold-tolerant indica rice varieties.

**Irrigation and drainage** The main constrain to higher rice production in the double-transplanted area is water control. Lack of adequate drainage in the deepwater area during the wet season prevents the spread of existing high yielding rice. Hydrologists fear that during the low flow period (dry season), if more water is extracted from the upstream, the coastal plain will be more vulnerable to severe salt intrusion, including those areas presently not affected. In this connection there must be a monitoring system to check the movement of salt intrusion line during the dry season.

**Fertilizers and pesticides** Supplies of fertilizers and pesticides have so far been adequate. However, during periods of peak demand, retailers attempt to manipulate the prices, thus causing an annual pseudo-shortage. The worse effect of this artificial shortage was that it encouraged retailers to falsify various products, rendering them less effective. For instance, mixed fertilizer of nitrogen, phosphorus, and potassium was mixed with ground brick and stone, urea with table salt, and emulsifiable insecticide with sand.

With regard to fertilizers, they are the inputs almost every farmer like to use. The general tendency is to apply only urea, although the recommended formula for the soil is nitrogen-phosphate-potassium (50-40-0) in the wet season. Phosphatic fertilizer was not given due attention during the past several years. Therefore, it was no surprise when many farmers suffered from high percentage of empty grains. The effect of the oil crisis on the prices and availability of fertilizers was hardly felt by farmers in this area. Agronomic efforts toward solving the fertilizer crisis have just taken off; the newly released IR28, IR29, and IR30 were said to be able to tolerate low fertility conditions. Insect ecology changes as high yielding rice area increases; hence the demand for insecticides will increase if insect-resistant rice varieties are not available soon enough. In the years ahead, farmers will have to buy pesticides at higher price and yet may not obtain the required quantities due to the worldwide insecticide shortage. Those who attempted chemical weed control once, immediately adopted the technology, especially when they could control the water level in the field. The acceptance was tremendous because this form of herbicide is simple to apply correctly without injuring rice plants. Unfortunately, the world has been in an acute shortage of herbicides.
8.5 Rice culture in Jumla, Nepal - A unique rice culture in high Himal

Gyan L. Shrestha

The tiny Himalayan agricultural country of Nepal, with its total land area of 147,181 square kilometers, is located between two Asian giants - China to its north and India on other sides. Moreover, its unique topography of different altitudes, ranging from 63 meters in the eastern Tarai to 8,848 meters of Mt. Everest, the Highest peak in the world, in its north based on the above mean sea level (amsl), has created unique agro-ecological system of at least 35 different types. In its south part, tropical to sub-tropical climate exists, and in the northern part, alpine climate exists. Different types of agro-climatic conditions exist in between making its agricultural farming very unique. Due to its unique topography and ecosystem, this country is also extremely rich in its biodiversity (Malla 1999). The total land area of this country is less than 0.1% of the total land area of the world, whereas its flowering plant species alone accounts for more than 2.5% of the world. Nepal possesses at least 7,000 flowering plant species, out of which at least 5,891 species has already been identified (Malla 1999) (Table 8.8).

| Table 8.8  Comparison of plant species of the world and Nepal |
|---------------------------------|-----------------|-----------------|--------------------------------|
| Flowering plant species         | >250,000        | >5,891          | 2.36                          |
| Pteridophytes                   | >12,000         | 383             | 3.19                          |
| Lichens                         | >17,000         | 471             | 2.77                          |
| Bryophytes                      | >114,000        | 853             | 6.09                          |
| Fungi                           | >70,000         | 1,822           | 2.60                          |
| Algae                           | 40,000          | 687             | 1.72                          |
| Total                           | >403,000        | 10,107          | 2.50                          |

Nepal is also very rich in rice biodiversity along with other components of agro-biodiversity. It shows existence of at least four species of wild rice viz.: *Oryza nivara*, *O. rufipogon*, *O. officinalis* and *O. granulata* (Shrestha and Vaughan 1989; Shrestha and Upadhyaya 1999). Over 1,800 local rice varieties existed in the form of walking genes until 1960’s. However, due to the quick spreading of improved varieties, over 75% local of varieties disappeared from the farming fields. Nepal is a rice growing country that cultivates about 1.51 million hectares of rice crop annually with the production and productivity of 3.71 million tons and 2.45 t/ha, respectively (NARC 2000) (Table 8. 9).
8.5.1 Jumla and its unique climate

