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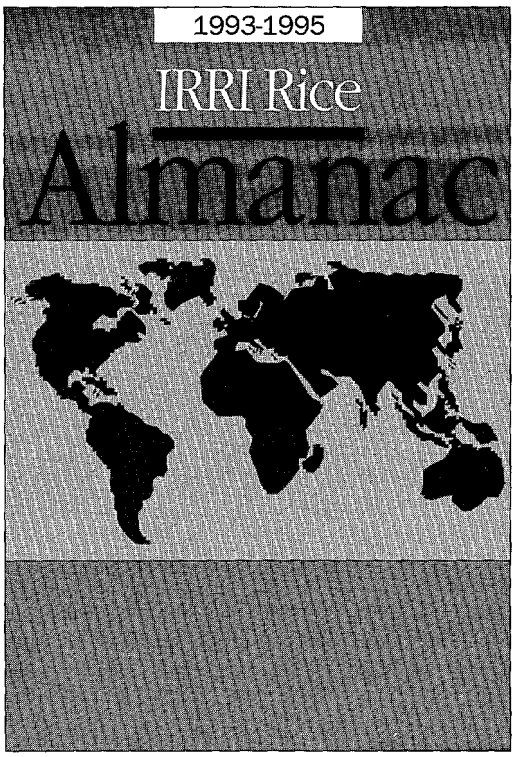

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Foreword

Almost everyone who deals with a crop that has the history, complexity, distribution and importance of rice looks for data, for facts. Up to now, that information could not be found easily. In many cases, after careful search the only solution was estimates based on the different figures that were available.

This situation precipitated the idea that IRRI should publish a rice almanac. The result is this book.

In developing the *IRRI Rice Almanac*, important data from Institute data bases, as well as sources such as FAO, were woven into a fabric that shows how rice fits into the political, social, and economic structure of rice-growing countries.

An almanac, almost by definition, is the product of many contributors, either as individuals or as members of a team. We have tried to list them individually in the Contributors list. Some, however, I wish to thank specifically:

The members of the IRRI Rice Statistics Task Force: Sadiq Bhuiyan, Sam Fujisaka, Kwanchai Gomez, Mahabub Hossain, Martin Kropff, Adelita Palacpac, Paul Teng, and Marco van den Berg. They provided guidance and review, shaped the central idea into a finished product, and searched for and verified the data collected.

The writer and editor, William H. Smith, consultant, assisted by Gloria Argosino and Teresita Rola.

The working group that prepared tables, charts and graphs: Grace Centeno, Susan Erquiza, Alice Laborte, Adelita Palacpac, and Joy Perez.

The graphic design group: Ram Cabrera, Anna Tamayo, Jess Recuenco, Leofrance Erasga, Erlie Putungan, and Ariel Paelmo.

The narratives and data related to different countries were reviewed by administrators of each national program concerned. Without their strong support, we would not have been able to present this compilation with confidence.

The publication was financed out of a grant from the Asian Development Bank for "Decentralized Participatory Research for Less Favorable Rice Ecosystems."

We strongly believe that the IRRI Rice Almanac will help to increase awareness among the large group of all those interested in the most important staple food in the world, RICE.

Klaus Lampe
Director General

October 1993

Preface

This first edition of IRRI Rice Almanac is a compendium on rice, bringing together information on its origin and diffusion, its growth and production, the ecosystems under which it is grown, and opportunities for increased yield and production.

Some idea of the relative importance of rice can be gained from the series of 26 essays on rice in different countries that is Chapter 5. In those essays, the reader should recognize that no reliable country data on production and yield by ecosystem exist. The numbers given are based on 1982 estimates and informed judgments by scientists, extrapolated to 1990.

As an overview of rice, the Almanac will perhaps be most useful to readers with some background in agriculture, but not necessarily with formal training or experience with rice. Other generalists who simply would like to know something about rice should also find adequate information here. The rice scientist is more likely to look upon the Almanac as a ready reference to common knowledge about rice.

Statistics used in the Almanac came from sources included in the IRRI RICESTAT data base (as of August 1993). IRRI itself is not a source of original statistics on rice, but gathers statistics from several international sources and national agencies. Inasmuch as there can be considerable differences in information about the same topic gathered by different agencies—primarily because of differences in procedures for obtaining data—the IRRI Rice Statistics Task Force has made judgments on what data sources to include in RICESTAT. That permits consistency on rice reporting at IRRI, but may not be altogether satisfactory for readers with a different perspective or criteria for choosing one set of data over another.

The selection of what material to include and at what level of detail is always puzzling for compilers. We are keenly aware that our judgments may have too strongly reflected our biases and only imperfectly met the needs of the reader. Still, such shortcomings are expected in a first effort.

We are confident that the Almanac fills a need for a reliable, up-to-date, ready reference on rice. We actively solicit the help of our readers in making subsequent editions of the Almanac more useful and complete. Please notify us of any major errors, inconsistencies, gaps in coverage of topics, or new topics that should be added in revised editions.

Suggestions or comments may be sent to: Mahabub Hossain, head, Social Sciences Division, or Martin Kropff, Agronomy, Physiology, and Agroecology Division, IRRI, P.O. Box 933, Manila 1099, Philippines.

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CHAPTER 1

Introduction

Origin and diffusion of rice

The origins of rice have long been debated. The plant is of such antiquity that the exact time and place of its first development will perhaps never be known. It is certain, however, that domestication of rice ranks as one of the most important developments in history. Rice has fed more people over a longer period than has any other crop.

The most convincing archeological evidence for domestication of rice in Southeast Asia was discovered by Wilhelm G. Solheim II in 1966. Pottery shards bearing the imprint of both grains and husks of *O. sativa* were discovered at Non Nok Tha in the Korat area of Thailand. Thermoluminescence and ^{14}C tests confirm that these remains date from at least 4000 B.C. This evidence not only pushed back the documented origin of cultivated rice but, when viewed in conjunction with plant remains from 10,000 B.C. (discovered in Spirit Cave on the Thailand-Myanmar border), suggests that agriculture itself may be older than was previously thought.

Early spread of rice

From an early beginning somewhere in the S to SE Asian arc, the process of diffusion has carried rice in all directions until today it is cultivated on every continent save Antarctica. In the early Neolithic era, rice was grown in forest clearings under a system of shifting cultivation. The crop was direct seeded, without standing water—conditions only slightly different from those to which wild rice was subject. A similar but independent pattern of the incorporation of wild rices into agricultural systems may well have taken place in one or more locations in Africa at approximately the same time.

Puddling the soil and transplanting seedlings were likely refined in China. Both operations became integral parts of rice farming and remain widely practiced to this day. Puddling breaks down the internal structure of soils, making them much less subject to water loss through percolation. In this respect, it can be thought of as a way of extending the utility of a limited water supply.

Transplanting is the planting of 1- to 6-wk-old seedlings in puddled soil with standing water. Under these conditions, the rice plants have an important head start over a wide range of competing weeds, which leads to higher yields. Transplanting, like puddling, provides the farmer with the ability to better accommodate the rice crop to a finite and fickle water supply by shortening the field duration (since seedlings are grown separately and at higher density) and adjusting the planting calendar.

With the development of puddling and transplanting, rice became truly domesticated. In China, the history of rice in river valleys and low-lying areas is longer than its history as a dryland crop. In Southeast Asia, however, rice originally was produced under dryland conditions in the uplands, and only recently came to occupy the vast river deltas.

Migrant people from South China or perhaps northern Vietnam carried the traditions of wetland rice cultivation to the Philippines during the second millennium B.C., and Deutero-Malays carried the practice to Indonesia about 1500 B.C. From China or Korea, the crop was introduced to Japan no later than 100 B.C.

Movement to western India and south to Sri Lanka was also accomplished very early. Rice was a major crop in Sri Lanka as early as 1000 B.C. The

crop may well have been introduced to Greece and the neighboring areas of the Mediterranean by returning members of Alexander the Great's expedition to India ca. 344-324 B.C. From a center in Greece and Sicily, rice spread gradually throughout the southern portions of Europe and to a few locations in North Africa.

Rice in the New World

As a result of Europe's great Age of Exploration, new lands to the west became available for exploitation. Rice cultivation was introduced to the New World by early European settlers. The Portuguese carried it to Brazil, and the Spanish introduced its cultivation to several locations in Central and South America. The first record for North America dates from 1685, when the crop was produced on the coastal lowlands and islands of what is now South Carolina. The crop may well have been carried to that area by slaves brought from the African continent. Early in the 18th century, rice spread to Louisiana, but not until the 20th century was it produced in California's Sacramento Valley. The introduction into California corresponded almost exactly with the timing of the first successful crop in Australia's New South Wales.

Genetic diversity of rice

Two rice species are important cereals for human nutrition: *Oryza sativa* grown worldwide, and *O. glaberrima* grown in parts of West Africa. These two cultigens belong to a genus that includes about 20 other species.

Wild *Oryza* species are distributed throughout the tropics. They can be grouped into four complexes of closely related species (Table 1). Two species, however, seem to be different from others in the genus: the tetraploid *O. schlechteri* and the diploid *O. brachyantha*.

Species of the *O. ridleyi* complex inhabit lowland swamp forests and species of the *O. meyeriana* complex are found in upland hillside forests.

The *O. officinalis* complex consists of diploid and tetraploid species found throughout the tropics. All the species in this complex are perennial; some are rhizomatous and others form runners. They also differ in the habitats where they are found. Some occur in full sun, others in partial shade. Variation exists within these species as shown by the responses of different populations to pests and diseases.

The *O. sativa* complex consists of the wild and weedy relatives of the two rice cultigens as well as the cultigens themselves. The wild relatives of *O. glaberrima* in Africa consist of the perennial rhizomatous species *O. longistaminata*, which

Table 1. Taxa in the genus *Oryza*: the complexes and genome groups to which they belong.

Complex	Taxon	Genome group	Distribution
	O. schlechteri	Tetraploid	New Guinea
	O. brachyantha	FF	Africa
O. ridleyi complex			
	O. longiglumis	Tetraploid	New Guinea
	O. ridleyi	Tetraploid	SE Asia
O. meyeriana complex			
	O. granulata	Diploid	S & SE Asia
	O. meyeriana	Diploid	SE Asia
O. officinalis complex			
	O. officinalis	CC	Tropical Asia to New Guinea
	O. eichingeri	CC	E. and W. Africa
	O. rhizomatis	CC	Sri Lanka
	O. minuta	BBCC	Philippines, Papua New Guinea
	O. punctata	BB, BBCC	Africa
	O. latifolia	CCDD	Latin America
	O. alta	CCDD	Latin America
	O. grandiglumis	CCDD	South America
	O. australiensis	EE	Australia
O. sativa complex			
	O. glaberrima (cultigen)	AA	West Africa
	O. barthii	AA	Africa
	O. longistaminata	AA	Africa
	O. sativa (cultigen)	AA	Worldwide
	O. nivara	AA	Tropical Asia
	O. rufipogon	AA	Tropical Asia
	O. meridionalis	AA	Tropical Australia
	O. glumaepatula	AA	South America

grows throughout sub-Saharan Africa. The annual and weedy relatives of *O. glaberrima* are found primarily in West Africa.

Among the wild relatives of *O. sativa*, the perennial *O. rufipogon* is widely distributed over South and Southeast Asia, southeast China, and Oceania; morphologically indistinguishable forms are found in South America, usually in deepwater swamps. A closely related annual wild form, *O. nivara*, is found in the Deccan Plateau and Indo-Gangetic Plain of India and in many parts of Southeast Asia. The habitats of *O. nivara* are ditches, water holes, and edges of ponds. Morphologically similar to (and sometimes indistinguishable from) *O. nivara* are the very widely distributed weedy forms of *O. sativa* (*O. fatua*), which represent numerous intergrading hybrids between *O. sativa* and its two wild relatives. Throughout South and Southeast Asia, these spontaneous rices are found in canals and ponds adjacent to ricefields and in the ricefields themselves.

The primary center of diversity for *O. glaberrima* is in the swampy basin of the upper Niger River. Two secondary centers are to the southwest near the Guinean coast.

