Amount of CO₂ consumption = yield × carbon content × O₂/C molecular weight ratio

(5)

The amount of O₂ generated in a hectare of rice field is 8.84 tons and 10.28 million tons for the whole rice field in Korea. It is difficult to put values on the economical impact of rice cultivation for refreshing the atmosphere, because the public benefit function is not easily discernible. Since crops uptake CO₂, the major compound causing greenhouse effect on earth, the role of agriculture in reducing harmful substances such as CO₂ produced by industries is of great importance.

The beneficial function of rice cultivation on atmospheric environment is very important, because the second and third industries which grow steadily give harmful effect on atmosphere.

4.1.6 Water purification function

Irrigated water in rice fields sometimes carries high contents of nitrogen and phosphorus into the fields from surrounding environment. Although nitrogen and phosphorus are crucial nutrients for crop growth, high contents of N and P in the irrigated water pollute the water. However, in the case of rice fields, nutrients are consumed by the rice plants and adsorbed into soil particles. Therefore, levels of N and P in the outlet water are much lower than those in the inlet water. This water purification function of rice cultivation can be calculated using formula 6.

Coefficient of water purification = (N and P contents in the inlet water - N and P contents in the outlet water) / N and P contents in the inlet water

(6)

COD purification rate is 31.6% in the common irrigated water containing low levels of N & P, while greater than 50% in the water containing high levels of N and P. In this case, N purification rate ranged 52.1 to 66.1%, and that of P 26.7 to 64.9%. N fertilizer applied to soil is mostly used by plants. However, some remaining in soil percolates through soil and contaminates the underground water. Upland maintains aerobic condition. Therefore, most part of the N fertilizer is retained in the soil in a nitrate form. However, nitrate form easily leaches into underground water because both nitrate and soil particles are negatively charged. Drinking water with high content of nitrate may cause harmful effects on human and animals.

In contrast, rice field maintains anaerobic condition. Thus, most of the nitrogen fertilizer is retained in the soil in an ammonium form. There is an attractive force between soil particles and ammonium. Thus, ammonium in the rice field is retained in the soil, and does not contaminate underground water in the rice field. If we were to lose this beneficial function of the rice field on the natural environment, a great expense will be required to maintain the water quality and clean atmosphere. Additional expense will also be required to recover the contaminated environment, although complete recovery of the contaminated rice fields into the original state would be difficult.
4.1.7 Additional benefit of rice cultivation on agriculture

**Reduction of harmful effects through continuous cropping**
No soil sickness nor significant yield reduction are observed in continuous rice cultivation except under climatic disorder. In paddy fields, harmful substances are removed from the rhizosphere and nutrients are supplied from the irrigated water ensuring a stable food supply, which might be the reason why the largest population has been living in the rice growing regions in Asia.

**Less yield reduction under low energy input**
The yield index of rice per unit area is 1.8 and 2.5 times higher than those of barley and soybean, respectively. No significant reduction in yield was observed in rice compared to other upland crops under low energy input, not only due to the natural nutrient supply from irrigated water and soil particles, but also because rice is not as sensitive to nutrients as the upland crops.

Under no artificial fertilizing, yield index to normal fertilization is 72% in rice, while 42, 44, and 32% in barley, wheat, and corn, respectively. We have observed that upland soil become fertile through transformation into rice field using irrigated water.

**Weeding effect of rice cultivation**
Weed control remains the biggest problem in agriculture. Our traditional weeding method involves both cultivating the soil by breaking the soil surface to soften the soil structure to help crops grow, and weeding. Generally, less weeds are found in the rice field than in the upland field, because submerging in water has a weeding effect. In paddy fields; aquatic or hydrophytic weeds are dominant, while xerophytic weeds are predominant under upland condition. However, total number of weeds is much higher in the upland field (Table 4.2).

Such weeds as green foxtail, crab grass, and common purslane are resistant to extreme environmental condition, although they are relatively sensitive to hydrophytic condition such as paddy fields. Furthermore, even the hydrophytic weed such as barnyard grass, can not germinate when submerged continuously under deep water (10~15cm). This indicates that the aquatic/ hydrophytic weeds can also be controlled through appropriate water management even in rice fields.

**Table 4.2 Amount of weeds in paddy and upland fields**

<table>
<thead>
<tr>
<th>Weed species</th>
<th>Dry weight (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Paddy (submerged)</td>
</tr>
<tr>
<td>Aquatic/ hydrophytic weed</td>
<td>9.60</td>
</tr>
<tr>
<td>Xerophytic weed</td>
<td>1.17</td>
</tr>
<tr>
<td>Total</td>
<td>10.77</td>
</tr>
</tbody>
</table>
4.2 Social and cultural value of rice cultivation

4.2.1 Preservation of natural scenery

The Korean agriculture provides beautiful sceneries. Rice cultivation, in particular, offers vast vivid green fields during spring and summer, and the fields turn into a golden ocean providing a feeling of fruitfulness during fall. Reservoirs constructed for rice cultivation long ago also provide unique scenery in harmony with the surrounding fields and mountains. In addition farmers protect the sceneries from being destroyed and recover what they already have destroyed by managing the rice field through rice cultivation.

Furthermore, our traditional agricultural system with rice cultivation functions to protect forests and wild lives indirectly. Side products of agriculture such as rice straw, barley straw, rice hulls, and soybean stem have been used as fuel and animal feeds, which greatly reduce the need for woods and grasses, thus protecting the natural environment as well as wild lives.

4.2.2 Social and cultural values

Examples of the social and cultural impacts of rice cultivation are as follows: (1) elevating rural economy by producing food, (2) preserving traditional native custom, (3) reducing migration into city by rural residents, (4) reducing physical tiredness and mental stress of people, (5) offering places for recreation and fresh life, and (6) preserving

<table>
<thead>
<tr>
<th>Items</th>
<th>Response ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>50</td>
</tr>
<tr>
<td>1. show the present status of agriculture</td>
<td></td>
</tr>
<tr>
<td>2. allow to feel the seasonal changes</td>
<td></td>
</tr>
<tr>
<td>3. allow to feel the natural fruitfulness</td>
<td></td>
</tr>
<tr>
<td>4. provide beautiful scenery</td>
<td></td>
</tr>
<tr>
<td>5. allow to feel the native local culture</td>
<td></td>
</tr>
<tr>
<td>6. provide relaxation</td>
<td></td>
</tr>
<tr>
<td>7. allow observation of see wild lives</td>
<td></td>
</tr>
<tr>
<td>8. provide desire to have a rest</td>
<td></td>
</tr>
<tr>
<td>9. protect from natural disaster</td>
<td></td>
</tr>
<tr>
<td>10. help air flow</td>
<td></td>
</tr>
<tr>
<td>11. easy to get food</td>
<td></td>
</tr>
<tr>
<td>(!) Positive response</td>
<td></td>
</tr>
<tr>
<td>(N) Negative response</td>
<td></td>
</tr>
<tr>
<td>(O) No response</td>
<td></td>
</tr>
</tbody>
</table>

*Figure 4.1 Degree of recognition of Korean public on the social and cultural impacts of rice cultivation*
regional society. About 60~90% of Korean public accepted the social and cultural values of rice cultivation (Figure 4.1).

In addition to food production, rice cultivation should be considered as an industry that has a function to preserve the natural environment, thereby contributing greatly to society compared to other industries. Therefore, each nation should evaluate the beneficial and adverse effects of agriculture on the natural environment based on its own agricultural situations.

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5 Rice Cultural Practices in Asia

Byun Woo Lee

*Oryza sativa*, the cultivated rice species, is believed to have originated somewhere in Southeast Asia, while rice is grown to a wide range of environmental conditions because of its natural dispersal and human selection. Wide distribution along with domestication of wild rice (*Oryza perennis* Moench) into cultivated rice (*O. sativa* L.) has caused differentiation of rice into numerous geographical races. These races have been further differentiated, and a large number of rice cultivars have thus been created around the world. *O. sativa* was developed into three ecogeographical races of indica, japonica, and javanica, each grown under different cultural practices ranging from upland to lowland and deep-water farmings. The tropical race, indica, has spread through the humid tropics, the Middle East, Europe, and Africa. Javanica has spread through parts of Asia and many contiguous island areas, including Indonesia, the Philippines, Taiwan, and Japan. The cool-season race, japonica, was developed in the lower Yangtze River area of China, from where it was introduced into Korea, Japan, and later into southern Europe, the U.S.S.R., the United States, and South America.

Varietal adaptations have led to an almost infinite range of plant development interactions with temperature, day length, solar radiation, nutrient supply, and hydrological conditions. With distribution of rice cultivars to the high latitudes, cultivar changes occurred in response to low temperature and long photoperiod during summer. This was accompanied by selection for short plant stature and plants with more determinate tillering and uniform heading. Within the last 2000 years, dispersal and cultivation of the cultivars in new habitats have further accelerated the diversification process. Today, thousands of rice varieties are grown in more than 100 countries. The complex groups of cultivars now known are categorized on the basis of hydrologic-edaphic-cultural-seasonal regimes and on genetic differentiation (Figure 5.1).