Jumla, 2,531 sq.km area with altitude ranging from 915 to 4,679 meters from amsl, is a unique district located in the far north-western part of Nepal (Figure 8.4). The famous Jumla valley along with Khalanga Bazaar, its headquarter, is located at 2,300 meters altitude from amsl and has a distinct agro-ecological system due to its partial rain-shadow area, which has resulted in the development of unique traditional rice culture. Total rice cultivation area in Jumla district is about 1,300 hectares with annual production of 2,410 tons with an average paddy grain yield of 1.85 t/ha.

Jumla valley and the surrounding crop areas receive more sunlight during summer, thus day temperature is higher than the areas of similar altitude in the eastern and central Nepal. Therefore, rice can grow in such high altitude valleys and hills, where winter temperature may drop to -10°C, similar to central Korea and Hokkaido in Northern Japan.

At these higher altitude regions, the rice growing season is shorter, and rice has to be transplanted between late May to early June before monsoon rain starts as in central Korea and Hokkaido of Japan, thus requiring irrigation. The permanent snowfields in the catchment areas are the main reliable water sources of irrigation. Rice cultivation is done up to an altitude of 3,000 meters amsl. Jumla has many small natural valleys from 2,000 to over 2,800 meters altitude from amsl. Among them, Haatsija (3,000 amsl) is a two-day walking distance from Khalanga Bazaar, and the rice is cultivated up to an altitude of 3,000 meters, probably the highest elevation in the world for rice farming.

8.5.2 Rice cultivation in Jumla

Historical evidences show that about 1,300 years ago one Hindu Saint (Guru) Chandan Nath brought a handful of rice from Kashmir and gave them to the local priest to cultivate rice in the present day Jumla valley. Since that time, the local people cultivated this

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### Table 8.9  Area, production, and productivity of cereal crops of Nepal during 1998/99

<table>
<thead>
<tr>
<th>Cereal crop</th>
<th>Area (ha)</th>
<th>Production (t)</th>
<th>Productivity (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice</td>
<td>1,506,340</td>
<td>3,709,770</td>
<td>2.450</td>
</tr>
<tr>
<td>Maize</td>
<td>802,290</td>
<td>1,345,910</td>
<td>1.678</td>
</tr>
<tr>
<td>Wheat</td>
<td>640,802</td>
<td>1,086,470</td>
<td>1.695</td>
</tr>
<tr>
<td>Fingermillet</td>
<td>263,950</td>
<td>291,370</td>
<td>1.104</td>
</tr>
<tr>
<td>Barley</td>
<td>31,843</td>
<td>31,798</td>
<td>0.999</td>
</tr>
</tbody>
</table>

* Source: Annual Report of NARC, 2000
particular rice variety, the only one in Jumla since that time and well known by the name of JUMLEE MARSI. This is the only rice variety in Jumla since that time. Chandan Nath Hindu temple of Khalanga Bazaar is the very sign of Chandan Nath’s contribution to rice cultivation in Jumla district.

8.5.3 Characteristics of JUMLEE MARSI

This variety is highly susceptible to the leaf and neck blasts under high fertile condition. Sheath rot has become another critical disease. Fortunately, chemical fertilizers have not yet reached Jumla; and this rice is cultivated under very low fertile condition. Its taste is very much preferred by the local people, and long ago, the ruling Rana family of Nepal also preferred this variety. It is cold tolerant at altitudes of up to 3,000 meters under natural condition of Jumla and shows consistent grain yield between 1.0 to 3.0 t/ha under low to medium condition of fertility. No chemical pesticides and fertilizers have yet been used in Jumla. Continuous efforts are being made to develop suitable alternative varieties of rice for Jumla (Table 8.10).