O. glaberrima varieties can be divided into two ecotypes: deepwater and upland. In West Africa, *O. glaberrima* is a dominant crop grown in the flooded areas of the Niger and Sokoto River basins. It is broadcast on hoed fields. On shallowly flooded land, a rainfed wetland crop is either directly sown by broadcasting or dibbling, or transplanted. About 45% of the land planted to rice in Africa belongs to the upland (dryland) culture, largely under bush fallow or after the ground has been hoed. Some African farmers still use axes, hoes, and bush knives in land preparation. In hydromorphic soils, *O. glaberrima* behaves like a self-perpetuating weed. In wetland fields planted to *O. sativa*, *O. glaberrima* has become a weed.

Ecological diversification in *O. sativa*, which involved hybridization-differentiation-selection cycles, was enhanced when ancestral forms of the cultigen were carried by farmers and traders to higher latitudes, higher elevations, dryland sites, seasonably deepwater areas, and tidal swamps. Within broad geographic regions, two major ecogeographic races were differentiated as a result of isolation and selection: 1) indica, adapted to the tropics, and 2) japonica, adapted to the temperate regions and tropical uplands.

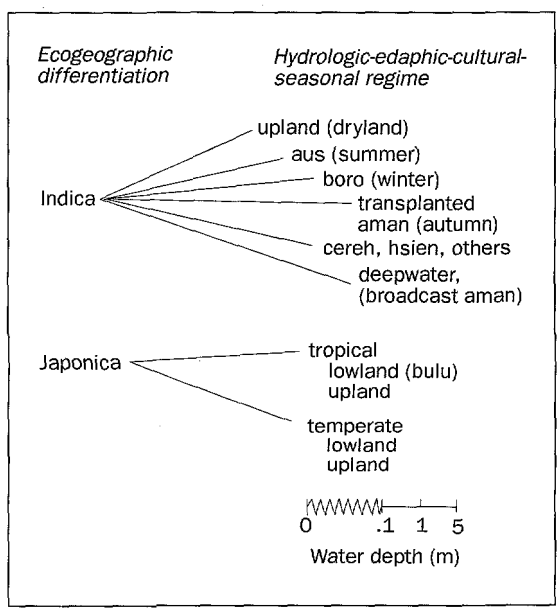
The combined forces of natural and human selection; diverse climates, seasons and soils; and varied cultural practices (dryland preparation and direct seeding vs puddling of the soil and transplanting) led to the tremendous ecological diversity now found in Asian cultivars. Selections made to suit cultural preferences and socioreligious traditions added diversity to morphological features, especially grain size, shape, and color, and endosperm properties.

The complex array of cultivars now known are categorized on the basis of hydrologic-edaphic-cultural-seasonal regimes as well as on genetic differentiation (Fig. 1).

Within the last 2,000 yr, 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 full spectrum of germplasm in the genus *Oryza* consists of the following:

- Wild *Oryza* species, which occur throughout the tropics, and related genera, which occur worldwide in both temperate and tropical regions.



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.

• Natural hybrids between the cultigen and wild relatives, and primitive cultivars of the cultigen in areas of rice diversity.

• Commercial types, obsolete varieties, minor varieties, and special-purpose types in the centers of cultivation.

• Pureline or inbred selections of farmers' varieties, elite varieties of hybrid origin, F_1 hybrids, breeding materials, mutants, polyploids, aneuploids, intergeneric and interspecific hybrids, composites, and cytoplasmic sources from breeding programs.

The diversity of Asian, African, and wild rices has given a wealth of genetic material for breeders to draw on for breeding improved cultivars.

Rice-growing areas

Rice is produced in a wide range of locations and under a variety of climatic conditions, from the wettest areas in the world to the driest deserts. It is produced along Myanmar's Arakan Coast, where the growing season records an average of more than 5,100 mm of rainfall, and at Al Hasa Oasis in Saudi Arabia, where annual rainfall is less than 100 mm. Temperatures, too, vary greatly. In the Upper Sind in Pakistan, the rice season averages 33 °C; in Otaru, Japan, the mean temperature for the growing season is 17 °C. The crop is produced at sea level on coastal plains and in delta regions throughout Asia, and to a height of 2,600

Table 2. Rice production, area, and yield for 25 leading producers, in order of decreasing rough rice production, 1991.

Country	Rough rice production ($t \times 10^3$)	Rice area ($ha \times 10^3$)	Arable land[a] ($ha \times 10^3$)	Arable land in rice (%)	% of world rice		Yield (t/ha)
					Area	Production	
China	187,450	33,100	93,283	35	22.3	36.1	5.7
India	110,945	42,200	165,400	26	28.4	21.3	2.6
Indonesia	44,321	10,187	16,000	64	6.9	8.5	4.4
Bangladesh	28,575	10,940	8,838	124[b]	7.4	5.5	2.6
Thailand	20,340	10,000	19,000	53	6.7	3.9	2.0
Vietnam	19,428	6,295	5,690	111[b]	4.2	3.7	3.1
Myanmar	13,201	4,830	9,567	50	3.3	2.5	2.7
Japan	12,005	2,049	4,121	50	1.4	2.3	5.9
Philippines	9,670	3,423	4,550	75	2.3	1.9	2.8
Brazil	9,503	4,143	50,400	8	2.8	1.8	2.3
Korea Rep.	7,478	1,209	1,953	62	0.8	1.4	6.2
USA	7,006	1,113	187,881	1	0.8	1.3	6.3
Korea DPR	5,100	680	1,700	40	0.5	1.0	7.5
Pakistan	4,903	2,060	20,300	10	1.4	0.9	2.4
Nepal	3,600	1,432	2,624	55	1.0	0.7	2.5
Nigeria	3,185	1,642	29,765	6	1.1	0.6	1.9
Egypt	3,152	433	2,330	19	0.3	0.6	7.3
Cambodia	2,400	1,800	2,910	62	1.2	0.5	1.3
Sri Lanka	2,397	860	925	93	0.6	0.5	2.8
CIS	2,200	605	225,100	0	0.4	0.4	0.3
Madagascar	2,200	1,100	2,580	43	0.7	0.4	2.0
Iran	2,100	585	14,100	4	0.4	0.4	3.6
Colombia	1,739	435	3,900	11	0.3	0.3	4.0
Malaysia	1,550	635	1,040	61	0.4	0.3	2.4
Laos[c]	1,400	640	890	72	0.4	0.3	2.2
World total	519,869	148,366	1,349,830	11	100.0	100.0	3.5

[a]Arable land here refers to land under temporary crops (double-cropped areas are counted only once), temporary meadows for mowing or pasture, land under market and kitchen gardens, and land temporarily fallow or lying idle. The figures are for 1990. [b]In countries such as Bangladesh and Vietnam, where multiple rice crops are taken from the same plot of land each year, the figure may exceed 100%. [c]The country source reports rice area of 570,000 ha and production of 1.22 million tons. Source of basic data: FAO AGROSTAT DATABASE, Information System of Food and Agriculture Organization, Rome.

regions throughout Asia, and to a height of 2,600 m on the slopes of Nepal's Himalaya. Rice is also grown under an extremely broad range of solar radiation, ranging from 25% of potential during the main rice season in portions of Myanmar, Thailand, and India's Assam State to approximately 95% of potential in southern Egypt and the Sudan. In terms of energy units, these extremes represent a range of 50-95 kilolangleys per crop.

Rice occupies an extraordinarily high portion of the total planted area in South, Southeast, and East Asia. This area is subject to an alternating wet and dry seasonal cycle, and also contains many of the world's major rivers, each with its own vast delta. Here, enormous areas of flat, low-lying agricultural land are flooded annually during and immediately following the rainy season. Only two major food crops, rice and taro, adapt readily to production under these conditions of saturated soil and high temperatures.

The highest rice yields have traditionally been obtained from plantings in high-latitude areas that have long daylength and where intensive farming techniques are practiced, or in low-latitude desert areas that have very high solar energy levels. Southwestern Australia, Hokkaido in Japan, Spain, Italy, northern California, and the Nile Delta provide the best examples.

In portions of the rice world, the crop is produced on miniscule plots using enormous amounts of human labor. At other locations, it is raised on huge holdings with a maximum of technology and large expenditures of energy from fossil fuels. The contrasts in the geographic, economic, and social conditions under which rice is produced are truly remarkable.

Rice production

Rice is most closely associated with the South, Southeast, and East Asian nations extending from Pakistan to Japan. Of 25 major rice-producing nations, 17 are located within this region (Table 2). The 8 countries outside the region jointly produce less than 6% of the world's rice.

In the world as a whole, rice occupies one-tenth of the arable land, but in the majority of the Asian rice arc countries, it occupies one-third or more of the total planted area. From Pakistan to Japan, rice is pre-eminent. Here, too, populations are high, and a close balance is maintained between rice production and food needs.

In the years since World War II, world rice area, yield, and production have changed considerably (Table 3). From 1948 to 1990, the area planted to rice increased by almost 71%, the mean yield obtained from that area went up by 110%, and total production more than tripled. During those four decades, rice became ever more important as a human food, as is suggested by the increasing portion of total arable land occupied by the crop.

World rice requirements are predicted to increase at the compound rate of 1.7%/yr between 1990 and 2025. This is a rate well above the projected population growth for the same period and reflects some substitution of other foods for rice, as well as an increase in the general well-being of the world population and increased per capita food consumption. For the leading rice-growing countries of Asia, the rate of increased production needed is even greater—2.1%/yr. This means that by the year 2025, the world will need an additional 13 million t of rough rice each year.

With accelerating loss of productive riceland to rising sea levels, salinization, erosion, and hu-

Table 3. World rice area, yield, and production, various years.

Year	Arable land + permanent crops[a] (ha × 10^3)	Rough rice			
		Area (ha × 10^3)	% of all arable land	Yield (t/ha)	Production (t × 10^3)
1948	1,232,000	86,700	7.0	1.68	145,400
1953	1,332,000	109,025	8.2	1.82	197,906
1958	1,390,000	117,017	8.4	1.92	224,093
1963	1,340,618	120,218	9.0	2.06	247,119
1968	1,363,220	129,450	9.5	2.23	289,055
1973	1,385,408	136,863	9.9	2.46	336,405
1978	1,409,351	144,016	10.2	2.69	387,732
1983	1,422,724	143,195	10.1	3.15	451,600
1988	1,440,313	146,185	10.1	3.36	491,045
1990	1,444,111	147,927	10.2	3.53	521,703
1991	n.a.	148,366	10.3	3.50	519,869

[a]This column reports land in both temporary and permanent crops. The world total in 1990 should not be confused with smaller "arable land" figure used in Table 2. Source of basic data: FAO production year book (various years), FAO, 1987; World crop and livestock statistics, 1948-85, Rome; FAO AGROSTAT DATABASE, Information System of Food and Agriculture Organization, Rome.

man settlements, the problem becomes one of increasing yields under ever-more trying circumstances. During the 20-yr period from 1965-67 through 1989-91, the improvements in productivity spawned by the Green Revolution spread rapidly. During those years, total rice production almost doubled. Seventy percent of this increase came from increased yields and increased cropping intensity, but 30% resulted from new land brought under cultivation or shifted into rice from other crops. Much of the yield increase could be traced to the introduction of the dwarfing gene and to the increased use of fertilizer, irrigation water, and other inputs. Further yield increases have been constrained by diminishing returns and have been increasingly difficult to achieve.

If predictions concerning population growth, climate change, and accelerating erosion of the agricultural base hold true, the turn of the century will be characterized by decreasing areas available for rice farming. Under such conditions, yield increases of 3% will be needed each year on the remaining arable land. Such a rate of increase has never been maintained beyond a year or two for any major food crop.

CHAPTER 2

Importance of rice

Rice as human food

Rice, wheat, and maize are the three leading food crops in the world; together they directly supply more than 50% of all calories consumed by the entire human population. Wheat is the leader in area harvested each year with 232 million ha, followed by rice with 148 million ha and maize with 129 million ha (Table 1). Human consumption accounts for 85% of total production for rice, compared with 60% for wheat and 25% for maize.

Rice provides 20% of global human per capita energy and 15% of per capita protein. Although rice protein ranks high in nutritional quality among cereals, protein content is modest. Unmilled (brown) rice of 17,587 cultivars in the IRRI germplasm collection averages 9.5% protein content, ranging from 4.3 to 18.2%.