5.1 Classification of cultural system of rice culture

Over centuries, a number of rice production systems have evolved to fit local conditions based on rice varieties, water supplies, climate, soil conditions, available labor and equipment, and economic and social conditions. Based on land and water management practices, ricelands are classified as either lowland or upland. Based on water regimes, ricelands can be classified as upland with no standing water, rain-fed lowland with 5~50 cm of standing water, deepwater with >51 cm standing water, and floating with 101 cm to 5~6 m of standing water.

Upland rice culture depends on rainfall for soil moisture, with monthly rainfall of at least 150 mm considered essential for minimal production on most soils. Upland rice is grown on about 12 million hectares in Asia in dry-seeded, nonflooded culture, usually...
with well-drained soil on level with sloping fields. Upland rice is the dominant culture primarily in Africa and Latin America. Grain yields are usually low, with an average of 0.5~1.5 t/ha in Asia, depending on the soil moisture and fertility.

Rain-fed lowland rice is transplanted or direct-sown in puddled or flooded soils in diked fields to conserve water. Flooding depth and duration vary depending on rainfall, thus the crops may be alternately flooded and drained. Rain-fed lowland rice is grown on 34 million hectares in Asia, particularly in the humid and subhumid tropics of South and Southeast Asia. Grain yields averaged 2.3 t/ha in 37 major rice-producing countries. Yields may depend on rainfall conditions and systems used to conserve water.

Irrigated rice is transplanted or direct-seeded in puddled soil with dikes for water control. In some areas, direct sowing of pregerminated seed is done either into shallow water or onto wet soil. Irrigated rice is planted on 73 million hectares, accounting for 56% of Asia’s harvested area and contributing 76% of Asian rice production. The use of controlled, continuous irrigation and heavy fertilization contributes to high crop yields in the average range of 5~8 t/ha. Irrigated rice is the mainstay of global rice security, consistently producing the highest average yields, which were 4.9 t/ha in 37 major producing countries.

Rainfed lowland rice is the dominant culture primarily in Africa and Latin America. Grain yields are usually low, with an average of 0.5~1.5 t/ha in Asia, depending on the soil moisture and fertility.

**Figure 5.1** Grouping of Asian rice cultivars by ecogeographic race, hydrologic-edaphic-cultural-regime, and crop season. Cultivars grown in standing water belong to the lowland type (IRRI, 1997)

**Table 5.1** Planted area, yield, and rough rice production in the rice ecosystems of Asia (1991)

<table>
<thead>
<tr>
<th>Rice ecosystem</th>
<th>Planted area</th>
<th>Production</th>
<th>Yield (t/ha)</th>
<th>Million ton</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigated</td>
<td>73</td>
<td>56.1</td>
<td>4.9</td>
<td>358</td>
<td>77</td>
</tr>
<tr>
<td>Rain-fed lowland</td>
<td>34</td>
<td>26.0</td>
<td>2.3</td>
<td>78</td>
<td>17</td>
</tr>
<tr>
<td>Upland</td>
<td>12</td>
<td>9.2</td>
<td>1.1</td>
<td>13</td>
<td>3</td>
</tr>
<tr>
<td>Deepwater/tidal wetland</td>
<td>10</td>
<td>8.7</td>
<td>1.5</td>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td>Total (all types)</td>
<td>129</td>
<td>100</td>
<td>3.1</td>
<td>464</td>
<td>100</td>
</tr>
</tbody>
</table>

Source: IRRI (1997)

Flood-prone rice is both direct-seeded and transplanted during the rainy season, mostly in South and Southeast Asia on the flood plains of major river systems such as the Mekong, Chao Phya, Irrawaddy, and Ganges. Typically, deep-water (flood-prone) rice is grown for 1 to 3 months under rain-fed conditions, subjected to drought and shallow flooding, followed by uncontrolled deep water, from 1 to 5 meters for a month or longer.
during seasonal land inundation. Where flooding exceeds about 1 m, deep-water rice cultivars, known as “floating rice,” are planted. Flood-prone rice is grown on about 10 million hectares, principally in South and Southeast Asia. Average yields are about 1.5 t/ha and account for about 9% of the Asian planted rice area.

5.2 Crop establishment methods

Under lowland rice culture, land is prepared wet or dry, but water is always held on the field by levees. Both rain-fed and irrigated lowland rices are classified into transplanted, direct-seeded, and ratooning rices according to stand establishment methods. In rice growing area of Asia, transplanted rice is by far the most important method of crop establishment. In the transplanting method seedlings are first raised in the seedbed before they are planted in the main field. With direct seeding, the seed is sown directly in the main field either by broadcast or row seeding on wet or dry paddy. In ratooning culture of rice, crop stand is established by the tillers grown from stubble of harvested plants.

5.2.1 Transplanted rice

For lowland rice in the tropics, seedlings are grown when an adequate moisture supply is available. In the case of irrigated rice, seedlings can be grown any time of the year as needed. For rain-fed rice, the starting of seedbeds usually conforms with the onset of monsoonal rains. Seeds of several tropical rice varieties have a dormancy period. A dormancy period of 2~3 weeks in rice seeds is an important advantage in the tropics, particularly for the wet-season crop, when high temperature and humidity at harvest would result in germination on the panicle if there is no dormancy. For seedbed seeding, farmers have to wait until the dormancy period is over or break dormancy by heat of 50°C for 5 days. Waiting until the end of the dormancy period is the usual practice. Rice seeds are soaked in water for one to several days depending on water temperature and then incubated for 48 hours for sprouting before they are placed on the seedbed. This pregermination process assures a quick and even start of the rice seedlings.

Major methods of seedling rearing are wet-bed, dry-bed, dapog, polyethylene film-covered bed, and nursery box for transplanter. The number of days in the nursery bed is generally 30 to 40 days in cool regions and in early season cultivation, 20 to 30 days in warm regions and in late season cultivation, and 15 to 20 days in tropical countries.

**Wet bed** In the wet-bed method, pregerminated seeds are broadcast uniformly on a raised bed of puddled soil, and the seedlings are reared for transplanting 20~25 days after the seeds are sown. Rate of seeding is about 100 g/m² of seedbed, which amounts to 50 kg/ha. The bed is drained occasionally to encourage the production of healthy seedlings. Flooding the soil with too much water for long period produces tall and weak seedlings that do not readily recover during transplanting.

**Dapog** The dapog method of raising seedling was developed in Laguna Province, Philippines. Land preparation is the same as in the wet-bed method, but banana leaves with the midribs removed, or plastic sheets are used to cover the surface of the bed. The strips of banana bracts of 5 to 8 cm are placed on all sides of the bed. The purpose of cov-
ering the top of the seedbed is to prevent the seedlings roots from coming in contact with the soil, thus facilitating the separation of seedling during transplanting. Fertilizer is not needed since the seedlings are nourished by the reserved nutrients in the seed. A bed or several beds with a total area of 40 m² can accommodate 45 to 60 kg of seeds, which are sufficient for planting a field of one hectare. Dapog seedlings are ready for transplanting 9 to 14 days after sowing. The advantages of this method are labor savings because the bed can be easily made, a short period for raising seedlings, and relative ease of seedling transport because seedling mat can be rolled, while seedlings raised in wet or dry beds have to be pulled, bundled, and tied for transplanting. However, dapog seedlings are short (10 to 13 cm tall). Thus, dapog seedlings are used only in areas where the water depth is controlled in the main fields especially during the early stages of seedling growth.

**Dry-bed** This method is practiced in some areas where water is not sufficient to warrant the use of the wet-bed. However, experiences in Korea indicate that upland-grown seedlings have better rooting ability and, hence, recover more quickly after transplanting. The upland-grown seedlings are shorter, have smaller leaves and more highly branched roots, and contain more nitrogen and starch than the lowland-grown seedlings. Upland-grown seedlings perform well when temperatures are cool during transplanting, the growing period is short, and hence, quickly recover from transplanting. At low altitudes in the tropics, however, temperatures are favorable for rice growth all year round and growth tends to be excessive. Under such conditions, seedling quality may not have much effect on grain yield. Dry-bed seedlings are grown in a manner similar to that used for wet-bed seedlings, except that the soil is not puddled and drainage is provided to keep the soil moist but not inundated.

**Polyethylene film-covered bed** Where the rice growing season is limited as in Korea, extension of the rice-growing period under indoor condition should result in an productivity increase. Seedbeds protected by polyethylene film are used to grow rice seedlings during the early cool season when rearing of seedlings under outdoor conditions is impossible. The seedbed is prepared as in wet- and dry-bed methods, and is covered with a polyethylene film in tunnel shape until the air temperature is high enough to grow rice seedlings naturally.