### Table 8.10  Jumla rice varietal trial -1999

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Rice entries</th>
<th>Grain yield (t/ha)</th>
<th>Days to maturity</th>
<th>No. of filled grains / panicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Chhomrong/No11-4J-2J</td>
<td>3.15</td>
<td>131</td>
<td>45</td>
</tr>
<tr>
<td>2</td>
<td>NR10288-10J-2J</td>
<td>4.51</td>
<td>129</td>
<td>47</td>
</tr>
<tr>
<td>3</td>
<td>NR10288-015J-015J-7</td>
<td>4.87</td>
<td>125</td>
<td>47</td>
</tr>
<tr>
<td>4</td>
<td>Yungen-1</td>
<td>5.72</td>
<td>127</td>
<td>41</td>
</tr>
<tr>
<td>5</td>
<td>NR10288-015J-015J-3</td>
<td>2.56</td>
<td>127</td>
<td>78</td>
</tr>
<tr>
<td>6</td>
<td>Jhingling-78</td>
<td>5.97</td>
<td>128</td>
<td>30</td>
</tr>
<tr>
<td>7</td>
<td>NR10262-9-2-3</td>
<td>3.72</td>
<td>134</td>
<td>45</td>
</tr>
<tr>
<td>8</td>
<td>Jumlee Marsi White</td>
<td>4.31</td>
<td>125</td>
<td>25</td>
</tr>
<tr>
<td>9</td>
<td>NR10293-015J-015J-8</td>
<td>4.73</td>
<td>122</td>
<td>34</td>
</tr>
<tr>
<td>10</td>
<td>NR10288-1J-1</td>
<td>4.90</td>
<td>127</td>
<td>37</td>
</tr>
<tr>
<td>11</td>
<td>NR10288-15J-15J-1</td>
<td>2.11</td>
<td>127</td>
<td>22</td>
</tr>
<tr>
<td>12</td>
<td>NR10288-15J-1J-1</td>
<td>4.58</td>
<td>124</td>
<td>27</td>
</tr>
<tr>
<td>13</td>
<td>NR10260-1J-4J</td>
<td>4.46</td>
<td>121</td>
<td>28</td>
</tr>
<tr>
<td>14</td>
<td>NR1088-15J-15-2</td>
<td>3.90</td>
<td>125</td>
<td>32</td>
</tr>
<tr>
<td>15</td>
<td>NR10288-015J-015J-6</td>
<td>3.97</td>
<td>120</td>
<td>22</td>
</tr>
<tr>
<td>16</td>
<td>Chhromong (Check)</td>
<td>4.86</td>
<td>134</td>
<td>45</td>
</tr>
<tr>
<td>17</td>
<td>NR10346-4-1-3</td>
<td>4.72</td>
<td>134</td>
<td>18</td>
</tr>
<tr>
<td>18</td>
<td>NR1045-8-1-1</td>
<td>4.49</td>
<td>136</td>
<td>24</td>
</tr>
</tbody>
</table>

* Source: Agriculture Research Station, Jumla, 1999

8.5.4 Climate of Jumla (from 2,000 and up to 3,000 meters amsl)

Jumla is a unique place from the rice cultivation point of view because of its high altitudes of 2,300 up to 3,000 meters in the Hatsija valley. The plane lands in Jumla district are located at the altitude of about 2,350 meters. This is one of the most important rice cultivation valleys in Jumla district. The overall climatic condition of the Jumla valley is given in Figure 8.5.
The annual average temperature of Hatsija is 9.4°C, and the average temperature between June to November is 14°C. During rice transplanting the average temperature is about 15.5°C. Because the temperature of this particular location is very much different from other locations, the following steps of rice transplanting must be strictly followed.