Environmental factors (soil fertility, wet or dry season, solar radiation, and temperature during grain development) and crop management (added N fertilizer, plant spacing) affect rice protein content. Breeding efforts to increase protein have been largely unsuccessful because of the considerable effects of environment and because of complex inheritance properties in the triploid endosperm tissue.

Rice also provides minerals, vitamins, and fiber, although all constituents except carbohydrates are reduced by milling. Milling removes roughly 80% of the thiamine from brown rice. A precook rinse or a boiling of milled rice results in additional loss of vitamins, especially B_1.

For the majority of Asians who eat rice, however, the grain accounts for a remarkably high proportion of total caloric intake (Table 2). For 1986-88, caloric intake was 2,434 calories/person per day in less developed countries compared with 3,399 calories/person per day in industrialized countries. For selected Asian countries (China and Japan not included), the 1980 per capita caloric intake relative to FAO/WHO recommended levels ranged from 85% in Bangladesh and 86% in India to 119% in Malaysia and 127% in the Republic of Korea. By 1990, caloric intake in Asia was 2,531 calories/person per day, with 35% coming from rice (based on a per capita consumption of 85 kg/yr). By comparison, rice accounted for 10% of caloric intake and grain consumption of 26 kg/person per yr in Latin America; 7% of caloric intake and 14 kg/person per yr in Africa; 8% of caloric intake and 5 kg/person per yr in Australia; and 2% of caloric intake and 6 kg/person per yr in the US. Rice, however, may account for as much as 30% of daily caloric intake among recent immigrants to the US from Southeast Asia.

Where rice is the main item of the diet, it is frequently the basic ingredient of every meal and is normally prepared by boiling or steaming. In Asia, bean curd, fish, vegetables, meat, and spices are added depending on local availability and economic situation. A small proportion of rice is consumed in the form of noodles, which serve as a bed for various, often highly spiced specialties or as the bulk ingredient in soups.

Most rice is consumed in its polished state. When such rice constitutes a high proportion of food, dietary deficiencies may result. Despite the dramatic food value losses resulting from milling, brown rice is unpopular because 1) it requires more fuel for cooking, 2) it may cause digestive disturbances, and 3) oil in the bran layer tends to turn rancid during storage even at moderate temperatures.

In contrast, parboiling rough rice before milling, as is common in India and Bangladesh, allows a portion of the vitamins and minerals in the bran to permeate the endosperm and be retained in the

Table 1. World food picture, 1990. (From IRRI Thursday seminar, 11 Mar 1993, by R.E. Huke.)

Human population (no. × 10^6)[a]			5,321			
Land use (ha × 10^6)[b]						
Total land area			13,392			
Crop area			1,444 (.28/cap)			
Human works			400			
Meadow and pasture			3,403			
Forest land			4,028			
Other land			4,206			
Food production 1990 [b]					Per capita/day	
Crop (1990)	Area (ha × 10^6)	Production (t × 10^6)	Food (t × 10^6)	Notes	Calories	Protein (g)
Rice (rough)	148	522	339	65% milling rate	628	12
Maize	129	479	120	75% for feed	222	5
Wheat	232	602	358	70% milling rate 15% for feed	645	18
Millet and sorghum	76	87	47	30% milling rate	82	2
Barley and rye	89	222	78	70% milling rate	137	4
Oats	22	43	4	65% milling rate	8	1
Potato	18	268	141	50% for feed	51	1
Sweet potato and yams	11	146	66	50% for feed	33	1
					1111	35
For all food (measured at farm gate)				Subtotal	2, 918	79
Calories						
Per capita daily needs[c]				Losses before consumption		
Male, 50 kg; female, 40 kg; Temp. 25 °C			1,860	Loss to rats and weevils, etc.		
Male, 65 kg; female, 55 kg; Temp. 10 °C			2,269	largely in storage-16%	-466	-13
Male, 70 kg; female, 55 kg; Temp. 5 °C			2,390	Loss to dogs, cats, etc.-4%	-100	-3
				Table waste, spoilage-5%	-120	-3
		Weighted mean	2,150	Actual availability/capita per day	2,232[d]	60[e]

[a]1990 World Population Data Sheet. Population Reference Bureau, Washington, D.C. [b]Sources: FAO *Agrostat Database*. Rome 1992, FAO *1989 yearbook of fishery statistics*. Rome 1991. [c]FAO *calorie requirements*. [d]FAO claims 2671 cal. for 1986-88. [e]FAO claims 70 g for 1986-88.

polished rice. This treatment also lowers protein loss during milling and increases whole grain recovery.

Even though rice diets are often marginally deficient in protein, vitamins, and minerals, clinical manifestations of deficiency are not common among persons whose diets are otherwise adequate in calories. The exception is when persons do heavy labor and their higher calorie demand is met by an increase in rice without a corresponding increase in other foods such as legumes or fish. Under these conditions, there is danger of beriberi, which is related to a deficiency of thiamine or vitamin B_1.

Rice and population

Agricultural population densities on Asia's rice-producing lands are among the highest in the world and continue to increase at a remarkable rate. Rapid population growth puts increasing pressure on the already strained food-producing resources.

The aggregate population of the less developed countries grew from 2.3 billion in 1965 to 4.1 billion in 1991. Asia accounted for 59% of the global population, about 92% of the world's rice production, and 90% of global rice consumption. Even with rice providing 35-80% of total calories

Table 2. Rice consumption, caloric intake, and percent of calories from rice, 1990.

Country	Milled rice consumption[a] (kg/cap per yr)	Total[b] calories/ capita per year	Rice calories/ capita per year	% calories from rice
Myanmar	190	2448	1893	77
Bangladesh	155	2100	1580	75
Indonesia	138	2631	1519	58
Thailand	128	2271	1258	55
Madagascar	104	2162	1091	50
Philippines	99	2452	995	41
China	94	2706	959	35
India	66	2243	673	30
Japan	62	2926	699	24
Brazil	43	2723	448	16
Egypt	28	3318	300	9
Pakistan	19	2377	189	8
Nigeria	12	2147	130	6
South Africa	8	3158	86	3
Mexico	6	2986	64	2
USA	6	3680	69	2
Turkey	6	3262	57	2
CIS	6	3391	56	2
World	55	2712	574	21

[a]Amount available for human consumption. [b]Data include all food available for human consumption. Source: FAO. AGROSTAT database. Information System of Food and Agriculture Organization, Rome.

consumed in Asia and with a slowing of growth in total rice area, rice production has so far kept up with demand. Bangladesh, China, India, Indonesia,, Thailand, and Vietnam are the world's largest rice producers, accounting for about 79% of world production in 1991.

The world's annual rough rice production, however, will have to increase by almost 70% over the next 35 yr to keep up with population growth and income-induced demand for food. While the global population expanded by only 40 million in 1950, nearly 100 million persons will be added per year at the start of the 21st century (Table 3), most in the less develped countries where population growth is much faster than that in industrialized countries. The industrialized countries will add 10-30% to their populations before levels are stabilized, while the less developed countries will experience 200-500% population increases.

The urban poor in Asia spend a large part of their income on rice. The consumption of rice will

Table 3. World population, 1950-90, with projection to the year 2025.

Year	Population	Annual growth rate (%)	Annual increase (x 10^6)
1950	2516	1.6	40
1960	3020	1.8	54
1970	3698	2.0	74
1980	4448	1.9	85
1985	4844	1.7	82
1990	5285	1.8	95
2000	6204	1.6	99
2010	7112	1.4	91
2025	8415	1.1	86

Sources: 1950, 1960, 1970, 1980. UN 1990 Revision of the World Population Prospects. 1985, 1990, 2000. Bulatao, et al. World Population Projections, 1989-90 edition.

continue to increase as incomes increase with growing urbanization.

Only 3-4% of global rice production was traded from 1980 to 1991. Most countries rely almost entirely on domestic production to feed their populations. With unreliable supplies, the world rice trade is volatile. Prices fluctuate more for rice than for any other food grain so rice is regarded as a political commodity in many countries in Asia.

Specialty uses of rice

Glutinous rice plays an important role in some cultures. In Laos and northeast Thailand, for example, glutinous rice is the staple food. In other cultures it is prepared in a sweetened form for snacks, desserts, or special foods for religious or ceremonial occasions. In a few areas, glutinous rice is pounded and roasted to be eaten as a breakfast cereal.

Alcoholic beverages made from rice are found throughout the rice-producing world. The most common is a rice beer produced by boiling husked rice; inoculating the mix with a bit of yeast cake, and allowing the mixture to ferment for a short period.

The mash left at the bottom of the container is often prized. Among the Ifugao of the Philippines, the mash is frequently reserved for the village priest. Among the Kachins of Myanmar, it is the first food offered to a recently captured and hungry wild elephant. Kachins believe that the elephant will be loyal forever to the person who first provides such a meal.

Sake is widely consumed in Japan, as is wang-tsiu in China. These winelike beverages are served warm and featured at ceremonial feasts.

In some portions of the world, especially North America and Europe, rice is developing a new market niche as a staple and as a gourmet food. This trend appears to be related to the arrival of large numbers of immigrants from Southeast Asia, who introduced aromatic rices to markets where they were previously unknown. These have been adopted by a food-quality-conscious public over the past several years.

CHAPTER 3

Rice growth and production

Morphology and growth of the rice plant

Morphology

Cultivated rice is generally considered a semiaquatic annual grass, although in the tropics it can survive as a perennial, producing new tillers from nodes after harvest (ratooning). At maturity the rice plant has a main stem and a number of tillers. Each productive tiller bears a terminal flowering head or panicle. Plant height varies by variety and environmental conditions, ranging from approximately 0.4 m to over 5 m in some floating rices. The morphology of rice is divided into the vegetative phases (including germination, seedling, and tillering stages) and the reproductive phases (including panicle initiation and heading stages).

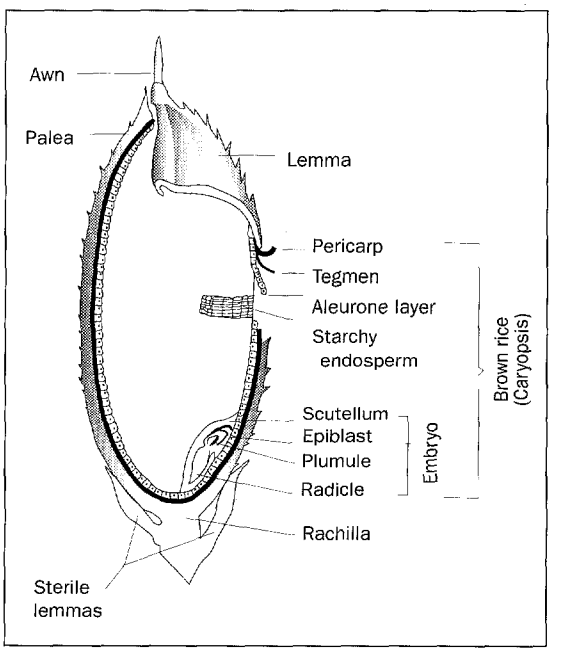
Seeds. The rice grain, commonly called a seed, consists of the true fruit or brown rice (caryopsis) and the hull, which encloses the brown rice. Brown rice consists mainly of the embryo and endosperm. The surface contains several thin layers of differentiated tissues that enclose the embryo and endosperm (Fig. 1).

The palea, lemmas, and rachilla constitute the hull of indica rices. In japonica rices, however, the hull usually includes rudimentary glumes and perhaps a portion of the pedicel.

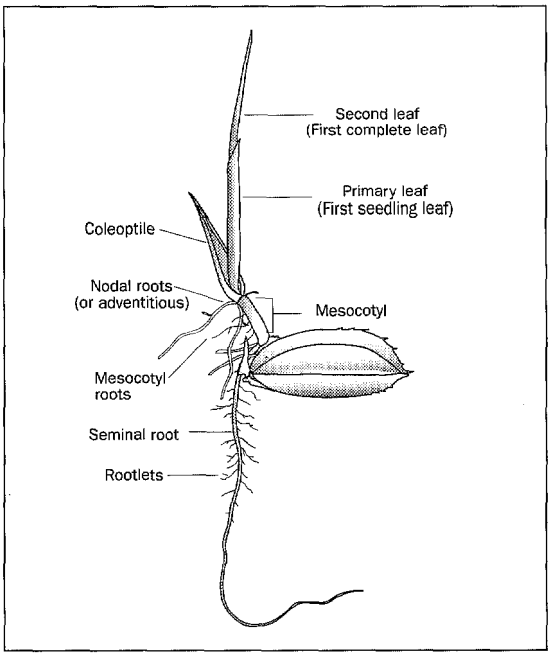
A single grain weighs about 10-45 mg at 0% moisture content. Grain length, width, and thickness vary widely among varieties. Hull weight averages about 20% of total grain weight.