**Nursery box for transplanter** Transplanting machine has been introduced in 1968 and 1977 in Japan and Korea, respectively, because of shortage and high cost of labor. Nursery box for mechanical transplanting is a common practice in Korea and Japan. Mechanical transplanters transplant seedlings raised in nursery box. Seedlings raised by this method are classified into infant, young, and medium-sized seedling depending on the raising period (Table 5.2).

<table>
<thead>
<tr>
<th>Type of seedling</th>
<th>Sowing density (g/box)</th>
<th>Raising period (days)</th>
<th>Plant height (cm)</th>
<th>Leaves (no.)</th>
<th>Shoot dry weight (mg/plant)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infant</td>
<td>200–220</td>
<td>8–10</td>
<td>7–8</td>
<td>1.5–2.0</td>
<td>7–0</td>
</tr>
<tr>
<td>Young</td>
<td>180–200</td>
<td>20–25</td>
<td>10–12</td>
<td>2.0–2.5</td>
<td>10–15</td>
</tr>
<tr>
<td>Medium-sized</td>
<td>100–130</td>
<td>30–35</td>
<td>12–15</td>
<td>3.5–4.0</td>
<td>20–30</td>
</tr>
</tbody>
</table>
Planting density  The number of seedlings planted per hectare depends on the method of raising seedlings and plant spacing. Ordinarily, 3–4 seedlings per hill are planted from wet-bed and 6–8 per hill from dapog seedbeds. It is desirable to select rice varieties with high tillering capacity to ensure adequate number of tillers per hill. In China, where rice is almost entirely irrigated, 8–10 seedlings per hill are commonly used. This is because Chinese varieties do not have high tillering capacity. Plant spacing is an important production factor in transplanted rice. Planting rice closer than necessary increases the cost of transplanting and the chances of lodging. On the other hand, spacing rice wider than necessary may result in lower yield because the number of plants in the area may be less than the optimum number needed for high yield.

Rice is planted in straight rows using the eye-marked string or transplanting machine. In many countries in South and Southeast Asia, rice is transplanted at a random spacing. Random planting is most common in rain-fed rice, particularly when traditional varieties are grown. Rice seedlings are transplanted at random in the field, and planting space is not uniform and no definite aligning pattern is followed. Random planting makes the use of the rotary weeder difficult or impossible, and this method sometimes does not result in an increased yield because of insufficient number of hills per unit area.

There is no single best spacing practice for all varieties. Optimum spacing of any variety depends on soil fertility and planting season. A uniform stand containing an optimum plant population is essential for proper crop development and high grain yield. In Korea, the standard transplanting spacing is $30 \times 15$ cm. However, transplanting spacing is different depending on the location and the planting season (Table 5.3)

<table>
<thead>
<tr>
<th>Location</th>
<th>No. of hills per 3.3 m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mountain area or late transplanting in plain area</td>
<td>110–130</td>
</tr>
<tr>
<td>Mid mountain area, saline area, east coastal area</td>
<td>90–110</td>
</tr>
<tr>
<td>Double cropping with barley</td>
<td>80–90</td>
</tr>
<tr>
<td>Plain area</td>
<td>70–85</td>
</tr>
<tr>
<td>Double cropping with vegetable</td>
<td>85–95</td>
</tr>
</tbody>
</table>

In Tropical Asia, rice cultivars of improved plant type and high tillering capacity can be planted at a wide range of spacing. The tiller number per unit area in a rice population is largely a function of plant density. The tiller number is positively or negatively correlated with grain yield depending on the rice variety and crop environment. According to the studies of plant density effects on the rice yield for traditional varieties and newly developed varieties, the short, lodging-resistant modern varieties should be spaced $20 \times 25$ cm in the wet season regardless of soil fertility. In the dry season, tall and leafy, heavy tillering varieties such as Peta are spaced $20 \times 25$ cm in relatively poor soil, and $30 \times 30$ cm in fertile soil. In wet season tall varieties are spaced $30 \times 30$ cm in poor soil and $35 \times 35$ cm in fertile soil. Studies at IRRI suggest that the optimum spacing for the lodging-susceptible tall variety Peta is $50 \times 50$ cm, where as the optimum spacing for non-lodging short variety Tainan-3 is $30 \times 30$ cm in the wet season. Data on varietal response to plant density demonstrate that if there is no lodging, the yields of most varieties do not change significantly when the planting distance is below 25–35 cm.
5.2.2 Direct-seeded rice

Many types of direct seeding methods are practiced in rain-fed and irrigated rice growing areas of Asia.

Direct seeding on puddled soil  Direct seeding on puddled soil is practiced in parts of India, Bangladesh, Sri Lanka, and the Philippines. For direct seeding on puddled soils, the land is leveled after the soil is puddled, and pregerminated seeds are either broadcast or machine-drilled. To obtain high yields with direct-seeded rice, precise water management, good weed control, and optimum fertilizer management are necessary. Root anchorage is poor and lodging is more serious with direct seeded than with transplanted rice.

In some rain-fed areas in the Asian tropics, wet-seeded lowland rice culture is an important system. Wet seeding is usually done by broadcasting in Sri Lanka, and parts of India, Bangladesh, and the Philippines. Pregerminated seeds are broadcast onto puddled fields without much standing water. Fields are prepared wet with various degrees of puddling. Stand establishment is often poor because of poor land preparation, weed competition, and poor water control.

Dry seeding on nonpuddled soil  Establishment of dry-seeded rice in lowland field must be in accord with the local rainfall pattern. Field observations suggest that dry seeding after rain commences results in poor seedling emergence and low yields. Dry seeding prior to the rainy season requires consideration of rainfall pattern and the effects of early rainfall on crop performance. For high yields, once rainfall begins, promotion of fast seed emergence and rapid early vegetative growth must be adequately achieved. Despite the above difficulties in stand establishment, dry seeding into dry soil provides a unique opportunity to increase cropping intensity through double cropping. For many years, farmers in northeastern India, Bangladesh, and Indonesia have grown rain-fed lowland rice by dry seeding directly onto nonpuddled soil at the beginning of the rainy season. This method of rice culture is known as aus cropping in northeastern India and Bangladesh. The aus (meaning early) rice is direct-seeded during March-April and harvested between July-August.

Drill seeding into dry soil  Drill seeding rice into dry soil is most common in the United States and Australia, where rice production is fully mechanized. In Korea and Japan this method is increasing as a labor-saving system. Under this system the final land preparation is done with a spring-tooth or disc harrow, followed by a spike-tooth harrow. Rice seed is sown 3~5 cm deep with a grain drill.

Water seeding  The practice of water seeding rice originated, and is still followed, in parts of Asia, including India, Sri Lanka, Malaysia, and Thailand. It is also widely practiced in the Americas, southern Europe, Russia, and Australia. In Korea and Japan it is increasing as a labor-saving system. For water seeding, precise water control must be achieved, and more seeds are required than the transplanting method. Good seed viability is essential. Oxygen deficiency does not appear to be a limiting factor in the establishment of rice stand in water-seeded rice.
5.2.3 Ratooning rice

Ratoon culture of rice is practiced in tropical and sub-tropical Asia. In southern China ratooning rice technique has spread to about 1 million hectares. Ratooning rice culture involves the application of fertilizer after harvest to allow tillering from the nodes of the rice stubble. Ratooning ability is very different from variety to variety. Rice production cost is significantly reduced because of the savings from seeds, land preparation, irrigation, fertilizer application, transplanting, and pest control expenses.

5.3 Water management practice

5.3.1 General effects of flooding

Rice, like other crops, requires adequate water to grow and develop at its maximal potential rate. Unlike other crops, rice is usually grown in flooded soil. With an adequate water supply from rain or irrigation, continuous flooding of 5 to 7 cm of standing water is desirable on most soils for the best moisture supply. Main reason for flooding a rice field is that most rice varieties maintain better growth and produce higher grain yields when grown in a flooded than in a nonflooded soil. Water affects the physical characteristics of the rice plant, the nutrient and physical status of the soil, and the nature and extent of weed control. Research generally has shown that maximum yield potential exists when the soil is maintained under flooded or saturated condition. In some situations yields have been increased by permitting occasional slight drying, provided the soil is flooded or saturated from panicle initiation until the crop nears maturity. The height of rice plant is directly related to the depth of water in the paddy, the plant height increases with increasing water depth. Tiller number, on the other hand, is inversely related, at least over a relatively wide range of moisture condition. One benefit of submerging rice soil is that the method increases the availability of many nutrients, particularly phosphorus, potassium, calcium, silicon, and iron. However, if the soil is highly permeable, nutrients are leached downward from the root zone. The question of whether internal drainage is desirable is often raised. The advantages of internal drainage are depression of the concentration of carbon dioxide, iron, and reducing substances, and prevention of the build-up of high concentrations of carbon dioxide, iron, and organic acids in cold soils. On the other hand, disadvantages are losses of water and nutrients. Internal drainage is desirable on cold, saline, and alkaline soils.