Water temperature is very critical in Jumla from the rice cultivation point of view. Since rice cultivation has to be performed with irrigation, water temperature, particularly in the initial stage of transplanting, becomes very critical. Whiteman (1978) observed that the river water for irrigation during March to May increases from 5 to 10°C. Moreover, irrigated water from the canals near the take-off point from the river causes stunted growth, late maturity, higher sterility, and lower grain yield than water abstracted from other parts of the canals, indicating a gradient of 1°C warmer for every 250 meters of canal. Young seedlings are protected from the cold at night through evening irrigation and the seedbeds are heated during the day time by draining the water as done

### Table 8.11 Cultural operation

<table>
<thead>
<tr>
<th>Date of treatment</th>
<th>Type of cultural operation</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>March 23 to 25</td>
<td>First day of seed soaking. Seeds are soaked for 4 days in cold river water</td>
<td>Fixed date of local calendar (Chaitra 12)</td>
</tr>
<tr>
<td>March 27 to 29</td>
<td>Soaked seeds are brought home and kept near or above the kitchen (cooking place) for 4 days</td>
<td>To attain higher temperature</td>
</tr>
<tr>
<td>April 2 to 4</td>
<td>Seeding is done in the seedbed. Wet seedbed preparation during March 20 to 31</td>
<td></td>
</tr>
<tr>
<td>By May 28</td>
<td>Transplanting is completed in winter fallow land, altitude and planting date vary</td>
<td></td>
</tr>
<tr>
<td>June last</td>
<td>Weeding and hoeing are completed</td>
<td></td>
</tr>
<tr>
<td>October 3rd week</td>
<td>Harvesting of rice</td>
<td>Late planted matures late</td>
</tr>
</tbody>
</table>

### Table 8.12 Mean air temperature during heading to flowering in main Jumla valley (unit: °C)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>July 21 to 31</td>
<td>15.6</td>
<td>14.1</td>
<td>14.2</td>
<td>13.7</td>
<td>15.2</td>
<td>14.6</td>
</tr>
<tr>
<td>August 1 to 10</td>
<td>15.6</td>
<td>12.0</td>
<td>12.6</td>
<td>13.8</td>
<td>15.7</td>
<td>13.9</td>
</tr>
<tr>
<td>August 11 to 20</td>
<td>15.6</td>
<td>12.9</td>
<td>12.2</td>
<td>13.8</td>
<td>14.0</td>
<td>14.1</td>
</tr>
<tr>
<td>August 21 to 31</td>
<td>13.9</td>
<td>12.8</td>
<td>11.3</td>
<td>13.8</td>
<td>9.7</td>
<td>12.3</td>
</tr>
<tr>
<td>Mean</td>
<td>15.7</td>
<td>14.4</td>
<td>14.5</td>
<td>14.4</td>
<td>15.0</td>
<td></td>
</tr>
</tbody>
</table>
during the old days in China (King 1911), and also probably in northern Korea and Hokkaido, Japan.

Rice is transplanted densely (about 10 cm apart) with single seedling per hill because cold irrigation water and minimum amount of nutrients applied causes low tillering. No chemical fertilizer has been applied so far. Number of filled grain per hill is also very low (about 20 to 50 grains per panicle) depending on cultivars.

### 8.5.5 Rice-based cropping system in Jumla

Because of high altitude, topographical shading and cool spring occurrence, cropping system varies from location to location. In general, rice crop in the summer season is followed by wheat, early maturing barley or finger millet below 2,000 meter above mean sea level. Above 2,300 meter above mean sea level, generally, the paddy field becomes fallow during the winter season because short duration winter cereal crops are not available under natural condition. Vegetable farming during the winter season is not possible in the paddy field due to the snowfall during the winter season. Use of polyethylene sheet in the field has yet to be introduced in Jumla farming. The following is the general cropping pattern depending on altitude.

**Table 8.13 Cropping pattern by altitude**

<table>
<thead>
<tr>
<th>Altitude</th>
<th>Cropping pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above 2,500 meters altitude</td>
<td>Rice + winter fallow</td>
</tr>
<tr>
<td>Most of the cases above 2,300 meters</td>
<td>Rice + winter fallow</td>
</tr>
<tr>
<td>Between 2,000 and 2,200 meters</td>
<td>Rice + early maturing barley, or</td>
</tr>
<tr>
<td></td>
<td>Rice + finger millet, or Rice + Winter fallow</td>
</tr>
<tr>
<td>At 2,000 meters or below</td>
<td>Rice + wheat, Rice + barley or</td>
</tr>
<tr>
<td></td>
<td>Rice + finger millet</td>
</tr>
</tbody>
</table>

### 8.6 Deepwater rice culture in Thailand

*Hae-Yeong Ryu*

Deepwater rice is grown in about 8 million hectares of flood-prone area in Asia and West Africa and more than 7 million hectares are in Asia, on flood plains along the major rivers in Bangladesh, Cambodia, India, Myanmar, Thailand, and Vietnam.