Seedlings. Germination and seedling development start when seed dormancy has been broken and the seed absorbs adequate water and is exposed to a temperature ranging from about 10 to 40 °C. The physiological definition of germination is usually the time when the radicle or coleoptile (embryonic shoot) emerge from the ruptured seed coat. Under aerated conditions the seminal root is the first to emerge through the coleorhiza from the embryo, and this is followed by the coleoptile. Under anaerobic conditions, however, the coleoptile is the first to emerge, with the roots developing when the coleoptile has reached the aerated regions of the environment.

If the seed develops in the dark as when seeds are sown beneath the soil surface, a short stem (mesocotyl) develops, which lifts the crown of the plant to just below the soil surface (Fig. 2). After



1. Cross-section of the rice grain.



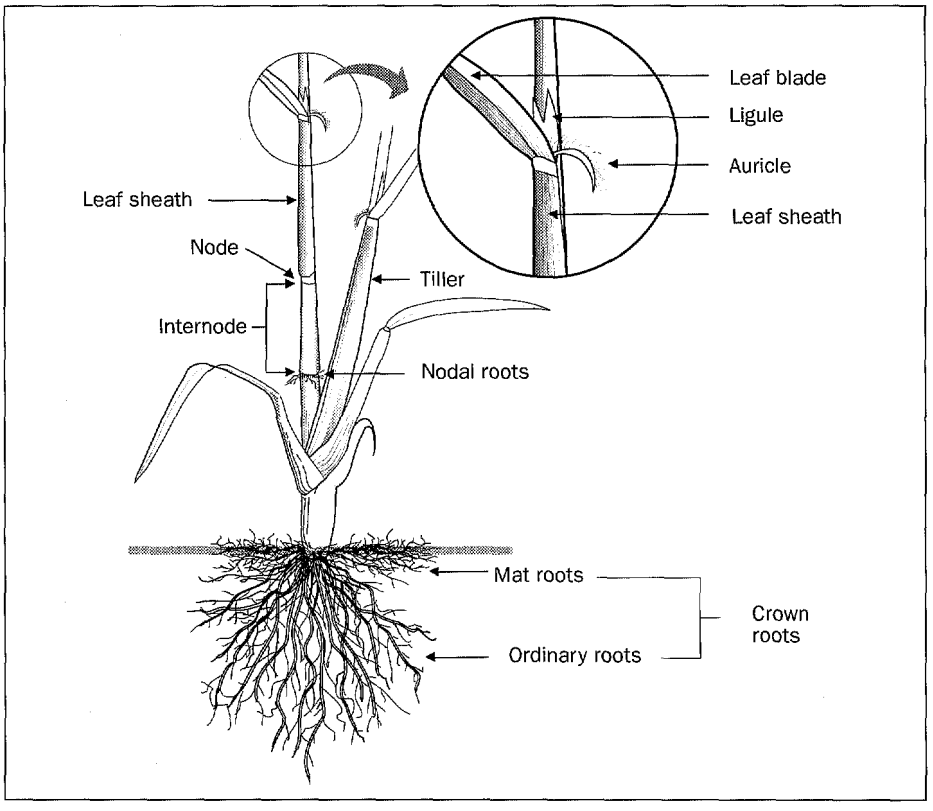
2. Parts of a young seedling germinated in the dark.

the coleoptile emerges it splits and the primary leaf develops.

Tillering plants. Each stem of rice is made up of a series of nodes and internodes (Fig. 3). The internodes vary in length depending on variety and environmental conditions, but generally increase from the lower to upper part of the stem. Each upper node bears a leaf and a bud, which can grow into a tiller. The number of nodes varies from 13 to 16 with only the upper 4 or 5 separated by long internodes. Under rapid increases in water level some deepwater rice varieties can also increase the lower internode lengths by over 30 cm each.

The leaf blade is attached at the node by the leaf sheath, which encircles the stem. Where the leaf blade and the leaf sheath meet is a pair of clawlike appendages, called the auricle, which encircle the stem. Coarse hairs cover the surface of the auricle. Immediately above the auricle is a thin, upright membrane called the ligule.

The tillering stage starts as soon as the seedling is self supporting and generally finishes at



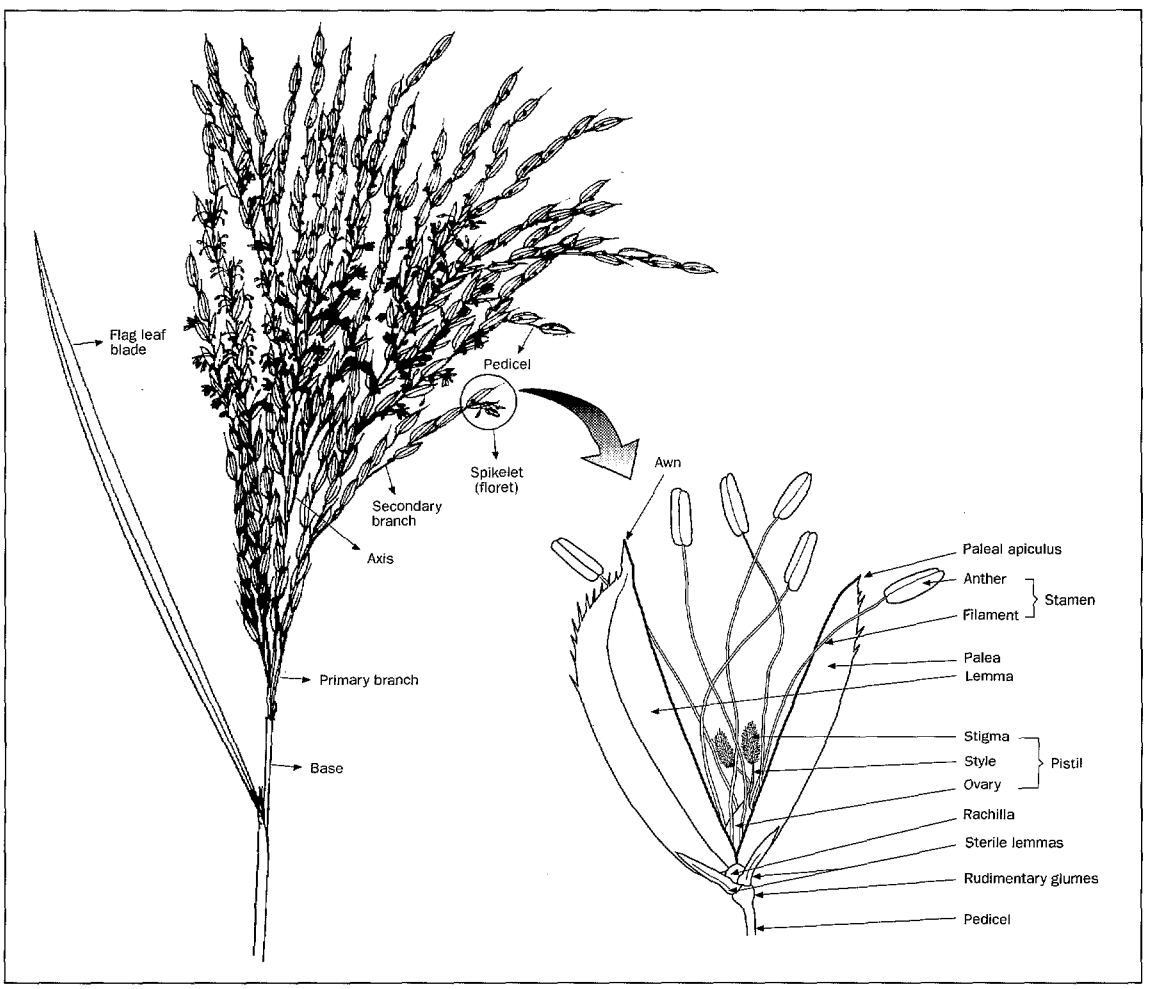
3. Parts of the rice stem and tillers.

panicle initiation. Tillering usually begins with the emergence of the first tiller when seedlings have five leaves. This first tiller develops between the main stem and the second leaf from the base of the plant. Subsequently when the 6th leaf emerges the second tiller develops between the main stem and the 3d leaf from the base.

Tillers growing from the main stem are called primary tillers. These may generate secondary tillers, which may in turn generate tertiary tillers. These are produced in a synchronous manner. Although the tillers remain attached to the plant, at later stages they are independent because they produce their own roots. Varieties and races of rice differ in tillering ability. Numerous environmental factors also affect tillering including spacing, light, nutrient supply, and cultural practices.

The rice root system consists of two major types: crown roots (including mat roots) and nodal roots (Fig. 3). In fact both these roots develop from nodes, but crown roots develop from nodes below the soil surface. Roots that develop from nodes above the soil surface usually are referred to as nodal roots. Nodal roots are often found in rice cultivars growing at water depths above 80 cm. Most rice varieties reach a maximum depth of 1 m or deeper in soft upland soils. In flooded soils, however, rice roots seldom exceed a depth of 40 cm. That is largely a consequence of limited O_2 diffusion through the gas spaces of roots (aerenchyma) to supply the growing root tips.

Panicle and spikelets. The major structures of the panicle are the base, axis, primary and secondary branches, pedicel, rudimentary glumes, and



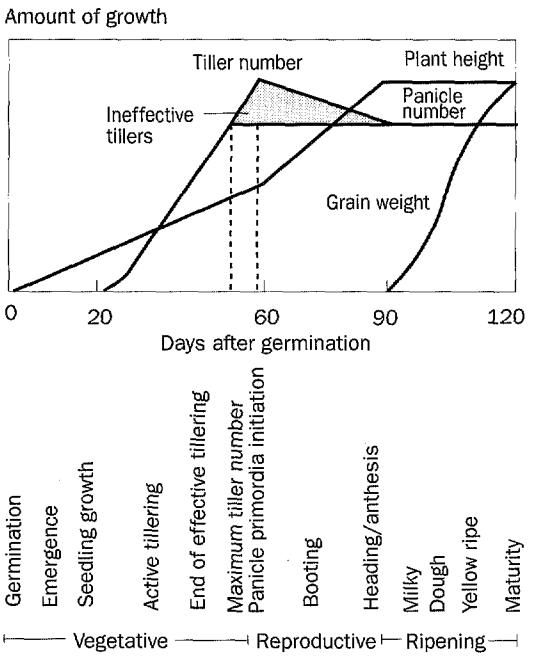
4. Rice panicles and spikelet.

the spikelets. The panicle axis extends from the panicle base to the apex; it has 8-10 nodes at 2- to 4-cm intervals from which primary branches develop. Secondary branches develop from the primary branches. Pedicels develop from the nodes of the primary and secondary branches; the spikelets are positioned above them (Fig. 4)

Since rice has only one fully developed floret (flower) per spikelet, these terms are often used interchangeably. The flower is enclosed in the lemma and palea, which may be either awned or awnless. The flower consists of the pistil and stamens, and the components of the pistil are the stigmas, styles, and ovary.

Growth

The growth duration of the rice plant is 3-6 months, depending on the variety and the environment under which it is grown. During this time, rice completes two distinct growth phases: vegetative and reproductive. The vegetative phase is subdivided into germination, early seedling growth, and tillering; the reproductive phase is subdivided into the time before and after heading, i.e., panicle exsertion. The time after heading is better known as the ripening period (Fig. 5).



5. Schematic of growth of a 120-day rice variety in the tropics.

Potential grain yield is primarily determined before heading. Ultimate yield, which is based on the amount of starch that fills the spikelets, is largely determined after heading. Hence, agronomically it is convenient to regard the life history of rice in terms of three growth phases: vegetative, reproductive, and ripening. A 120-day variety, when planted in a tropical environment, spends about 60 d in the vegetative phase, 30 d in the reproductive phase, and 30 d in the ripening phase.