Flooding soil causes chemical reduction of iron and manganese, as well as other elements in the soil. Various organic acids, such as acetic and butyric acids, and gases, such as carbon dioxide, methane, and hydrogen sulfide, are produced. All except methane, when present in large amounts, retard root development, inhibit nutrient absorption, and cause root rot. Toxicity is most often noticed when oxygen in the soil is depleted due to the rapid decomposition of large quantities of organic matter. Oxygen may be brought into the soil by allowing drainage with moderate drying. The reduced substances are then oxidized and the toxic gases may escape through the soil surface. Percolation water can bring oxygen into the soil and leach toxic substances beyond the rooting zone. Percolation rates of 2~3 mm/day may correct toxicity problems. Emergence of weeds and the type of weeds are closely related to the moisture content of the soil and the water
depth in the rice field. For transplanted rice, proper water management can substantially reduce weed emergence. Grasses can be completely eliminated if continuous flooding of a 16-cm depth is maintained throughout the crop growth. Even with 5 cm of continuous standing water, grasses are substantially controlled.

5.3.2 Water requirement

Water is lost from irrigated rice during the crop season, through transpiration, evaporation, and percolation. Water losses through percolation are the most variable. Total loss of water (Table 5.4) ranges from 5.6 to 20.4 mm/day, but most of the observed values for total water loss range from 6 to 10 mm/day. Thus, on the average, about 180~300 mm water/month is needed to produce a reasonably good crop of rice.

| Water requirement of an irrigated rice crop in 43 locations in China, Japan, Korea, the Philippines, Vietnam, Thailand, and Bangladesh (Kung, 1971) |
|---|---|---|---|---|
| By water loss |  |
| Transpiration | 1.5~9.8 mm/day |
| Evaporation | 1.0~6.2 mm/day |
| Percolation | 0.2~15.6 mm/day |
| Range of total daily loss | 5.6~20.4 mm/day |
| By field operation |  |
| Seed nursery | 40 mm |
| Land preparation | 200 mm |
| Field irrigation | 1,000 mm |
| Total | 1,240 mm/crop |

In field operation, 1,240 mm is the average water requirement for an irrigated rice crop. However, the amount varies depending on many factors that affect water losses from rice field, including soil type, topography, proximity to drains, depth of water table, area of contiguous rice fields, maintenance of levees, fertility of both top and subsoil, field duration of the crop, land preparation method, and, most of all, evaporative demand of the growing season.

5.3.3 Water management practices

The effort required to implement specific water management practice increases as the amount of water available decreases and the desired degree of water control increases. Continuous flooding, continuous flowing, and rotational irrigation are the most common water management practices.

**Continuous flooding** Continuous flooding at a shallow depth of 2.5~7.5 cm provides the potential to produce optimum rice yields. With adequate water supply, management need is minimal. Continuous deep flooding of 15 cm or more has the potential to produce yields similar to those at shallow depth. Deep flooding increases plant height substantial-
and decrease tiller number. In Korea and Japan, some farmers practice deep flooding to suppress unproductive tillers and to protect rice plants from cold damage during booting state.

**Continuous flowing** The practice of continuous flowing irrigation may be useful if irrigation water temperature is high. Such is the case in the tropics, where field water temperature is often as high as 40°C. Therefore, this practice will lower the water and soil temperatures, check abnormal soil reduction, and reduce sterility in rice grains. However, it is more desirable to reduce the water temperature before being introduced in the main field. Continuous flowing irrigation may increase the availability of soil nutrients. Generally, flowing irrigation will keep the surface soil oxidized, a highly desirable effect in soils that are strongly reduced. Continuous flow irrigation is also practiced in reclaimed paddy fields of tidal land to prevent rice plants from salt injury and to desalinate the paddy soil.

**Rotational irrigation** Rotational irrigation is the application of required amount of water into fields at regular interval. The field may often be without standing water between irrigations, but generally moisture content of the soil does not drop below the level moisture stress to develop. Rotational irrigation is often recommended to irrigate a large area with a limited water supply to ensure better equity among water users. A major advantage of rotational irrigation is possibly the more effective use of rainfall in the rice field. Rotational irrigation is recommended to supply oxygen into rhizosphere during ripening stage in Korea and Japan.

5.3.4 Water management at different growth stage

Seasonal water requirements differ with different growth stages. For water management practices of rice, the growth stages of rice can be divided into seedling, vegetative growth, reproductive, and ripening stages. In areas with low rainfall or a highly variable rainfall pattern, irrigation practices should be developed to assure adequate water at the critical growth stages. Rice is most sensitive to moisture stress between 20 days before and 10 days after heading, and uses the maximum amount of water during that time. The critical period for moisture stress coincides with the period in which plants use the most water.

**Seedling establishment stage** At seedling establishment and seedling stage the water requirement is low. If seeds are submerged, germination and emergence is affected by lack of oxygen supply. Seeding into standing water is not common in the tropics because a lack of proper water control and low oxygen concentration in water under high temperatures in the tropics lead to poor stand establishment. Where rice has been drilled or broadcast in a dryland soil and covered, the soil may need to be flushed if moisture is inadequate for germination or if a crust has formed as a result of drying following rain. A flush should be applied before the young seedlings lose penetrating power. Germination of seeds is poor if the seeds are covered by both water and soil.

**Vegetative stage** During vegetative stage it is most important to produce an adequate number of tillers for optimum yield. Immediately after tillering deep irrigation is required to prevent excessive water loss in rice plants and facilitate early rooting. Following the
early rooting stage, a shallow water depth facilitates tiller production and promotes firm root anchorage in the soil. Excessive water at this stage seriously hampers rooting and decreases tiller production. Leaf blades and leaf sheaths of the submerged plants become weak, turn light green, and break easily. In Korea and Japan midsummer drainage is recommended to suppress unproductive tillers and lodging. Midsummer drainage is done late in the tillering stage prior to the panicle initiation stage, when the number of panicles is fixed and the water requirement by the rice crop is minimal. Midseason drainage changes the root zone temporarily into an oxidized state. Removal of anaerobic toxins and carbon dioxide is a distinct advantage of midseason drying of some soils. Another advantage is regulation of nutrient supply to the crop, particularly nitrogen supply at the later stages to suppress growth of late tillers. Some irrigation water may also be saved. However, where water supply and control are poor, as is the case in the Asian tropics, midseason drying may subject the rice crops to undue water stress. Other disadvantages include possible root pruning caused by soil shrinkage, reversal of beneficial pH changes, and increased loss of nitrogen.

**Reproductive growth stage** Reproductive growth starts when maximum tiller production is completed and includes the panicle primordia development, booting, heading, and flowering stages. A large amount of water is consumed during the major part of the reproductive growth period, which explains why rice is sensitive to moisture stress during reproductive growth. Two factors should be considered for water management at this stage. Drought at this stage causes severe damage, particularly when it occurs from panicle initiation to flowering stages. Increased panicle sterility, caused by impeded panicle formation, heading, flowering or fertilization, occurs if sufficient moisture is not provided. The other factor is excessive water at the reproductive stage, particularly at the booting stage, which decreases culm strength and increases lodging. During the booting stage rice plant is most sensitive to sterile-type cold damage. Thus, deep irrigation of over 20 cm with warm water above 20°C is recommended to protect rice plants from cold damage.

**Grain ripening stage** During grain ripening stages, very little water is needed. Thus, rotational irrigation rather than continuous flooding is more desirable to keep the rice root healthy. After the yellowish ripening stage, standing water is not required. Field is drained about 10 days before harvest, which facilitates harvesting by machine.

5.4 Mineral nutrition and fertilizer management

5.4.1 Nutrients requirement

Like other crops, rice need 16 essential elements, which include carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, sulfur, calcium, magnesium, zinc, iron, copper, molybdenum, boron, and chloride. All essential elements must be present in optimum amounts and in forms usable by rice plants. Nitrogen, phosphorus, zinc, and potassium are nutrient elements most commonly applied by rice farmers. Sulfur is occasionally applied to some soils but is usually supplied as an ingredient of (NH₄)₂SO₄, K₂SO₄, and CaSO₄, even where it is not needed. Silicon, although not an essential element, is applied in Japan, Republic of Korea, and Taiwan. All other essential nutrients are provided through water, soil, and plant residues, or as contaminants in commercial fertilizers.
Nutrient uptake is affected by climate, soil properties, amount and type of fertilizers applied, variety, and method of cultivation. Nevertheless, the changes in nutrient content at various stages in the life history of the rice plant are strikingly similar. The nitrogen, phosphorus, and sulfur contents in the vegetative parts are generally high during early growth stages and decline toward maturity. In contrast, the silicon and boron contents are low during early stages and increase steadily toward maturity. The contents of nitrogen and phosphorus are generally higher in the panicles than in the straw (leaves plus culm), whereas those of potassium, calcium, magnesium, silicon, manganese, iron, and boron are higher in the straw. Sulfur, zinc, and copper contents are almost equal in both straw and panicle.

