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Rice Ecosystems

Rice production systems differ widely in cropping intensity and yield, ranging from single-crop rainfed lowland and upland rice with small yields (1–3 t ha^{-1}), to triple-crop irrigated systems with an annual grain production of up to 15–18 t ha^{-1}. Irrigated and rainfed lowland rice systems account for about 80% of the worldwide harvested rice area and 92% of total rice production. To keep pace with population growth, rice yields in both the irrigated and rainfed lowland environments must increase by 25% over the next 20 years. Currently, upland and flood-prone rice account for less than 8% of the global rice supply, and it is unlikely that production from these systems can be significantly increased in the near future.

In this chapter

1.1 Irrigated Rice

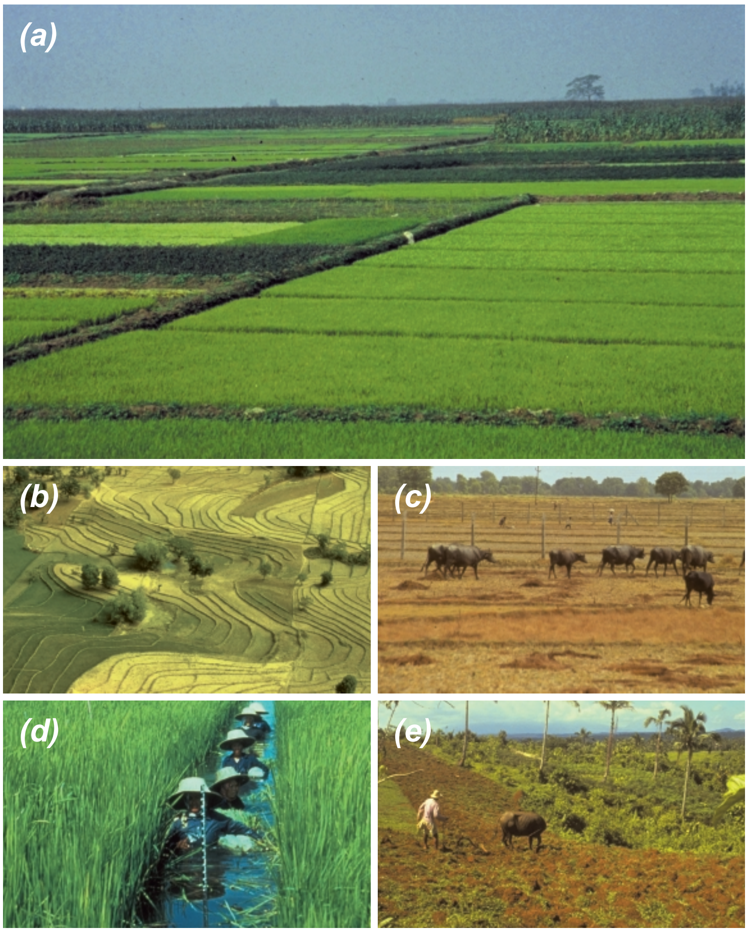
Intensive, irrigated rice-based cropping systems are found on alluvial floodplains, terraces, inland valleys, and deltas in Asia. Irrigated rice is grown in puddled soil in bunded rice fields with one or more crops planted each year. Irrigation is the main water source in the dry season and is used to supplement rainfall in the wet season. Irrigated rice accounts for 55% of the global harvested rice area and contributes 75% of global rice production (~410 M t of rice per year) .

Area

Worldwide, the total harvested area of irrigated rice is about 79 M ha, with 43% (34 M ha) in East Asia (China, Taiwan, Japan, Korea), 24 M ha in South Asia, and 15 M ha in Southeast Asia. The countries with the largest areas of irrigated rice are China (31 M ha), India (19 M ha), Indonesia (7 M ha), and Vietnam (3 M ha).

Cropping systems

Irrigated rice systems are intensive cropping systems with a total grain production of 10–15 t ha^{-1} $year^{-1}$. Cropping intensities range from one (in the temperate regions) to three (in the tropical regions) crops grown per year. Examples of intensive rice-based cropping systems are rice-rice, rice-rice-rice, rice-rice-pulses, rice-wheat, and rice-rice-maize rotations. In rice monocropping systems, 2–3



Rice is grown in a range of contrasting farming systems

(a), (b) Irrigated systems and irrigated terraces provide the largest yields. (c) Rainfed rice fields may be affected by drought. (d) Deep water fields are prone to flooding. (e) In upland rice fields, low soil fertility status is the major production constraint.

short-duration crops are grown per year; at some sites, up to seven crops are grown in 2 years. Fallow periods between two crops range from a few days to 3 months. The major irrigated rice-cropping systems are double- and triple-crop monoculture rice in the tropics, and rice-wheat rotations in the subtropics. Together, they cover a land area of 36 M ha in Asia and account for ~50% of global rice production. Most irrigated rice land is planted to modern semidwarf indica and japonica varieties, which have a large yield potential and respond well to N fertilizer. In China, hybrid rice varieties are used in >50% of the irrigated rice area, and yields are about 10–15% larger than for conventional rice varieties.

Recent changes in production technology include the following:

- the change from transplanting to direct seeding,
- increased use of herbicides for weed control, and
- the introduction of mechanized land preparation and harvesting techniques.