Vegetative phase. The vegetative phase is characterized by active tillering, gradual increase in plant height, and leaf emergence at regular intervals. Tillers that do not bear panicles are called ineffective tillers. The number of ineffective tillers is a closely examined trait in plant breeding since it is undesirable in irrigated varieties, but sometimes an advantage in rainfed lowland varieties where productive tillers or panicles may be lost due to unfavorable conditions.

Reproductive phase. The reproductive growth phase is characterized by culm elongation (which increases plant height), decline in tiller number, emergence of the flag leaf (the last leaf), booting, heading, and flowering of the spikelets. Panicle initiation is the stage about 25 d before heading when the panicle has grown to about 1 mm long and can be recognized visually or under magnification following stem dissection.

Spikelet anthesis (or flowering) begins with panicle exsertion (heading), or on the following day. Consequently, heading is considered a synonym for anthesis in rice. It takes 10-14 d for a rice crop to complete heading because there is variation in panicle exsertion among tillers of the same plant and among plants in the same field. Agronomically, heading is usually defined as the time when 50% of the panicles have exserted.

Anthesis normally occurs between 1000 and 1300 h in tropical environments and fertilization is completed within 6 h. Only very few spikelets have anthesis in the afternoon, usually when the temperature is low. Within the same panicle it takes 7-10 d for all the spikelets to complete anthesis; the spikelets themselves complete anthesis within 5 d.

Ripening follows fertilization, and may be subdivided into milky, dough, yellow-ripe, and maturity stages. These terms are primarily based on the texture and color of the growing grains. The length of ripening varies among varieties from

about 15 to 40 d. Ripening is also affected by temperature with ranges from about 30 d in the tropics to 65 d in cool, temperate regions such as Hokkaido, Japan, and Yank, NSW, Australia.

Wetlands and rice soils

Wetlands

Wetlands are defined as having free water at or near the surface for at least the major part of the growing season of arable crops, or for at least 2 mo of the growing season of perennial crops, grasslands, forests, or other vegetation. The floodwater is sufficiently shallow to allow the growth of a crop or of natural vegetation rooted in the soil. Free surface water may occur naturally, or rainfall, runoff, or irrigation water may be retained by field bunds, puddled plow layers, or traffic pans.

Wetlands as defined here have at least one wet growing season, but may be dry, moist, or without surface water in other seasons. Wetland soils may therefore alternately support wetland and upland crops when cultivated.

The transition from wetlands to uplands is often gradual. It may fluctuate from year to year, depending on variations in precipitation, runoff, or irrigation. If water (both drainage and irrigation) can be fully controlled, the farmer can choose to establish wetlands or uplands. But in most wetlands drainage capacities are insufficient to prevent soil submergence during the rainy season, particularly in the lowlands of the humid tropics.

Rice soils

Rice soils are wetland soils that are grown to rice. The presence of "aquic" soil conditions is indicated by redoximorphic features, such as zones of accumulation and depletion of Fe and Mn. Plowing and puddling often result in the development of a dense layer below the cultivated topsoil.

There are three types of water saturation in rice soils: 1) endosaturation, in which the entire soil is saturated with water, 2) episaturation, in which upper soil layers are saturated but underlain by unsaturated subsoil layers, and 3) anthric saturation, a variant of episaturation with controlled flooding and puddled surface soil.

A typical soil profile of a flooded rice soil during the middle of a growing season has the following properties.

Horizon	Description
Ofw	A layer of standing water that becomes the habitat of bacteria, phytoplankton, macrophytes (submerged and floating weeds), zooplankton, and aquatic invertebrates and vertebrates. The chemical status of the floodwater depends on the water source, soil, nature and biomass of aquatic fauna and flora, cultural practices, and rice growth. The pH of the standing water is determined by the alkalinity of the water source, soil pH, algal activity, and fertilization. Because of the growth of algae and aquatic weeds, the pH and O_2 content undergo marked diurnal fluctuations. During daytime, the pH may increase to 11 and the standing water becomes oversaturated with O_2 because of photosynthesis of the aquatic biomass. Standing water stabilizes the soil water regime, moderates the soil temperature regime, prevents soil erosion, and enhances C and N supply.
Apox	The floodwater-soil interface that receives sufficient O_2 from the floodwater to maintain a pE + pH value above the range below which NH_4^+ is the most stable form of N. The thickness of the layer may range from several mm to several cm, depending on pedoturbation by soil fauna and the percolation rate of water.
Apg	The reduced puddled layer is characterized by the absence of free O_2 in the soil solution and a pE + pH value below the range at which Fe(III) is reduced.
Apx	A layer that has increased bulk density, high mechanical strength, and low permeability. It is frequently referred to as a plow or traffic pan.
B	The characteristics of the B horizon depend highly on water regime. In epiaquic moisture regimes, the ho-

rizon generally remains oxidized, and mottling occurs along cracks and in wide pores. In aquic moisture regimes, the whole horizon, or at least the interior of soil peds, remains reduced during most years.

Many rice-growing countries have developed classification systems that distinguish natural wetland soils from rice soils. The only soil clasification systems applicable worldwide are found in the legend of the FAO-UNESCO Soil Map of the World and the US Department of Agriculture Soil Taxonomy.

In the FAO-UNESCO Soil Map of the World, Gleysols, Fluvisols, Planosols, Plinthosols, and Histosols make up most of the wetland soils. Gleyic subunits of Arenosols, Andosols, Cambisols, Solonetz, Solonchaks, Chernozems, Pharozems, Greyzems, Luvisols, Podsoluvisols, Podsols, Lixisols, Acrisols, Alisols are also mostly wetland soils. Although Vertisols, Nitosols, and Ferralsols have no gleyic subunits, these soils may be artificially flooded and sown to rice.

Soil Taxonomy does not recognize wetland soils, but classifies soils with aquic conditions at the suborder level and soils with hydromorphism at the subgroup level. Most hydromorphic soils, which have an aquic moisture regime, are equivalent to wetland soils in Soil Taxonomy. Suborders with aquic conditions are found in the orders of Spodosols, Andosols, Oxisols, Vertisols, Ultisols, Mollisols, Alfisols, Inceptisols, and Entisols. Most Histosols are wetland soils per se. Practically all Aridisols are upland soils. Soils within the aquic subgroups showing hydromorphism generally are not wetland soils since signs of wetness are found only in subsoil horizons.

CHAPTER 4

Rice environments

Agroecological zones

Agroecological zones (AEZs) are geographic mapping units developed by FAO. They are based on climatic conditions and land forms that determine relatively homogeneous crop growing environments. Characterization of AEZ's permits a quantitative assessment of the biophysical resources upon which agriculture and forestry research depend.

The classification system distinguishes between tropical regions, subtropical regions with summer or winter rainfall, and temperate regions. These major regions are further subdivided into rainfed moisture zones, lengths of growing period, and thermal zones based on the temperature regime that prevails during the growing season.

The definitions of terms used in AEZ classifications are:

tropics	regions with monthly mean temperature, corrected to sea level, of >18 °C for all months
subtropics	regions with monthly mean temperature, corrected to sea level, of <18 °C for one or more months
temperate	regions with monthly mean temperature, corrected to sea level, of <5 °C for one or more months
warm	daily mean temperature during the growing period of >20 °C
cool	daily mean temperature during the growing period in the range of 5 to 20 °C (including the moderately cool range of 15 to 20 °C)
warm/cool	daily mean temperature during part of the growing period <20 °C
arid	LGP[a] <75 d
semiarid	LGP 75-180 d
subhumid	LGP 180-270 d
humid	LGP >270 d.

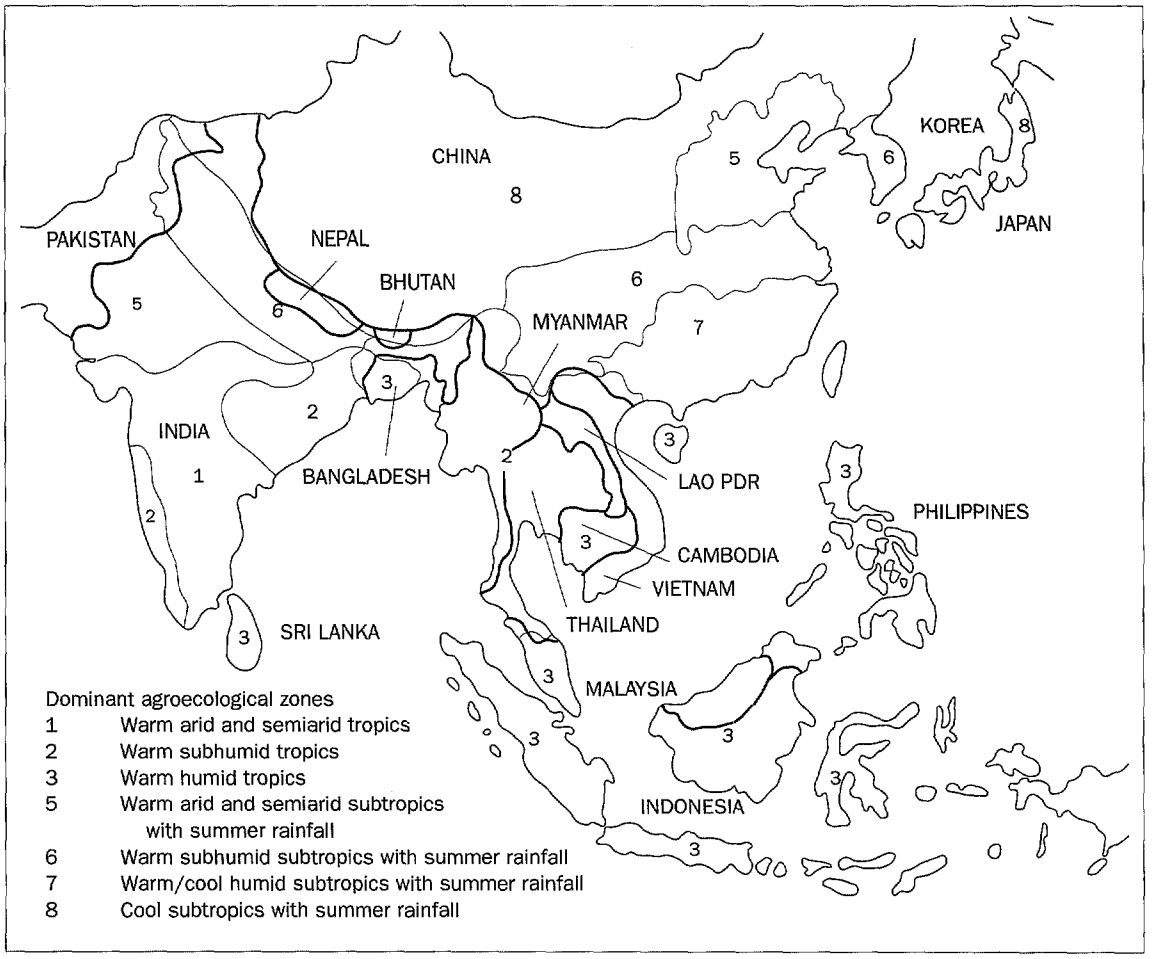
The distribution of agroecological zones in Asia is shown in Figure 1.

AEZs, population pressure, and food grain production

The distribution of arable land, population, and production of food crops in the AEZs of Asia is shown in Table 1. Population pressure on arable land is highest in the humid and subhumid subtropics and humid tropics but these AEZs also have favorable growing conditions for food grain crops. The production of food grain per ha of arable land is about 5.7 times higher in the subhumid subtropics (southern and southwestern China and Taiwan) than in the semiarid tropics (southern and western India). The semiarid tropics has the lowest production potential of the AEZs. The higher production potential in favorable AEZs, however, is offset by higher population pressure on land. So the difference between AEZs in food grain production per capita is small. In 1990, food grain production per capita was highest in the subhumid subtropics (377 kg per person), and almost 50% higher than in the semiarid tropics, which produced the lowest (Table 1).