Nutrient uptake by the rice plant through its growth cycle is shown in Figure 5.2. Nutrient uptake patterns are curvilinear and resemble the growth curve, demonstrating a close relationship between these factors. Nutrient accumulation is continuous throughout all phases of development, but the highest demand occurs during the active tillering period. Each essential nutrient plays a rather specific role in the physiological processes of rice plant, and its absorption, accumulation, and proper function depend on an adequate supply and balance of the element.

Nutrient uptake ranges from 30~40 g/ha per crop for copper to 890~1,018 kg/ha per crop for silicon. Uptake of silicon is far greater than those of other nutrients. Nutrient removal by a rice crop increases almost proportionally to the rice yield increases. To produce 1 t/ha it is necessary to absorb 12~24 kg nitrogen (average of 20.5 kg), 4~6 kg phosphorus (average of 5.1 kg), and 35~50 kg potassium (average of 44.4 kg) in the tropics. In temperate regions lower amounts of nutrients are absorbed to produce the same yield (Table 5.5). Thus, the efficiency of nitrogen appears to be 20% higher in temperate regions than in the tropics.

![Figure 5.2](image.png)

**Figure 5.2** Nutrient uptake by rice. (Mikkelsen and Patrick 1968)

<table>
<thead>
<tr>
<th></th>
<th>Yield (t/ha)</th>
<th>Nutrient removal (kg/ t rough rice)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>P</td>
</tr>
<tr>
<td>Tropics (IRRI)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IR8</td>
<td>8.70</td>
<td></td>
</tr>
<tr>
<td>Peta</td>
<td>6.09</td>
<td></td>
</tr>
<tr>
<td>Av. of 3 varieties × 4 crops</td>
<td>4.74</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Japan</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Japan contest winner (Mr. Kihara, 1958)</td>
<td>12.80</td>
<td>15.2</td>
</tr>
<tr>
<td>Av. of 14 agric. exp. sta.</td>
<td>5.34</td>
<td>17.0</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5.4.2 Soil flooding and nutrient availability

Rice is generally grown on flooded soil. Flooding the soil for a certain period or for the entire crop season in most rice growing areas has been considered indispensable for obtaining high grain yield of rice. A continuously submerged soil has two distinct layers of extremely different properties. Surface layer of soil is an oxidized zone about 1~10 mm thick created when atmospheric oxygen diffuses through the water layer and also from oxygen supplied by the superficial algal population. Aerobic microorganisms thrive in this zone, where oxidized materials such as nitrates, sulfates, and ferric iron are also present. Below the thin oxidized layer extends a reduced zone characterized by its dark color, the presence of reduction products, low Eh (oxidation reduction potential) values, and the presence of anaerobic microorganisms.

A major portion of the chemical changes occurs in the soil reduction layer, where dynamic reactions may produce beneficial or sometimes harmful effects on rice plants. In the reduced soil layer, anaerobic microorganisms utilize successively weaker electron acceptors in place of oxygen for respiration. After oxygen is consumed, the next strongest electron acceptor is NO$_3^-$, which is reduced into N$_2$ and N$_2$O gases. The only part of the flood soil in which NO$_3^-$ is stable is the surface aerobic layer and aerobic microsites within the anaerobic layer. However, this NO$_3^-$ usually moves into the reduced soil layer by diffusion and mass flow, where NO$_3^-$ is biologically denitrified into N$_2$ and N$_2$O. Ammonium N, formed as a result of organic matter mineralization or added into flooded soil as fertilizer, moves into the soil solution, from where it is rapidly adsorbed onto the cation-exchange complex of the soil, and some ammonium-N may be fixed by certain clay minerals. Ammonium N is retained effectively by the soil colloidal fraction or may exist in a combined form with soil organic matter.

When oxygen and nitrates become exhausted, the soil redox potential drops and Mn$^{4+}$ and Fe$^{3+}$ are reduced to Mn$^{2+}$ at +200 mV and Fe$^{2+}$, respectively. If the supply of electron acceptors is less than the rate of consumption, even stronger reducing conditions develop, and sulfate is reduced into sulfide. At values of -250 to -300 mV, microorganisms use energy stored in organic compounds by reducing hydrogen and hydrogen ions and by fermenting organic matter into carbon dioxide, organic acids, and alcohols, and ultimately into methane and hydrogen.

Concentrations of phosphorus, potassium, iron, manganese, and silicon increase in the soil solution after soil submergence. The concentration of zinc, however, decreases. Increase in ferrous iron concentration is often excessive, inducing iron toxicity in rice. The phosphorus-supplying capacity of flooded rice soils is higher than that of upland soils. Flooded rice frequently does not show response to P addition even though upland crops grown in the same soils show a high response. The availability of P is closely related to the degree of reduction of the soil. Contents of available P and Fe increase proportionally with the increase in Eh. These increases in the availability of soil and fertilizer phosphorus upon flooding are generally attributed to the reduction of ferric phosphate (FePO$_4$·2H$_2$O) into ferrous phosphate (Fe$_3$(PO$_4$)$_2$·8H$_2$O) and to the hydrolysis of aluminum and iron phosphate.
5.4.3 Fertilizer management

Fertilizer is one of the most effective production inputs for rice. Development and dissemination of fertilizer-responsive cultivars of rice have encouraged a steady increase in the use of fertilizer in the developing countries. Fertilizer responsiveness is a key factor in differentiating among the traditional rice and the new high-yielding cultivars. Only where the levels of fertility are at least modest do yield differences between the new and the old become significant; with fertilizer, the yield potential is often double or even triple that of the traditional ones.

Fertilizer use efficiency can be described as the output of economic produce by any crop per unit of fertilizer nutrient applied under a specific set of soil and climatic conditions. The least amount of fertilizer needed to match plant use at maximum grain yield is the most efficient rate of fertilizer application. Several factors determine fertilizer efficiency in rice. At the farm level, they are soil, cultivar, season, time of planting, water management, weed control, insect and disease control, cropping sequence, sources, rate, methods, and time of fertilizer applications.

As the efficiency of nutrient utilization appears to be almost constant regardless of the rice yield achieved, the rice yield shows linear relationship with the fertilizer consumption (Figure 5.3). The difference in fertilizer consumption across Asian countries is substantial; from almost negligible in Myanmar, Cambodia, and Laos, to less than 100 kg in Thailand, Philippines and India, and to more than 300 kg in East Asia.

Nitrogen

Nitrogen is the most important nutrient for rice, and its deficiency common unless nitrogen is applied as a fertilizer. Lowland rice responds better to nitrogen application than to applications of phosphorus and potassium. Yet, lowland rice depends more on soil fertility than on fertilizers. In lowland rice, 50 to 80% of the nitrogen absorbed by the crop is from the native soil nitrogen pool.

Sources of soil N include soil organic matter, N released during the decomposition of organic materials, N fixed by living biota in the floodwater and soil, rainfall, groundwater, and fertilizer N added to the flooded soil environment. Nitrogen is one of the most difficult plant nutrients to manage, since losses may occur in both the oxidized and reduced soil layers, from the floodwater, by outflow and leaching, and by absorption through biological forms in the soil.

Efficiency of fertilizer N varies with soil types, fertilizer rates, timing, method of application, and agronomic and crop management factors. The efficiency of N recovery usual-
ly ranges from 30 to 50% in the tropics. The highest efficiency occurs with the first increment of fertilizer applied, with additional doses providing smaller increases. Deep placement of fertilizer N and top dressings late in the plant development stage also increase fertilizer efficiency.

Nitrogen utilization efficiency for grain production in the tropics is about 50 kg rough rice per kg N absorbed, which is about 20% higher in temperate areas of the world. Using values obtained through research for N recovery percentage and utilization efficiency, Yoshida has estimated fertilizer N efficiency in the range of 15~25 kg rice per kg of applied N. It is apparent that maximizing N uptake at the critical growth stages and minimizing losses should be fertilizer management objectives. Poor utilization efficiency can be attributed largely to losses of N from the soil-plant system by denitrification, ammonia volatilization, and leaching; all are ultimately affected by the fertilizer source, rate, time, method of application, agronomic practices, and weather conditions.

**Sources of nitrogen** For flooded rice, in most instances, ammonium-containing (ammonium sulfate, ammonium chloride, anhydrous ammonia, etc.) or ammonium-producing (urea) fertilizers are almost equally effective in terms of grain yield response and are excellent sources of fertilizer nitrogen for flooded rice. In certain instances, urea was reported to be inferior to ammonium sulfate, but no specific reasons were cited for its low performance. In certain problem soils, which are low in iron, such as degraded paddy soils of Japan and Korea, urea, ammonium chloride, and other non-sulfur-carrying nitrogen fertilizers are preferred to ammonium sulfate. Nitrate sources are unsatisfactory as preplant fertilizer nitrogen because losses through nitrification are almost complete, although they may be used as top-dressing at later stages of rice growth, when the superficial root system is well developed.