Deepwater rice is grown in areas with a flooding depth of more than 50 cm for 1 month or longer during the growing season. It includes all types of rices adapted to water deeper than 50 cm. Among these, rices adapted to area flooding deeper than 1 meter are called very deepwater or floating rices, which have been reported to elongate by as much as 6 m. At depths of 50~100 cm, the deepwater rices survive through tall stature and long leaves and the floating rices survive chiefly through elongation ability.
However, the depth of water, duration of flooding, the rate of increase in water level, temperature, turbidity and time of occurrence vary for different areas, so that the term, deepwater may have different meanings in different countries. Gregorio et al. (2001) classified deepwater rice into two categories. One is deepwater rice surviving 80~150 cm depth of water and the other is very deepwater or floating rice surviving in more than 1.5 meters depth of water.

Since total flood control is unlikely to be realized in the near future, deepwater rice and floating rice still remain as the only alternative crops in the deeply flooded river basins of Asia and West Africa during the wet season. Moreover, the irreversible degradation of watersheds and the predicted rise in world sea levels may cause more extensive flooding and thus greater role of deepwater rice is necessary in these areas.

There are probably 50 to 100 million people living in the deepwater rice areas, and they are the poorest in Asia. Since inputs for deepwater rice cultivation is low, it remains suitable for subsistence farming. Moreover, deepwater rice can be combined with other crops to provide more secure cropping patterns and stable environment.

8.6.1 Rice area in Thailand

Thailand lies between 5° and 21° N latitude and between 97° and 106° E longitude. The country is characterized as tropical warm sub-humid region. Temperatures in the Central Plain during the rainy season of May to November average 27°C. There is a brief cool period from December to January, with temperature as low as 2~3°C in the northern highlands. Total land area devoted to rice production in the country is about 9.6 million hectares (IRRI 1997). This area can be subdivided as rain-fed lowland of 8.16 million hectares, irrigated lowland of 0.94 million hectare, deepwater (>100cm) of 0.34 million hectare, and upland of 0.2 million hectare. Areas planted with deepwater rice are reported at about 0.82 million hectare covering 27 provinces in the country (IRRI. 1990). However, deepwater rice areas of 0.65 million hectare are concentrated in the Central Plain and Northern Floodplain. The distribution of deepwater rice in Thailand is shown in Figure 8.6, and the estimate of Thailand’s deepwater rice areas in Table 8.14.

<table>
<thead>
<tr>
<th>Table 8.14 Estimates of extent of deepwater rice in Thailand (Floating rice is probably less than 50%) (unit: 1,000 ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>763</td>
</tr>
</tbody>
</table>

8.6.2 Environmental conditions

The Central and Northeast plains, main deepwater rice areas, have a tropical monsoon climate. The beginning and ending of season in terms of rainfall, mean temperatures, and solar radiation are essentially the same. The climograph shown in Figure 8.7 for Don Muang, which lies to the north of Bangkok, is typical for the Central Plain. Climatic features of the Central Plain and Northeast Plateau are shown in Table 8.15.
Central Plain has a pronounced dry season from December to the end of March. Amount of rainfall increases from April to May with long periods of dry, hot conditions with maximum temperatures averaging 35–36°C. Newly planted rain-fed rice is subjected to severe drought stress during this period. In major parts of Chao Phraya basin, the moist season begins last week of April and the humid period starts in the second week of May. The humid period ends in early November. During flowering and ripening periods in November and December, solar radiation is also high, which can lead to rapid grain filling and improved grain quality.