Analysis of land use patterns in the AEZs of Asia (Fig. 2) indicates that rice is the dominant food crop in the humid subtropics (78% of the area

[a]LGP = length of growing period: number of days during the year when available soil moisture supply (rainfed) is greater than half potential evapotranspiration. Includes the period required to evapotranspire up to 100 mm of available soil moisture stored in the soil profile. Excludes any time interval when daily mean temperature is < 5 °C.



1. Regional agroecological zones in Asia.

Table 1. Population pressure and food grain production in the AEZs of Asia, 1990.[a]

Agroecological zone	Share of arable land (%)	Share of population (%)	Arable land per capita (ha)	Production of food grain[b] (t/ha of arable land)	Food grain production per capita (kg/yr)
Warm arid and semiarid tropics	15.6	10.3	0.20	1.22	240
Warm subhumid tropics	21.6	14.8	0.19	1.52	288
Warm humid tropics	16.1	17.4	0.12	2.24	269
Warm arid and semiarid subtropics with summer rainfall	19.1	16.2	0.15	1.99	304
Warm subhumid subtropics with summer rainfall	17.8	25.3	0.09	4.16	377
Warm/cool humid subtropics with summer ainfall	4.5	11.5	0.05	6.64	331
Cool subtropics with summer rainfall	5.3	4.5	0.15	2.02	300
Asia[c]	100.0	100.0	0.13	2.40	310

[a]Source: Compiled from FAO Agrostat data base and national statistical publications. [b]Includes cereals, oilseeds, and pulses. [c]Excludes Middle East and transitional economies in Central Asia.

Ecoregion	Rice	Wheat and maize	Other cereals	Pulses	Oilseeds
Warm arid and semiarid tropics (AEZ 1)	20.3%	8.5%	30.5%	17.9%	21.9%
Warm sub-humid tropics (AEZ 2)	69.9%	11.3%	2.2%	8.9%	6.8%
Warm humid tropics (AEZ 3)	73.7%	16.8%	0.3%	5.0%	5.7%
Warm arid and semiarid sub-tropics with summer rainfall (AEZ 5)	6.6%	49.3%	16.8%	21.4%	6.9%
Warm sub-humid sub-tropics with summer rainfall (AEZ 6)	20.6%	46.3%	4.9%	10.3%	9.3%
Warm/cool humid sub-tropics with summer rainfall (AEZ 7)	77.5%	7.0%	0.1%	7.5%	10.4%
Cool subtropics with summer rainfall (AEZ 8)	4.9%	66.2%	6.2%	11.5%	11.1%

2. Relative importance of food crops in agroecological zones in which rice is grown. (Figures indicate percent of area for each crop.)

under food grains), humid tropics (74%), and subhumid tropics (70%). It is an important crop in the subhumid subtropics (30%) and semiarid tropics (20%), but is insignificant in the semiarid and cool subtropics.

AEZs and rice ecosystems

The interface between IRRI's rice ecosystems and the FAO-designed AEZs is shown in Figure 3. The irrigated rice ecosystem, which accounts for 55% of the harvested rice area and contributes 76% of global rice production, is concentrated mostly in the humid and subhumid subtropics and humid tropics. This ecosystem is gradually losing land to urbanization and industrialization, and farm yields are approaching the ceiling of average yields obtained in experiment stations. It is characterized by high cropping intensity and intensive use of agrochemicals, with potential adverse effect on human health and sustainability of the natural resource base. The unfavorable rice ecosystems dominate the subhumid subtropics (eastern India, Myanmar, Thailand) and large parts of the humid tropics (Bangladesh, Cambodia, Laos). These are

Ecoregion	Irrigated	Rainfed lowland	Upland	Deep water
Warm arid and semiarid tropics (AEZ 1)	6.8%	3.0%	2.0%	0.4%
Warm subhumid tropics (AEZ 2)	7.2%	11.3%	3.6%	4.0%
Warm humid tropics (AEZ 3)	12.7%	7.1%	3.0%	3.6%
Warm arid and semiarid subtropics with summer rainfall (AEZ 5)	3.1%	0.0%	0.0%	0.0%
Warm subhumid subtropics with summer rainfall (AEZ 6)	14.1%	2.6%	0.9%	0.9%
Warm-cool humid subtropics (AEZ 7)	13.0%	0.9%	0.2%	0.0%
Cool subtropics with summer rainfall (AEZ 8)	0.6%	0.0%	0.0%	0.0%

3. Relative importance of rice ecosystems in the agroecological zones. (Figures indicate percent of total rice area for each AEZ and each rice ecosystem.)

regions where modern rice technologies have yet to make an impressive impact; area expansion has been an important source of growth in rice production. Strategic research is needed for these regions, not only for maintaining the natural resource psi but also for genetic improvements of seeds, so that constraints to increased rice production imposed by abiotic stresses—droughts, floods, waterlogging, and salinity—can be minimized.

Irrigated rice ecosystem

Irrigated rice is grown in bunded, puddled fields with assured irrigation for one or more crops a year. Some areas are served only by supplementary irrigation in the wet season. Rainfall variability is the basis for subdividing the irrigated ecosystem into 1) irrigated wet season, and 2) irrigated dry season.

Irrigated wet season areas are those where irrigation water may be added to the ricefields during the local wet season as a supplement to rainfall. Relatively small volumes of water early in the season or during a midseason dry period can pay large dividends in assuring the success of a crop threatened by erratic precipitation.

Irrigated dry season areas are those where no rice crop can be grown without supplemental water in this season. Rainfall is very low, cloud cover is minimal, and the levels of incoming solar radiation are markedly above those of the rainy season.

In the dry season evapotranspiration is high and water needs are considerably greater than during the wet season. In most areas the combination of assured water throughout the season, high solar radiation, low pest incidence, and high input levels results in the year's highest yield.

Worldwide, about 80 million ha of rice is grown under irrigated condition. Average yields vary from 3 to 9 t/ha. Generally, farmers of irrigated land use more purchased inputs than farmers of nonirrigated lands. More than 75% of the world's rice supply is produced in irrigated ricelands. Improved rice cultivars that have been developed for irrigated ricelands are of short duration and N responsive, and incorporate resistance to several biological stresses and some tolerance for adverse soils.

East Asia, 93% of which is irrigated, accounts for about 40% of the world rice area (Table 2). In the tropics of South and Southeast Asia, less than 40% of the rice area is irrigated.

Productivity

Based on current national or regional yield averages, the irrigated rice ecosystem can be divided into high-yielding areas where yields are > 5 t/ha, medium-yielding areas with yields of 4-5 t/ha, and low-yielding areas that typically achieve yields of < 4 t/ha.

China, Egypt, Japan, Indonesia, the People's Democratic Republic of Korea, and the Republic of Korea typify high-yielding areas. Medium-yielding areas include Bangladesh, northwestern and southern India, Laos, Malaysia, Myanmar, Philippines, Sri Lanka, Thailand, and Vietnam.

Table 2. Estimated harvested area in irrigated rice-producing countries and regions of the world, 1991.

Irrigated rice-producing countries and regions	Irrigated rice area (% of total rice area)	Irrigated rice area (ha x 10^3)	Percent of world's Irrigated rice area
ASIA			
South Asia			
Bangladesh	22	2407	
Bhutan	50	13	
India	45	18,990	
Nepal	23	329	
Pakistan	100	2,060	
Sri Lanka	37	321	
Subtotal		24,120	30.4
Southeast Asia			
Cambodia	8	144	
Indonesia	72	7335	
Laos	2	13	
Malaysia	66	419	
Myanmar	18	869	
Philippines	61	2088	
Thailand	7	720	
Vietnam	53	3336	
Subtotal	40	14,924	18.8
East Asia			
China (incl. Taiwan)	93	30783	
Japan	99	2033	
Korea, DPR	67	456	
Korea, Republic of	91	1100	
Subtotal	93	34,372	
Total	57	73,943	93.3
LATIN AMERICA			
Brazil	19	787	
Colombia	67	291	
Cuba	100	143	
Dominican Republic	93	70	
Ecuador	54	136	
Guyana	71	54	
Peru	80	126	
Suriname	92	51	
Uruguay	100	120	
Total	33	2046	2.6
AFRICA			
Côte d'Ivoire	6	34	
Egypt	100	433	
Guinea	5	32	
Liberia	0	0	
Madagascar	10	110	
Nigeria	16	263	
Sierra Leone	0	0	
Tanzania	3	10	
Total	17	1107	1.4
Other countries		2114	2.7
Grand total	55	79,210	100.0

Cambodia, eastern India, Madagascar, Nepal, and Pakistan are representative of low-yielding areas of the irrigated rice ecosystem.

Although production constraints in the low- and medium-yielding areas are generally the least site-specific, they vary in frequency and intensity. The main yield limiting factors are 1) poor input management, 2) yield and quality losses from pests, 3) inadequate water supply, 4) inefficient use of scarce irrigation water, 5) inadequate drainage, leading to the buildup of salinity and alkalinity, and 6) environmental stresses.

Some of the same problems that are found in the low- and medium-yielding areas are yield limiting in the high-yielding areas as well. The main problems encountered, however, are 1) an average on-farm yield plateau of about 6 t/ha in some countries 2) yield instability due to pests, 3) difficulty of sustaining high yields under intensive cropping, and 4) environmental degradation because of excessive inputs.

Research accomplishments for the irrigated rice ecosystem have been significant. They include the development of semidwarf varieties with high yield potential (10-11 t/ha), short growth duration (around 100 days), greater yield stability due to genetic resistance to pests, and, to a lesser extent, tolerance for some environmental stresses such as problem soils.

Breeding programs have improved grain quality and increased grain size and milling recovery of the modern, high-yielding varieties. Increasing nutritional value by increasing protein content, however, has proven to be extremely difficult.

The irrigated ecosystem benefited, too, from the design of associated management practices that allow the semidwarf varieties to express their yield potential.

IRRI research on the irrigated rice ecosystem focuses sharply on the resilience of intensively cropped systems. Some research is designed to identify factors that contribute to stagnating or even declining yields. Other work examines technological innovations that can reverse these negative trends.

The objectives are to extend the yield frontier through varietal improvement; more efficient use of inputs; and rehabilitation and maintenance of the physical, biological, and human resource base. Technologies to increase the efficiency with which

the rice crop uses inputs should improve the ricelands, reduce dependence on chemicals, and increase the profitability of rice production.

Rainfed lowland rice ecosystem

Physical description

Rainfed lowland rice grows in bunded fields that are flooded for at least part of the cropping season to water depths that do not exceed 50 cm for more than 10 consecutive days. Rainfed lowlands are characterized by lack of water control, with floods and drought being potential problems. About one-fourth of the world's total riceland or approximately 40 million ha is rainfed, contributing 18% of the global rice supply (Table 3). Adverse climate, poor soils, a lack of suitable modern varieties (MVs), and poverty keep farmers from being able to increase productivity.

The rainfed lowland rice ecosystems may be divided into five subecosystems: 1) favorable rainfed lowland, 2) drought-prone, 3) submergence-prone, 4) drought- and submergence-prone, and 5) medium-deep water. Technologies for the irrigated rice sector can also be applied in the favorable rainfed lowland subecosystem. IRRI's rainfed lowland rice program, therefore, focuses on the four other subecosystems, giving priority to the ones that occupy a greater area and have a higher potential for productivity increases—i.e., the drought-prone and the submergence-prone subecosystems.

Predominant cropping system

The rainfed lowlands include areas in which farmers grow only one crop of rice, although in some areas farmers grow rice and a postrice crop, usually on a smaller area. Legumes (e.g., mungbean, soybean), wheat, maize, or vegetables are the most common second crops. Farmers often cultivate rainfed lowland rice at several toposequence levels such that on one farm some fields may be drought-prone, while others may be flood- and submergence-prone in the same season.

Productivity

The world's rainfed lowlands offer substantial potential for increasing rice production. The area planted is increasing, but yields remain low.

Table 3. Estimated harvested area in rainfed rice-producing countries and regions of the world, 1991.