There are potential advantages in releasing the plant nutrients throughout the growing season. Slow-release fertilizers, IBDU (isobutylidenediurea), UF (urea-formaldehyde), CDU (crotonylidenediurea), SCU (sulfur coated urea), and resin-coated fertilizers, offer potential for increasing the efficiency of N uptake through the release characteristics, but the added costs of manufacture somewhat limit their use. Green manures and compost are good organic sources of nitrogen for rice. The experiences of temperate East Asia indicate that dependence on compost and other organic sources of nitrogen declines with increased industrialization and associated high cost of labor rather than because of any decline in rice yields from continuous use of inorganic fertilizer in rice. In tropical Asia, with increased availability of urea and other nitrogenous fertilizers and with greater use of short, stiff-strawed, nitrogen-responsive rice varieties, the use of organic sources of nitrogen provides a supplement rather than an alternative to inorganic fertilizers for lowland rice.

**Timing of nitrogen application** One way to achieve the increased nitrogen fertilizer efficiency by achieving higher yields with the same amount of nutrients absorbed is to apply the fertilizer at an optimum time to meet the demand of rice plant. The major N requirement of rice occurs during the early vegetative growth, with a second period at the beginning of the reproductive phase, usually identified as panicle initiation. Therefore, split application of nitrogen, with one dose at transplanting and another at panicle initiation, is best for obtaining high grain yields, particularly in the case of medium and long-
season varieties. Nitrogen absorbed by the plant from tillering to panicle initiation tends to increase the number of tillers and panicles, and that absorbed during the panicle development increase the number of filled spikelets per panicle. Nitrogen absorbed after flowering tends to increase the 1,000-grain weight.

In tropical areas many farmers split fertilizer N into three applications, often for convenience but also due to personal experience. The first application is usually made prior to transplanting, desirably with soil incorporation but frequently into water without incorporation. A second application is made at the maximum tillering stage, and the final topdressing is made at or just prior to panicle initiation. In Korea, it is recommended to split fertilizer N application four times prior to transplanting, at two weeks after transplanting, at panicle initiation stage, and at flowering time.

The capacity of soil to hold applied nitrogen is an important consideration in determining the efficiency of basal versus split applications of nitrogen fertilizer. Recovery percentages of applied nitrogen differ among soils when the fertilizer was applied deeply to minimize nitrogen loss through denitrification. Higher recovery percentages correlate with increases in grain yield attributable to nitrogen applications. Apparently, the applied ammonia is lost through leaching, the degree of which depends on soil properties. Soils with montmorillonite clays tend to have higher recovery rates than those with kaolinite clays or allophane.

For soils with low nitrogen-holding capacities, split applications of fertilizer should result in a higher nitrogen recovery and, hence, a higher yield than a basal application. On the other hand, split applications may not be more effective than a basal application in soils where the applied ammonia is well-held by clays.

**Method of N application** Loss of fertilizer N can be significantly reduced and availability to rice enhanced by placement of ammonium-form N fertilizers into the reduced zone of flooded soils. Deep placement, usually at depths varying from 5 to 10 cm, reduces the likelihood of nitrification-denitrification losses and avoids allowing fertilizers to enter the floodwater where losses may occur in runoff and through ammonia volatilization. However, leaching loss is accelerated by the deep placement in soils with high percolation rate.

**Phosphorus**

Phosphorus deficiency occurs widely in soils of low or high pH: acid latosolic soils, acid sulfate soils, calcareous soils, and alkali soils. Ando soils, which have a high capacity to fix applied phosphorus, need much greater amount of phosphorus than usual. For example, the optimum for acid Ando soils in northern Japan is about 200 kg P₂O₅/ha, that for calcareous soils at Dokri, Pakistan, about 45 kg P₂O₅/ha, and that for calcareous soils at Rajendranagar, India, about 80~100 kg P₂O₅/ha.

In general, response to phosphorus in flooded rice is less common than that to added nitrogen. This is because flooded rice is able to draw in sources of soil P relatively unavailable to upland crops.

There is little significant difference among phosphorus sources for flooded rice except
in extremely acid or alkaline soils. Superphosphate is a very efficient source of phosphorus for rice on all except very acid soils, in which rock phosphate and bone-meal have been found to be as efficient or even better than superphosphate. Other sources such as triple superphosphate, ammoniated phosphate, and nitrophosphate are used for rice.

In general, phosphorus is applied to rice at planting, but later application can be made, provided it is not later than the time of active tillering. Early application of phosphorus is essential for root elongation. Phosphorus applied during the tillering stage is not efficiently used for grain production. Split application of phosphorus has not been proven to be of value due to the high mobility of phosphorus from old leaves to young ones, the availability of soil phosphorus increasing with time during submergence, and low leaching losses.

**Potassium**

Most rice soils are not particularly deficient in potassium. That is because irrigation water usually contains significant amount of potassium. Majority of rice soils in Asia respond more to N and P than to K.

A response to potassium is obtained on light soils, where leaching causes considerable loss of bases. Favorable responses to potassium have been demonstrated from sandy and coarse textured soils of Vietnam, Sri Lanka, and Malaysia. In Sri Lanka, about 25% of the total rice fields suffer from potassium deficiency. Average increase in yield in Taiwan from potassium application is about 50%. Responses are most significant in red and yellow earths, and the effects of potassium are generally higher in the second crop than in the first.

Common sources of potassium are potassium chloride and sulfate. Potassium is usually applied during the final land preparation, when a low rate of potassium (30 kg/ha) is applied, and it is better to topdress once at the active tillering stage. Results occasionally indicate that split application of potassium is beneficial to rice grown on coarse textured soil. In Korea it is recommended to apply two-thirds of the total potassium fertilizer prior to transplanting and the remainder as topdressing at panicle initiation stage.

### 5.5 Control of weed, insect pest, and disease

#### 5.5.1 Weed control

Weeds are one of the most important sources of yield loss. Worldwide loss in rice yield due to weeds has been estimated to be around 10% of total production. Weeds are universal competitors of rice, competing for moisture, light, and plant nutrients essential to plant growth and yield. They also create problems during harvesting, drying, and cleaning, and reduce the quality and marketability of the produce. Insect pests such as leafhoppers and stemborers also live on weeds as alternate hosts and directly attack the rice crop, sometimes spreading virus-based diseases. Water management is often impeded when weeds block irrigation systems, thus slowing the drainage. Mechanical harvest of rice is more expensive, as are cleaning and drying, when weeds grow in competition with the crop.
In upland culture of rice weeds are a major barrier to satisfactory rice production wherever they occur, but are especially troublesome in upland rice where their growth is less restricted and conservation of available moisture is critical. Weeds in upland rice consist of annual broadleafs, sedges and grasses, and a wide variety of perennials, including some shrub species. Since rice is grown under such a wide range of climatic conditions, soil types, and crop rotations, it is not possible to identify the most damaging weed species. *Echinochloa crus-galli, E. colonum, Cyperus rotundus, Rottboellia cochinchinensis,* and *Imperata cylindrica* are serious weed pests in most upland areas of the world.

In lowland rice culture, aquatic and semi-aquatic annual and perennial weeds flourish. The most prevalent weeds are grasses, broadleaf weeds and sedges. Among the most damaging lowland and aquatic weeds in rice are *Echinochloa spp.*, *Eichhornia crassipes, Fimbristylis spp.*, *Cyperus spp.*, *Monochoria vaginalis, Sagittaria spp.*, *Salvinia spp.*, *Polygonum spp.*, *Marsilea quadrifolia, Alternanthera spp.*, *Eclipta alba, Jussiaea spp.*, *Sphenoclea zeylanica,* and *Ischaemum rugosum.*

The control of weeds in flooded lowland is facilitated by thorough land preparation before planting. When this is properly done, most weed seeds fail to germinate and weeding becomes easier and less expensive. Straight row transplanting enables farmers to use push-type rotary weeder along the rows, providing a distinct advantage over random transplanting. Hand weeding, involving pulling or trampling the weeds into the mud, is a satisfactory alternative where rotary weeder are not available. Water management has long been known to be an effective means of weed control in both transplanted and directly seeded rice. The germination of weeds and the types of weeds that emerge are closely related to soil moisture content and depth of flooding. Flooding at depths of 15 cm from 4 days after transplanting to the late dough stage suppresses grass and sedge germination. Weeds with broadleaf cannot be controlled by flooding. Current trend leans towards increased use of chemical weed control in place of manual and mechanical methods. Several factors have contributed to the increased use of herbicide for weed control. Traditional varieties of rice, although low yielding, are naturally competitive with weeds due to their early vegetative growth, tall stature, and drooping leafs. Modern high-yielding varieties are relatively less competitive. Thus, compared with traditional varieties, modern varieties tend to be more heavily infested by weeds. Due to the higher yield potential of modern varieties, yield gains obtained through a given intensity of weed control are also higher.