Yields and major constraints

The global average yield of irrigated rice is 5 t ha^{-1} per crop, but national, regional, and seasonal yield averages vary widely. Large yields (more than 5–6 t ha^{-1}) are obtained in the USA, Australia, China, Egypt, Japan, Indonesia, Vietnam, and the Republic of Korea. Medium yields (4–5 t ha^{-1}) occur in Bangladesh, northwestern and southern India, Lao PDR, Malaysia, Myanmar, the Philippines, Sri Lanka, and Thailand. Yields are smaller (<4 t ha^{-1}) in Cambodia, eastern India, Madagascar, Nepal, and Pakistan.

In the tropics, skilled rice farmers achieve yields of 7–8 t ha^{-1} per crop in the dry season, and 5–6 t ha^{-1} in the wet season when cloud cover reduces the amount of solar radiation and thus the potential yield. The main agronomic problems encountered where intensive rice cultivation is practiced are:

- yield instability due to pests,
- poor input management and unbalanced nutrient use,
- inefficient use of irrigation water, and
- environmental degradation due to misuse of inputs.

Fertilizer use and fertilizer use efficiency

In intensive rice systems, the indigenous N supply is never sufficient, and mineral N fertilizer inputs represent the largest part of the N cycle. In most Asian countries, irrigated rice farmers apply 100–150 kg N ha^{-1} to dry-season rice crops and 60–90 kg N ha^{-1} to wet-season crops. The cost of N fertilizer usually represents 10–20% of the total variable production costs. More than 20% of N fertilizer produced worldwide is used in the rice fields of Asia, but N recovery efficiency in most farmers' fields is only about 25–40% of applied N. The requirement for mineral fertilizer may be reduced when organic nutrient sources such as farmyard manure, legume green manure, and azolla are used. Green manuring and organic manure use, however, have decreased in recent years as mineral fertilizer has become a more convenient and cost-effective source of N.

Most irrigated rice farmers apply 15–20 kg P ha^{-1} per crop. P balances vary widely, however, and both soil P depletion (e.g., in Cambodia) and excessive P accumulation (e.g., in Java) have been reported.

In the short term, the indigenous K supply in most lowland rice soils is sufficient to sustain average yields of 4–6 t ha^{-1}. Farm surveys conducted in various countries, however, suggest an average use of only 15–20 kg K ha^{-1} per crop and negative K balances of 20–60 kg K ha^{-1} per crop. One factor contributing to negative K balances is the increasing trend to remove straw from rice fields, for use as fodder or fuel or to make land preparation easier. Depletion of soil K reserves appears to be a problem in many intensive rice farms in Asia and, if left uncorrected, will limit future yield increases and result in poor N use efficiency.

Problems with weeds, insects, and diseases

Weeds are mainly a problem in areas where direct-seeded rice is grown and hand weeding is not possible due to labor scarcity. This has led to the use of herbicides as a standard practice in regions such as California (USA), South Vietnam, Malaysia, Central Thailand, and Central Luzon (Philippines). In most cases, insecticide application is not necessary during the first 40 days after planting, and integrated pest management techniques using smaller amounts of insecticide have been widely adopted in recent years. The need for larger N fertilizer rates to maintain or increase yields, however, often results in greater pest and disease pressure. The large leaf area required to achieve high yields results in a dense canopy that provides a microclimate environment that favors the development and spread of many rice pests and diseases. K or Si deficiency increases susceptibility to pests, particularly when coupled with excessive N supply.

Sustainability and environmental problems

There have been reports of declining yields in some long-term, double- and triple-crop rice experiments in Asia, where the best management practices have been rigorously followed. There is also anecdotal evidence of diminishing returns to N fertilizer use in farmers' fields. In many countries, the rate of increase in rice yields has decreased in recent years, and this may be related to declining factor productivity from applied inputs. It remains unclear whether yield or productivity decline is widespread in Asia. Where they occur, they are caused mainly by soil nutrient depletion, changes in soil organic matter, or accumulation of toxic substances in soil, particularly in systems with short and wet fallow periods between two crops.

Global methane (CH_4) emissions from flooded rice fields are about 40–50 Tg year^{-1}, or ~10% of total global methane emissions. In irrigated rice areas, controlled water supply and intensive soil preparation contribute to improved rice growth but result in the production and emission of larger amounts of CH_4. Improved water management techniques can reduce the emission of CH_4 from rice fields, but feasible management practices that reduce CH_4 emissions *without* increasing N losses and reducing yield have yet to be developed.

As much as 60–70% of applied fertilizer N may be lost as gaseous N, mainly because of NH_3 volatilization and denitrification. Nitrous oxide emissions occur as a result of nitrification-denitrification during periods of alternate soil wetting and drying. In irrigated rice systems with proper water control, N_2O emissions are usually small except where excessive amounts of N fertilizer are applied to fertile rice soils. In poorly drained, 'puddled' lowland rice soils, little nitrification takes place and NO_3 leaching losses are therefore usually <10% of applied fertilizer N.

Future challenges

N is the main driving force to produce large yields. Because of the wide variation in soil N-supplying capacity between lowland rice fields with the same soil type, however, site-specific soil and fertilizer management practices are required to improve the fit between nutrient supply and crop demand. The main strategies for improving N use efficiency are as follows:

- Adjust fertilizer N rates according to soil N supply.
- Time the split applications precisely according to plant N demand.
- Use novel fertilizer products such as slow-release fertilizers.
- Maintain the proper ratio between N, P, and K through balanced fertilizer use.
- Consider disease-nutrient interactions.
- Use better water management techniques.