Rainfed rice-producing countries and regions	Rainfed rice area (% of total rice area)	Rainfed rice area (ha x 10^3) rice area	Percent of world's Rainfed rice area
ASIA			
South Asia			
Bangladesh	47	5,166	
Bhutan	33	1	
India	35	13,926	
Nepal	66	942	
Pakistan	0	0	
Sri Lanka	53	454	
Subtotal	36	20,488	50.5
Southeast Asia			
Cambodia	48	864	
Indonesia	7	713	
Laos	56	323	
Malaysia	21	133	
Myanmar	52	2,512	
Philippines	35	1,198	
Thailand	85	8,568	
Vietnam	28	1,763	
Subtotal	43	16,073	39.6
East Asia			
China (incl. Taiwan)	5	1655	
Japan	0	0	
Korea, DPR	20	136	
Korea, Republic of	8	97	
Subtotal		1,888	4.7
Total	27	38,753	95.6
LATIN AMERICA			
Brazil	6	246	
Colombia	10	44	
Cuba	0	0	
Dominican Republic	7	5	
Ecuador	7	18	
Guyana	29	22	
Peru	20	32	
Suriname	8	4	
Uruguay	0	0	
Total	7	427	1.1
AFRICA			
Côte d'Ivoire	0	0	
Egypt	427	0	
Guinea	0	0	
Liberia	0	0	
Madagascar	74	814	
Nigeria	0	0	
Sierra Leone	0	0	
North Africa			
Tanzania	76	280	
Total	17	1,373	3.4
Grand Total	25	40,553	100.0

Farmers have developed a range of practices that address variability across sites as well as heterogeneity within local ecosystems.

Uncertainty characterizes rice farming in rainfed lowlands. Crops suffer droughts, floods, pests, weeds, and soil constraints. Since most rainfed lowlands depend on erratic rainfall, conditions are diverse and unpredictable. Understanding how farmers' practices help reduce risk and assure some production is essential to developing improved technologies for the rainfed lowlands.

Most rainfed lowland rice farmers are poor and must cope with unstable yields and financial risks. They adapt their cropping practices to the complex risks, potentials, and problems they face. They typically grow traditional, photoperiod-sensitive cultivars and invest their labor instead of purchasing inputs. Farmers bund the fields to store water. They weed, may redistribute seedlings to ensure good crop stands, and usually harvest by hand. Suitable MVs and associated production technologies have been limited.

Although new technology developed in the 1960s and 1970s focused on the irrigated sector, rainfed lowland rice farmers were not forgotten. Researchers have tried to produce new varieties and improved farming practices for nutrient management, crop establishment, on-farm water collection, and weed and pest control. These practices can potentially contribute to higher yields, especially in the favorable rainfed subecosystem.

Rainfed lowland rice farmers in less favorable areas use traditional varieties that do not respond well to higher fertilizer rates. In Bangladesh, India, Indonesia, Philippines, and Thailand, however, adoption of new rice varieties is increasing as scientists are now developing new breeding lines with single or combined traits adapted to rainfed lowland stresses. Rices that are bred for tolerance for submergence, late transplanting, and resistance to lodging allow farmers to apply fertilizers and use more intensive weed management practices.

Rainfed lowland rice varieties of the future will need to respond to improved management while retaining the tolerance of the traditional varieties for drought, floods, and soil stresses. Such rices should perform well under favorable conditions and still equal the productivity of traditional cultivars under adverse conditions. Farmers would then be able to invest money and labor in potentially more productive land preparation and fertility management practices that will assure higher yields.

Upland rice ecosystem

Physical description

Upland rice is grown in Asia, Africa, and Latin America. Of 148 million ha of world rice area in 1991, about 17.3 million ha was planted to upland rice: 10.5 million ha in Asia, 3.8 million in Latin America, and 2.8 million ha in Africa (Table 4). Although upland rice constitutes a relatively small proportion of the total rice area, it is the dominant rice culture in Latin America and West Africa. In Asia, the area of the upland ecosystem is much larger than the area under rice, because rice is grown in rotation with many other crops.

Landforms for upland rice vary from low-lying valley bottoms to undulating and steep sloping lands with high runoff and lateral water movement. In South and Southeast Asia, most upland rice is grown on rolling and mountainous land with slopes varying from 0 to more than 30%. In West Africa, upland rice grows on hills in the humid zone and on flatland in the drought-prone and moist forest zones. Most upland rice in Brazil is on level to gently rolling (0-8% slope) land under mechanized cultivation. In north and northeast Brazil, some upland rice is grown on rolling topography under shifting cultivation.

Upland rice soils range from erodible, badly leached Alfisols in West Africa to fertile volcanic soils in some areas in Southeast Asia. Their texture, water-holding capacity (WHC), cation exchange capacity (CEC), nutrient status and soil-related problems vary greatly. In Brazil, where upland rice is a major crop, soils have extremely low CEC values, high P fixation, and high levels of exchangeable Al. Upland rice soils in most of Africa have low available WHC because of coarse texture, are often kaolinitic, and have severe nutrient deficiencies and AL and Mg toxicities.

Dry soil preparation and direct seeding in fields that are generally unbunded are common in upland rice culture. Another critical distinguishing characteristic of upland ricefields is that surface water does not accumulate for any significant time during the growing season. In some countries such as in eastern India and Bangladesh, upland ricefields are frequently bunded to save scarce water.

Table 4. Estimated harvested area in upland rice-producing countries and regions of the world, 1991.

Upland rice-producing countries and regions	Upland rice area (% of total rice area)	Upland rice area (ha x 10^3)	Percent of world's Upland rice area
ASIA			
South Asia			
Bangladesh	8	875	
Bhutan	4	1	
India	15	6,330	
Nepal	3	43	
Pakistan	0	0	
Sri Lanka	7	60	
Subtotal	13	7,309	42.6
Southeast Asia			
Cambodia	2	36	
Indonesia	11	1121	
Laos	41	234	
Malaysia	12	76	
Myanmar	6	290	
Philippines	2	68	
Thailand	1	52	
Vietnam	8	504	
Subtotal	9	2,381	13.9
East Asia			
China (incl. Taiwan)	2	662	
Japan	1	16	
Korea, DPR	13	88	
Korea, Republic	1	12	
Subtotal	2	778	4.5
Total	8	10,539	61.4
LATIN AMERICA			
Brazil	75	3100	
Colombia	23	100	
Cuba	0	0	
Dominican Republic	0	0	
Ecuador	0	0	
Guyana	0	0	
Peru	0	0	
Suriname	0	0	
Uruguay	0	0	
Total	59	3686	21.5
AFRICA			
Côte d'Ivoire	87	498	
Egypt	0	0	
Guinea	47	306	
Liberia	94	132	
Madagascar	14	154	
Nigeria	51	837	
Sierra Leone	63	225	
Tanzania	22	80	
Total	42	2800	16.2
Other countries		127	10.7
Grand total	12	17,152	100.0

Predominant cropping systems

Depending on the size of their farms and their resources, upland rice farmers use farming systems ranging from shifting to permanent cultivation. Shifting cultivation is common in Indonesia, Laos, Philippines, northern Thailand, and Vietnam in Asia, and in the forested areas of Latin America and West Africa. Farmers plant a rice crop alone or in association with other crops such as maize, yam, beans, cassava, or banana. In Indonesia, the common cropping pattern is upland rice + maize. In Brazil, rice and maize are intercropped, followed by cowpea or soybean or beans. In West Africa, one or more crops may be mixed with upland rice. Farmers use an area for 1 to 3 yr until soil fertility declines and weed and pest infestations increase. They then abandon the land and return to previously abandoned farmland or start cropping on other available virgin land.

One variation of shifting rice cultivation is pioneer cultivation where fallow is replaced by perennial vegetation such as pasture or trees. Rice is intercropped with young fruit and forest trees for 2-3 yr (intercalary cultivation). As the trees grow, they shade more area and less rice is planted. After a few years, the rice crop is transferred to a new area. Pioneer cultivation is common in Brazil, but rare in Asia and Africa.

Permanent cultivation of upland rice is practiced in many Asian and Latin American countries. This is characterized by more orderly intercropping, relay cropping, and sequential cropping with a number of crops. To maintain their intensive cropping system, farmers have to use inputs from animal manure, organic matter, chemical fertilizers, and pesticides. However, the use of these inputs, particularly chemicals, is far less than the recommended rates because of cost. The draft animal is commonly used in this system in Asia. Partial or high mechanization is more common in upland rice in Latin America, especially in Brazil.

Productivity

Although accounting for 12% of total world rice area, upland rice contributes only 4% to total world rice production. Grain yields average about 1 t/ha in most of the upland rice-producing countries except in some large, partly mechanized upland farms in Latin America where yields are as

high as 2-3 t/ha. In addition to the biological and physical constraints, the socioeconomic situation contributes to low yields. Most of the farmers have low income and poor access to credit, inputs, and modern technologies.

Production constraints

Biological and physical constraints that limit upland rice yield are numerous. Weeds are the number one constraint, followed by blast disease and brown spot. Weeds reduce upland rice grain yield and quality. Estimates of yield losses caused by weeds in upland rice range from 30 to 100%. Small farmers cannot afford weed control. In shifting cultivation they abandon their fields after 2-3 yr of cropping. Stem borers and rice bugs are the predominant insect pests. Nematodes can cause yield losses up to 30%. Rodents are reported by many countries as a major problem and birds are sometimes serious.

Amount and distribution of rainfall and poor soil fertility are the most serious physical constraints. In Asia, the monsoonal rainfall ranges from 1,500 to more than 3,500 mm. Rainfall is usually erratic during the monsoon season. In Africa, annual rainfall ranges from 1,200 to 2,000 mm where upland rice is grown. Rainfall is frequently erratic in semiarid areas of West Africa. Mean annual rainfall in Latin America ranges from 1,400 mm in central Brazil to 4,800 mm in Costa Rica. Dry spells frequently occur during the growing season in most of these areas, mainly in north and central Brazil.

Upland rice soils are predominantly acidic (pH varies from 4 to 7) and depleted in major elements. In South and Southeast Asia, more than half of the upland rice is grown in infertile soils. In most upland soils, P rather than N is the most common limiting nutrient. Physiological disorders result from major and trace element imbalances. Major toxicities are caused by high Al and Mg content in strongly acidic soils.

The temperature of most regions of Asia, Latin America, and Africa is relatively favorable to upland rice except in some high-altitude areas in India, Indonesia, Myanmar, Nepal, and Thailand. Minimum and maximum temperatures average 20 and 30 °C for Latin America, 20 and 32 °C for South Asia, and 18 and 35 °C for Africa. The optimum temperature for maximum rice photosynthesis is 25-30 °C.

Flood-prone rice ecosystem

Physical description

Around 10 million ha of ricelands in South and Southeast Asia are subject to uncontrolled flooding (Table 5). Rice yields are low and extremely variable because of problem soils and unpredictable combinations of drought and flood. Although average yields are only about 1.5 t/ha, these areas support over 100 million people.

The flood-prone ecosystem incorporates many types of rice (Fig. 4). It deals with problems of excess water in places ranging from stagnant > 50 cm deep to the very deeply flooded (up to as much as 8 m) areas where floating rice is grown. Conditions may be temporary submergence of 1-10 days (which affects both rainfed lowland and deepwater rice), long periods (1-5 months) of standing water, or daily tidal fluctuations that sometimes cause complete submergence.

Flood-prone rice is grown in the backswamps of the floodplains and deltas and on the slopes of natural levees.

The soils are of various ages and are complex and diverse, particularly in river floodplain areas. Many of these alluvial sediments have undergone little soil formation; their texture varies from medium to fine. Soil texture is usually more coarse on natural levees and finer in depressions and backswamps. Although many soils are fertile, some adverse soils such as acid sulfate and saline soils occur.

In most of Asia flooding occurs during the wet season months of June to November. Most crucial for the rice plants are the age of plants at the time of inundation, the rate of water rise, and the duration of the flood.