Weed problems are, however, more serious in direct-seeded rice than in transplanted rice. As weeds and rice emerge simultaneously in direct-seeded fields, the competitive effect of weeds on rice is much greater. Success of the direct-seeding method depends critically on the weed control.

### 5.5.2 Insect pest control

Rice is grown under diverse conditions of climate and culture over a wide geographical range. Because of crop adaptability to warm, humid conditions, the survival and proliferation of insects are critical problem in the tropics and semi-tropics, diminishing somewhat in the temperate rice areas. More than 70 species of rice pests are known and some 20 have major significance. They attack virtually all parts of the rice plant at all growth
stages. Insects also serve as vectors of virus-based diseases that attack rice and contribute to low rice yields obtained in the humid tropics. Continuous cropping and favorable environment of the humid tropics allow overlapping insect populations throughout the year, with no distinct diapause or dormancy period.

Among the rice insect pests, the rice stemborers (Chilo suppressalis and Tryporyz incertulas) are generally considered the most detrimental in tropical rice production. Others include green leafhoppers (Nephotettix virescens) and brown planthoppers (Nilaparvata lugens). The rice water weevil (Lissorhoptrus oryzophilus) is a common problem in the temperate zone, in addition to the rice stinkbug (Oebalus pugnax) and planthopper (Sogatodes orizicolae), among others. Other destructive groups include grasshoppers, locusts, gall midges, rice hispa, armyworms, cutworms, whorl maggots, and thrips.

Current control of rice insect pests depends largely on the use of pesticides, even though many traditional and new cultivars have some degree of resistance to insect pests. Chemicals will no doubt continue to play important roles in rice crop protection. With tropical rice where pesticides are costly and sometimes not available, it is increasingly important to combine various compatible management practices that provide crop protection at a minimum cost. The easiest integration of pest control methods is to combine cultivar resistance, cultural practices, and the timely use of pesticides. The Integrated Pest Management (IPM) concept has received considerable attention in both temperate and tropical countries. An example of IPM success comes from Indonesia. Since the introduction of IPM through the United Nations’ Food and Agriculture Organization (FAO) program using Indonesian and IRRI’s technologies, the number of insecticides used was drastically reduced. Rice yields increased.

5.5.3 Disease control

More than one hundred types of diseases have been identified from rice field throughout the world. Common rice diseases are grouped according to the disease-causing organisms as fungal, bacterial, viral, and nematode diseases.

Among the rice diseases, fungal diseases form a major group. Forty fungal diseases have been recorded. These pathogens are distributed worldwide, covering every rice-growing country. As a group, they infect rice plant parts ranging from seed to leaves, leaf sheath, culm, nodes, panicles, and roots. Some have caused devastating epidemics, while others maintain endemicity year after year in certain localities. Among all fungal diseases, perhaps all rice diseases, blast has received the widest attention since ancient times. In addition, sheath blight, leaf scald, sheath rot, bakanae, brown leaf spot, and stem rot are also detrimental fungal diseases.

Twelve rice diseases are caused by bacterial pathogens, among which two are of importance. Bacterial leaf blight, a systemic disease, is widespread throughout Asia, and is caused by Xanthomonas oryzae. Bacterial leaf streak caused by Xanthomonas translucens is limited to the tropics.
Virus diseases of rice have become a major constraint in rice production in tropical Asia since the introduction of modern cultivars. Prior to 1960s, no rice virus diseases had been reported in tropical Asia except in the Philippines and Japan. During this time, only dwarf, stripe, and yellow dwarf were described and characterized. Since the beginning of modern rice production during 1960s, several virus epidemics of rice occurred in Asia. Among the rice virus diseases with a high epidemic potential, tungro ranked number one, followed closely by grassy stunt and ragged stunt. The three virus diseases found in the temperate Asian countries are dwarf, black streak dwarf, and stripe. Those found in the tropics and subtropics are transitory yellowing, tungro, waika, bunchy stunt, gall stunt, grassy stunt, ragged stunt, wilt stunt, yellow mottle, chlorotic streak, mosaic, necrosis mosaic, and hoja blanca.

Most rice diseases can be managed to minimize losses. The most important strategies for rice disease management are to rotate crops, use resistant varieties, avoid excessive nitrogen application, and use fungicides when necessary. An integrated approach that uses all these methods is the most effective. However, farmers still depend largely on the use of fungicide for rice disease control.

References


6 Achievements and Advanced Technology of Rice Production in Korea

Hae Chune Choi

6.1 General view of rice production

6.1.1 Cultural environment

Korea is situated in Far East Asia on a peninsula which is bound to the continent in the north and the remaining are surrounded by sea. Korean peninsula lies between 33° 06’ N and 43° 01’ N in latitude and 124° 11’ E and 131° 53’ E in longitude, and belongs to the northern temperate zone of the Eastern Hemisphere.

The area of the peninsula is about 222,196 square kilometers, of which 99,434 square kilometers belong to the Republic of Korea (as of 1999). The peninsula is geomorphologically characterized by abundant hills and mountains, that is, the northern and the eastern parts consist of high and long mountain ranges, and the southern and the western parts of hills and plains. Because of the mountainous topography, the arable land is approximately 1.90 million hectares in the Republic, only 19.1 percent of the total area, of which 60.7 percent is paddy fields.

The climate is relatively mild with clear distinctive four seasons. It is characterized by freezing and snowy winter, warm and humid summer, and mild and dry spring and autumn. Annual average temperature is around 12°C ranging from 12 to 15°C in the southern, 10 to 12°C in the central, and 5 to 10°C in the northern area. Mean monthly temperatures range from 0°C in the coldest month of January to above 25°C in the warmest month of August.

Because of temperature restrictions, rice cropping is allowed from April to October, with only one crop annually. During the rice
season, mean monthly temperature gradually increase from about 13°C in April to above 25°C in the warmest month of August, then declined gradually to below 13°C in October (Figure 6.1). Variations in temperature are observed in different regions.

The south and the coastal areas are generally higher in temperature than the north and the inland, respectively. Lower temperatures in the mountainous areas result in short growing duration and low temperature injuries.

Average annual precipitation is 1,274 mm with some variation by regions. However, it is heavily concentrated in summer with more than 60 percent of total precipitation occurring during the period of June through August. On the other hand, it is more or less dry during seedling and maturing seasons. The drought at the early rice-cropping season often causes delays in transplanting in the rain-fed areas. Dry weather during maturing and harvest, however, provides enough sunshine for good ripening and high production.

Average monthly solar radiation is generally sufficient for rice growing. Total yearly duration of sunshine ranges from 2,200 to 2,300 hours, longer in southern inland and along the eastern coastal areas. The rate of sunshine is generally higher, 50–60% during the period of early and late rice growth, while it decrease by 30–40% during the rainy summer from June to August. Day length ranges from 12 to 14 hours, with the longest in late June.

Most soils in Korean peninsula are made up of granites and granite gneiss of the late Archeozoic era. Also abundant are igneous and sedimentary rocks. In general, paddy soils are shallow in plow depth and very low in infiltration rates. It is also very compact and hard with high bulk density and low clay content.

The rice soils in Korea are grouped into the following six management groups: well-paddified, sandy, poorly drained, ungleid, saline, and acid sulfate soils.

Well-paddified soils covering about 33% of total paddy area are relatively high in fertility and productivity. Sandy soils covering about 32% paddy area usually are found in plains near rivers, and are characterized by a coarse texture and by lower clay and organic matter contents.

The newly converted rice fields belong to the ungleid soils (23%), which are characterized by relatively high clay and low organic matter content. The poorly drained soils show extremely low water permeability due to the high ground water table. Potassium deficiency and iron toxicity are frequently observed in these soils.

Saline soils (2.7%) generally are found in the coastal reclamation land, which contains high salt content, high pH, and low organic matter and phosphorus contents. Acid sulfate soils are very limited, found mostly in the southern coastal areas in Korea.

Major factors of biological constraints in rice production are disease and insect pests. Even though the assessment of actual damages due to disease and insect pests is very difficult, the annual yield losses of rice due to rice diseases have been estimated at around four percent of the total production during the last three decades.
Majority of rice diseases are caused by fungi including rice blast (*Pyricularia grisea*) and sheath blight (*Thanatephorus cucumeris*). Bacterial and several virus diseases also occur significantly in Korea.

The occurrence of rice diseases has continuously changed in years mainly due to the varietal shifting of rice and changes in cultural practices. Up to 1960’s when only japonica rice was grown, the major rice diseases were blast and stripe virus. However, minor rice diseases including sheath blight, bacterial blight, and dwarf virus have increased since 1971 along with the rapid spreading of Tongil-type rices, which are semi-dwarf high-yielding and resistant to japonica-compatible blast races and stripe virus diseases. Black-streaked dwarf virus transmitted by small brown planthopper was newly identified during 1970’s, and its damage increased steadily particularly in the southern area up to 1980’s.