Table 8.15  Major climatic zones of Thailand with data relevant to the culture of deepwater rice

<table>
<thead>
<tr>
<th>Item</th>
<th>Central plain</th>
<th>Northeast plateau</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual rainfall (mm)</td>
<td>1,225–1,439</td>
<td>1,180–1,281</td>
</tr>
<tr>
<td>Season begins</td>
<td>Apr. 24-25</td>
<td>Apr. 15-25</td>
</tr>
<tr>
<td>humid period starts</td>
<td>May 10-12</td>
<td>May 6-12</td>
</tr>
<tr>
<td>ends</td>
<td>Nov. 8</td>
<td>Oct 21-Nov. 7</td>
</tr>
<tr>
<td>Rainfall total (mm) in 3 pre-monsoon months*</td>
<td>267–278</td>
<td>264–298</td>
</tr>
<tr>
<td>Rainfall, first month, 80% probability &gt; 50 mm &gt; 100 m</td>
<td>May</td>
<td>May</td>
</tr>
<tr>
<td>Potential evapotranspiration (mm), monthly mean first month exceeded by rainfall</td>
<td>Aug.-Sept.</td>
<td>June-Sept.</td>
</tr>
<tr>
<td>3 pre-monsoon months</td>
<td>188–198</td>
<td>199–208</td>
</tr>
<tr>
<td>Solar radiation (MJ/m²), monthly mean</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 pre-monsoon months</td>
<td>20–22</td>
<td>21–22</td>
</tr>
<tr>
<td>June-Jan.</td>
<td>17–18</td>
<td>18–19</td>
</tr>
<tr>
<td>Temperature (°C), monthly mean</td>
<td></td>
<td></td>
</tr>
<tr>
<td>maximum 3 pre-monsoon months</td>
<td>35–36</td>
<td>35–36</td>
</tr>
<tr>
<td>maximum June-Dec.</td>
<td>32–34</td>
<td>31–33</td>
</tr>
<tr>
<td>daily average Nov.-Jan.</td>
<td>26–27</td>
<td>23–25</td>
</tr>
<tr>
<td>minimum Nov.-Jan.</td>
<td>19–23</td>
<td>16–20</td>
</tr>
</tbody>
</table>

* March to May
radiation and mean temperatures are favorable. A moderate daily temperature fluctuation of 8–11°C results in better grain filling.

The Delta of Central Plain and Northern Floodplain consist of thick quaternary alluvial deposits. A band of saline and non-saline marine deposits occurs near the Gulf of Thailand, followed by a vast brackish-water series of deposits in a wide central zone, and more recent freshwater alluvium dominates the northern part of the plain. All these soils are deep and clayey with red and yellow mottles in the profiles. They have high base saturation and high cation exchange capacity. The availability of K is high, but available P is low to moderate. The main exception is the acid sulfate soils, which are characterized by low base saturation, low pH, and a low to very low P content. Acid sulfate soils in the Central Plain were estimated at 0.86 million hectare in 1986. Most areas are planted with rice, including large areas of deepwater rice.

8.6.3 Cultural practices

Cultural practices are somewhat unique for deepwater rice-growing areas, which are in a continuum from the medium-deep rain-fed lowland rice culture. A calendar of cultural practices is given in Figure 8.8. Deepwater rice stubble is burnt in the field during February and March. Land preparation for broadcast fields begins with the first good rain falling in April or May and can extend to July if the rain is late. The fields for transplanting are puddled from June to August.

Dry seed is broadcast from mid-April to late June, most commonly in mid-May. The seeding rate is high and variable, averaging 126 kg/ha (range 75–176 kg/ha). In the Northern Floodplain, sowing is done from May to June at 100–120 kg/ha. Farmers tend to increase the seeding rate in deeply flooded areas. The transplanting of tall, weakly elongating deepwater rice in the shallower areas takes place from mid-June to August. Usually 30–40-day-old seedlings are planted at 2–3/hill with random spacing or in rows at 25 x 25 cm.

Three methods of applying the required amount of irrigation water to the rice crop can be considered. These include continuous submergence, intermittent irrigation, and midseason soil drying to change the root zone temporarily into an oxidized state. The method of continuous submergence is commonly adopted in deepwater rice culture due to the difficulty in controlling the flooding water. This method keeps the paddy fields under submerged conditions until floodwater drains away. Basically, water control scheme has been well operated and main-
tained through the central management system of the Royal Irrigation Department in Thailand.