Changes in cultural practices such as high nitrogen application and early transplanting also brought about the changes in disease occurrence. In general, rice blast is more prevalent in the northern, bacterial disease in the south western, and virus disease in the south-eastern areas.

Major rice insects in these days are brown planthopper, white-backed planthopper, small brown planthopper, rice leaf folder, rice stem maggots, rice water weevil, and rice leaf beetle. Damages by rice insects also continuously change due to the changes in variety and cultural practice. Brown planthopper, the most significant rice insect, do not overwinter in Korea but migrate during the rice crop season through the summer wind and typhoon from the southern part of China.

### 6.1.2 Rice production

The annual acreage of rice cultivation in Korea changed slightly from 1.12 to 1.26 million hectares during the past three decades up to 1991. However, it rapidly decreased to 1.06 million hectares by 1995, and has been maintained as of 2001 (Table 6.1 & Figure 6.2).

National production of milled rice in 1950 was estimated to be around 2.5 million tons. The annual production increased to 3.9 million tons by 1970, during which japonica rice were grown. During the 1970’s annual production increased remarkably from 4 million tons in 1971 to 5.6 million tons in 1979. The highest production reached above 6.0 million tons.

<table>
<thead>
<tr>
<th>Year</th>
<th>Rice cultivation area (1,000 ha)</th>
<th>Average milled rice yield per ha(t)</th>
<th>Amount of milled rice production (1,000 t)</th>
<th>Self-sufficiency ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1966 - ’70</td>
<td>1,208</td>
<td>3.10</td>
<td>3,750</td>
<td>93.3</td>
</tr>
<tr>
<td>1971 - ’75</td>
<td>1,197</td>
<td>3.55</td>
<td>4,256</td>
<td>90.3</td>
</tr>
<tr>
<td>1976 - ’80</td>
<td>1,228</td>
<td>4.25</td>
<td>5,227</td>
<td>97.7</td>
</tr>
<tr>
<td>1981 - ’85</td>
<td>1,222</td>
<td>4.40</td>
<td>5,390</td>
<td>91.7</td>
</tr>
<tr>
<td>1986 - ’90</td>
<td>1,252</td>
<td>4.58</td>
<td>5,731</td>
<td>102.2</td>
</tr>
<tr>
<td>1991 - ’95</td>
<td>1,132</td>
<td>4.60</td>
<td>5,044</td>
<td>95.2</td>
</tr>
<tr>
<td>1996 - 2000</td>
<td>1,060</td>
<td>5.00</td>
<td>5,286</td>
<td>99.8</td>
</tr>
</tbody>
</table>
both in 1977 and 1988. This remarkable increase in national rice production had been brought about through the development of both high-yielding Tongil-type and japonica rices and improved cultural technology. However, rice production in 1980 sharply decreased to 3.6 million tons mainly due to severe cold injury. Self-sufficiency of rice production in Korea has continuously been maintained during the last two decades (Table 6.1).

The national average milled rice yield per hectare increased from 2.5 tons in 1950 to 4.70 tons in 1989 and again to 5.18 tons in 1997. The gradual increase in yield per hectare has been brought on mainly through improved varieties and technologies in cultural practice (Figure 6.3).

6.1.3 General cultural methods

**Irrigation** Most Korean rice is grown under lowland irrigation system with water supplied from reservoirs, multi-purpose dams and rivers or by well-pumping. It is estimated that about 80 percent of rice acreage is irrigated through the irrigation facilities. Outside of irrigation facilities, rice is usually grown through rain-fed schemes, especially in valley bottoms and hilly terrace, in which little water control is possible by the growers.

**Seedling raising** Seedling is raised by seeding and shooting in indoor seed box and removing to the paddy seed-bed nursery under the polyethylene-film tunnel for machine transplanting. Seeding time is influenced, directly or indirectly, by air and water temperatures, transplanting or direct seeding time and method, harvest time of pre-rice crops, and the maturity of rice variety along with seeding date. Seeding is usually done from early to mid April for very early varieties in the cool temperature areas of alpine and mountains, from mid to late April with early and medium maturing varieties in the central plains, and from late April to early May with medium-late or late varieties in the southern plains and coastal areas. The length of seedling raising is generally from 8–10 days to 35 days according to transplanting time or cropping pattern.

**Transplanting** Transplanting is performed mainly by machine transplanter. The entire rice fields were transplanted through hand-labor until 1977. The machine transplanting areas have rapidly increased since 1978 and reached 94 percent of total rice cultivation area in 1993.
**Application of fertilizers**  Rice soils are generally deficient in nitrogen, phosphorous, and potassium. Thus, the addition of 150 kg/ha each of three fertilizers is recommended for seedling nursery. The standard application level of nitrogen fertilizer is 110 kg/ha for japonica rice and 150 kg/ha for Tongil-type rice in the paddy fields. Split application of nitrogen, with 50% as basal, and 20% and 30% as top-dressing at the initiation of tillering and panicle formation, respectively. The recommended amounts of phosphorous and potash are 45–70 kg/ha and 57–90 kg/ha, respectively. Phosphorous is usually applied as basal, and potash is split into 70% as basal and 30% at the initiation of panicle formation.

**Water management**  Water usually affects the physical characteristics of the rice plant, nutrient status of the soil, and the nature and extent of weed growth. Seasonal water requirement differs from different growth stages: seedling, vegetative growth, reproductive growth, and ripening stages. Mid-summer drainage of rice paddy is necessary to temporarily change the root zone into an oxidized state. It is done at the maximum tillering stage, prior to the early panicle formation stage. The final drainage is usually done during ripening stage around 30–35 days after heading.

**6.1.4 Rice-based cropping systems**

Rice-barley cropping pattern was common in the southern plains up to 1960’s due to the shortage of food supply, but it has declined by about 4% during the recent years, mainly due to increase in labor cost, low income from barley products, and self sufficiency of rice production.

Presently, rice-vegetable cropping system is increasing steadily in terms of acreage of farming. Major vegetables, which are grown pre- or post-rice crops, are watermelon, melon, onion, garlic, and strawberry, among others. Forage and green manure crops such as rye and Italian rye are also grown during rice off-season.

**6.1.5 Rice growing region**

The rice growing area can be divided into three major regions, the north, the central and the south based on the climatic weather conditions, and six sub-sections with respect to varietal distributions and eco-system as follows (Figure 6.4):

- The south-western and southern coastal (I), in which the medium-late maturing varieties are usually grown,
- The southern plains (II) consist of two sub-ecosystem divided into Honam plains in the west and Yeongnam plains in the east by Sobaegsan mountain ranges. The medium-late maturing varieties are adaptable in these areas.
- The central plains (III) including the mid-western and south-eastern coastal areas are favorable for intermediate maturing varieties.
- The northern plains and the mid-mountainous areas (IV), in which the early maturing varieties with cold tolerance are mostly required.
- The alpine or high elevation areas (V), in which the very early or short growth duration varieties are usually adaptable. Early rice varieties tolerant to the sterility-type cold damage are essential.
- Rice-vegetable cropping system area. This section is a newly emerging rice eco system mainly for double cropping, after cash crop in the southern coastal areas and
plains. In this area, rice transplanting usually occurs very late around the late June and early July after harvesting the vegetable crops. Therefore, the essential characteristics of rice varieties adaptable to this area are short-growth duration of less than 100 days and adaptability to late transplanting.

### 6.2 Varietal Improvement

The world rice supply and demand are maintained relatively stable, with about 12~14% stock, and the national rice production in Korea also continues to be self-sufficient since 1975, except in severely cold years (Kim & Park 2000). However, the self-sufficiency of cereal food supply is about 54% and that of cereal supply including live-stock feeds is only about 30%. Rice, the Korean staple food currently provides 23% of farmer’s income, 43% of agricultural income, about 41% of caloric intake per capita, and about 24% of protein intake per capita.

Continuous improvement of Tongil-type high-yielding rice cultivars had greatly contributed to self-sufficient rice production in the country through the so-called ‘green revolution’ during 1970’s–1980’s. In addition, the development of high-yielding and high-quality japonica rice cultivars during 1980’s–1990’s played a major role not only in ensuring self-sufficiency of rice production but also in enhancing the competitive power of rice products against free trade. Korea has the most advanced techniques in rice breeding and maintains the highest level of rice yield potential per acreage, producing the best rice quality around the world. However, the country still shows inferiority in international competitiveness of rice goods, since the size of rice farm is so small and the production cost is still very high. Presently, Korea is confronted with a strong pressure of opening the market of agricultural products, especially after the formalization of the World Trade Organization (WTO) (Kim & Kim 2000).

#### 6.2.1 Achievement in rice varietal improvement

The target of rice breeding in Korea is the development of high-quality and high-yielding rice cultivars suitable for labor-saving, low-cost, and safe grain production under different environmental conditions. Currently, the main direction of the country’s rice breeding program is on how to increase the yield potential, safe grain production, and how to improve the marketing quality and palatability of cooked rice. However, the breeding objectives have been changed to meet the socioeconomic needs and cultural