Little hand weeding is carried out. Broadleaf weeds and sedges are barely controlled with herbicides, because most farmers do not regard grasses as important pests.

Deepwater rice is generally harvested after the floodwater has been drained from the fields from the end of November to late January. Harvesting is performed earlier in the southeast and southwest delta flat regions. In the northern Floodplain and Northeast Plateau, both floating and transplanted rice are harvested from November to December. Despite the mechanization of deepwater rice culture, reaping is still done manually by sickle. This practice is unlikely to change, because of the difficulty of working with long, prostrate stems lying on waterlogged soil. The crop is hauled to the homestead by cart, motor-drawn trailer or small vehicle. Though threshing is carried out by driving a tractor or tiller over the stacked crop, modern axial flow threshing machines are fast becoming popular. The long stubble is usually left in the field.

### 8.6.4 Cultivars for deepwater area

Farmers still mainly cultivate traditional, photoperiod-sensitive cultivars (Table 8.16). Although several of these, such as Pin Gaew 56 and Leuang Pratew 123, have been improved through pure line selection, more improved cultivars such as RD19 and Huntra 60 have been released for planting in fields. Traditional cultivars tolerant to acid sulfate soils are grown in the southeast delta flat region. Although by local standards most floating rice do not have particularly good grain quality, they do have satisfactory cooking and eating qualities preferred by Thai farmers.

Short duration cultivars flower during the third and fourth weeks of November, while medium-duration ones during the first two weeks of December, and long-duration cultivars during the last two weeks of December. In the Central Plain, day length varies during the year from 11 to 13 h. At panicle initiation, day length is about 11 h 40 min.

### 8.6.5 Cropping patterns

During monsoon period, the deeply flooded Central and Northern Floodplain turn into large rice lands. During the dry season, however, these fields are left fallow, and no crops are grown. Thus, almost without exception, deepwater rice is a single crop in Thailand.

<table>
<thead>
<tr>
<th>Deepwater rices (water depth 50–100 cm)</th>
<th>Floating rices (water depth &gt; 100 cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Recommended</strong></td>
<td><strong>Huntra 60, Leb Mue Nahng 111,</strong></td>
</tr>
<tr>
<td>Leuang Pratew 123, Khao Tah Haeng 17</td>
<td><strong>Nahng Chalawng, Pin Gaew 56,</strong></td>
</tr>
<tr>
<td>Khao Mah Na, Nam Sagui 19, Niew Ubon 1,</td>
<td><strong>RD 19, Tapow Gaew 161,</strong></td>
</tr>
<tr>
<td>RD 6, RD 13, RD 17, RD 19, RD 27</td>
<td></td>
</tr>
<tr>
<td><strong>Others</strong></td>
<td><strong>Gawn Gaew, Jek Chuey 159, Khao Nahng</strong></td>
</tr>
<tr>
<td>Khao Bai Lod, Khao Gaw Diau</td>
<td><strong>Nuey 11, Khao Puang 32, Nahng Kiew,</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Plai Ngahm, Sam Ruang</strong></td>
</tr>
</tbody>
</table>
The alternative cropping pattern has been a steady increase in the irrigated dry season crop at the expense of medium-flooded deepwater rice. This change has occurred mainly along the Southeast and West Banks of the Chao Phraya, and in the northwest part of the old delta. Double cropping with rice is not extensive in these areas. In the upper Northern Floodplain, water control and irrigation schemes were designed to increase the cropping intensity from 98 to 177 percent by growing mung bean after deepwater rice. Fertilizer use is low in all parts of the Central Plain except for areas with acid sulfate soils in the southeast delta flat region. Average application amounts for all sites in the Central Plain are 21 kg N and 9 kg P/ha. In the deeply flooded areas, floating rice normally receives no fertilizer, and transplanted rice only small amounts. There are no regular control measures for the major pests such as stem borers, rats, and crabs.

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