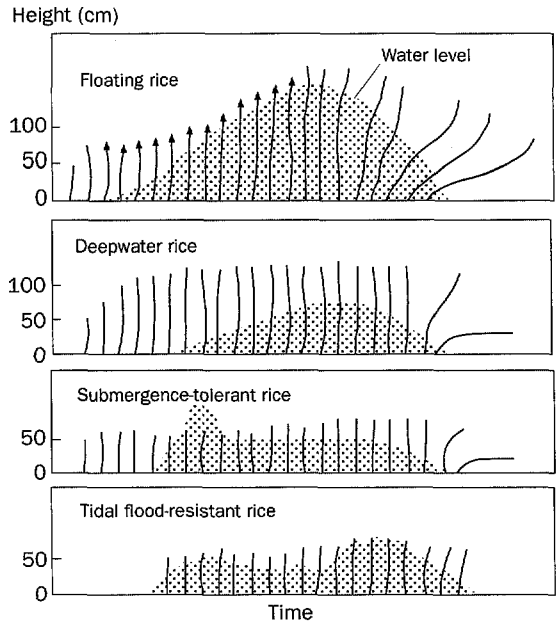
Predominant cropping systems

The cropping systems vary depending upon the time, depth, and duration of flooding. No crop other than rice can be grown during the rainy season. There are five major rice cultural types grown in the flood-prone ecosystem: 1) submergence-tolerant, 2) deepwater, 3) floating, 4) tidal, and 5) boro.

Most rice varieties can survive submergence for only 3 or 4 days. But submergence-tolerant varieties can survive complete submergence for about 12 days. They are grown during the wet

Table 5. Estimated harvested area in flood-prone rice-producing countries and regions of the world, 1991.

Flood-prone rice-producing countries and regions	Flood prone rice area (% of total rice area)	Flood-prone rice area (ha x 10^3)	Percent of world's flood-prone rice area
ASIA			
South Asia			
Bangladesh	31	2,492	
Bhutan	42	11	
India	7	2,954	
Nepal	8	118	
Pakistan	0	0	
Sri Lanka	3	25	
Subtotal		5,589	48.89
Southeast Asia			
Cambodia	42	756	
Indonesia	10	1018	
Laos	0	0	
Malaysia	1	7	
Myanmar	24	1159	
Philippines	2	69	
Thailand	8	660	
Vietnam	11	692	
Subtotal	12	4,361	38.1
East Asia			
China (incl. Taiwan)	0	0	
Japan	0	0	
Korea, DPR	0	0	
Korea, Republic	0	0	
Subtotal	0	0	87.5
Total	8	10,016	
LATIN AMERICA			
Brazil	2	0	
Colombia	0	0	
Cuba	0	0	
Dominican Republic	0	0	
Ecuador	39	98	
Guyana	0	0	
Peru	0	0	
Suriname	0	0	
Uruguay	0	0	
Total	2	108	0.9
AFRICA			
Cote d'Ivoire	7	40	
Egypt	0	0	0.0
Guinea	48	312	
Liberia	6	8	
Madagascar	2	22	
Nigeria	33	542	
Sierra Leone	37	132	
Tanzania			
Total	20	1,327	11.6
Grand total		11,451	



4. The flood-prone ecosystem includes tall deepwater rices, which tolerate 50-100 cm of flood water; floating rices, which grow rapidly taller to maintain their foliage above floodwaters that can be from 100 to 400 cm deep; submergence-tolerant rices, which can survive flash floods for up to 12 days; and tidal wetland rices, which can survive daily tidal fluctuations and submergence for short periods.

season in flood-releasing areas, and in the periphery of old deltas.

Deepwater varieties elongate (2-3 cm/day) when submerged. They can grow and reproduce in a maximum water depth of around 1 m. They are widely grown during the wet season in both young and old deltas.

Floating rices elongate rapidly under submergence, sometimes up to 20 cm/day. They are adapted to rapid and very deep floods that occur in floodplains.

Tidal rices are found in coastal zones. They are cultivated only during the wet season. They can tolerate submergence due to flash floods or tidal fluctuations. They do not elongate since floodwaters recede within about 2 wk. Salt-tolerant tidal rices are grown in areas where there is saltwater intrusion from the sea. During the dry season, these lands are too dry or saline for any cropping.

Boro rices are those grown in the flood-prone ecosystem during the dry season in Bangladesh and India.

Traditionally, boro rices were cultivated only in local land depressions, where there is sufficient residual water in the soil for a crop during the dry season. But with improved irrigation, mainly from tubewells, boro rice cultivation has now spread to other floodplains with low water percolation. Irrigated boro is fast replacing floating rices, and has become a second rice crop in some young deltas. Similar rice cropping changes have occurred in Vietnam following the construction of canals from the rivers.

In Bangladesh, deepwater rice farmers have traditionally grown a wide range of crops after the floods by broadcasting seeds onto the straw of the deepwater rice crop. These crops include pulses, oil seeds, spices, potato, onion, garlic, wheat, and barley. Postflood and dry season cropping are now widely practiced in Bangladesh, India, Myanmar, and Vietnam.

Preflood cropping, although not common, includes millet, sesame, chili, and sorghum. Sometimes jute or maize is planted along with deepwater rice or just before the deepwater rice crop is sown. These crops, if successful, are harvested before the main floods arrive. In India, farmers in many deepwater rice areas have recently incorporated grain legumes (mainly mungbean), sesame, maize, and sorghum into their rotation. They grow these crops on stored soil water between the deepwater rice harvest and the start of the wet season.

In irrigable areas of Vietnam some farmers grow floating rice during the flood and then upland crops such as sesame, maize, and eggplant. They find that rotation more profitable and ecologically sustainable than growing two crops of irrigated rice during the dry season.

Productivity

Wet season rice yields range from 0.5 to 3.5 t/ha depending on the rice type, location, and season. Floating rice yields are usually low, ranging from 0.5 to about 2.5 t/ha. Deepwater rices yield higher than floating rice, up to 4 t/ha. Submergence-tolerant varieties usually produce the highest yields in this ecosystem. Yields of tidal rices vary widely; crop failure can occur in salt-affected areas.

Although fertilizer tends to increase deepwater rice yields, the response is often irregular because of many other stresses. As a consequence, fertilizer use is limited and yields are also low. Boro rice on the other hand is a highly productive crop. Yields can range from 4 to 7 t/ha.

There are opportunities for increasing the rice yields of the flood-prone ecosystem. The yield potential of deepwater rices could be improved by introducing an appropriate plant type. With increased tolerance for submergence, salinity, and acidity, yields of flash-flood and tidal areas could be increased. Varieties with tolerance for cold at the seedling stage and other early vegetative stages could increase yields of the boro rice crop. Yield increases in floating rices through varietal improvement is considered doubtful.

Increased productivity in deepwater areas also depends on better crop management. Improved stand establishment, weed control, N management, and stem borer control are the most important for deepwater areas. In some tidal areas, soil and water management practices that reduce soil toxicities would increase productivity.

CHAPTER 5

Rice in different countries

Annual world rice production is about 520 million t. More than 50 countries throughout the world contribute to that total with production of at least 100,000 t of rice annually. Asian farmers produce 92% of the world total, with two countries, China (including Taiwan) and India, producing fully 57% of the total crop.

For most rice-growing countries where production exceeds 1 million t annually, rice is the staple food. In Bangladesh, Cambodia, Indonesia, Laos, Myanmar, Thailand, and Vietnam, rice provides 55-80% of total calories consumed. Notable exceptions are Egypt, Nigeria, and Pakistan, where rice contributes less than 10% to per capita daily caloric intake.

The typical Asian farmer plants rice primarily to meet family needs. Less than half the crop goes to market, and most of that is sold locally. Only about 4% (13.4 million t) of world rice production is traded internationally. Major exporters are Thailand (36%), the United States (19%), Vietnam (10%), and Pakistan (7%). China and India, the world's two largest rice producers, export less than 1 million t annually combined.

In the narratives that follow, we present the rice situation and outlook for 26 representative rice-producing countries. For the most part, they are countries producing 1 million t or more of rough rice annually and whose populations depend on rice for 15% or more of their daily caloric intake. A few countries do not meet these criteria. They are included, however, because they export a large percentage of their crop, or because rice is an important, yet small, part of the daily diet.

The narratives give some indication of the importance of rice to each country, production constraints, and opportunities for increasing production.

Sources of information

National statistical organizations do not generate data on area and production under different rice ecosystems. The basic source of IRRI's information on rice area by ecosystem is Huke and Huke (1982). The data is estimated from the returns of agricultural censuses and available landsat imagery maps. The Hukes revised the data in 1988 on the basis of the most recent information available to them.

The 1991 data are estimated by applying the proportion of area under different ecosystems to the total harvested rice area as published by FAO. Adjustments have been made for countries which publish information on irrigated rice area, assuming that the increase in area under the irrigated ecosystem is at the expense of area under the rainfed lowlands.

The estimates of rice yields for different ecosystems are from personal communications with national agricultural research systems and outposted IRRI scientists. To make the data consistent with total rice production for a country, as published by FAO, we used the yields reported by the national system for the minor ecosystems; yield for the major ecosystem was derived as the residual. Production figures are derived from area and yield estimates.

All other information are from the FAO agrostat data base and from statistical publications of individual countries.

Sources of maps

IRRI takes no reponsibility for the graphic representation of the country borders illustrated in the used maps. The maps were collated from a variety of sources. We have attempted to rectify the data

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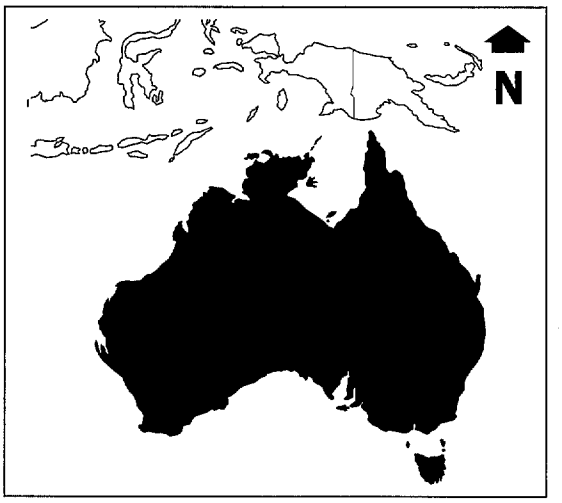
to a common base map, using the commercial software package *Atlas Pro*™. In most cases, the maps are not geographically projected; that may make the map appear distorted. We also understood that some borders may be in dispute.

The areas identified as rice ecosystems may not always be proportional to the production figures. In order to make some rice ecosystems visible to the reader, we found it necessary to exaggerate some portions of the shading. For some countries, the area of flood-prone rice is so small, it was impossible to include on the indicator map. Our use of these maps is meant to be heuristically, not cartographically, accurate.

Australia



The island continent of Australia is surrounded by the Tasman and Coral Seas to the east, the Arafura and Timor Seas to the north, and the Indian Ocean to the west and south. It is located between 10° and 44° S latitude and 115° and 155° E longitude. Australia is about the same size as the continental US, but its population of 16.8 million is only about 7% that of the US. The western two-thirds of the continent range from hyperarid to semiarid. The majority of the population lives along the relatively well-watered eastern and southeastern coasts.

The climate ranges from the warm humid tropics to cool subtropics. Agriculture contributes about 4% to GDP. The main feature of Australian agriculture is the dominance of broadacre dryland farming and grazing systems. Most irrigated agriculture is found in the Murray-Darling Basin in New South Wales (NSW). Irrigated agriculture represents 16% of the value of agricultural production; about 5% of the value of irrigated agriculture is rice.

Importance of rice

The annual per capita consumption of rice is estimated at 7.5 kg. Rice contributes about 8% to the calorie supply. The major portion of Australian rice is exported. The rice industry accounts for a sizable proportion of regional employment in the Riverine plains region in NSW. It employs 2,846 persons (8.6% of the regional employment) and directly provides 8.8% of regional household income. The rice industry is vertically integrated with farmers engaged in production, processing, and marketing activities. In total, the Australian rice industry provides employment to about 9,000 individuals, making the Rice Growers Cooperative Australia's 43d largest export company.

Rice environment

In 1892, the NSW Department of Agriculture unsuccessfully attempted to produce upland rice varieties under natural rainfall conditions at Grafton Experimental Farm. California varieties were introduced in the 1920s, and by 1930, rice was grown on 8,096 ha with yields of 4 t/ha. That had expanded to 128,000 ha in 1992 with average yields more than doubling to 9 t/ha.

Rice is grown mainly in the irrigated areas in the Murray-Darling Basin in NSW. It is often grown in rotation with legume pastures and dryland crops, which improves soil fertility and limits the need for pesticides. In one of the areas, the number of farms growing rice is restricted because of the restrictions on the amount of water available for irrigation. Average farm size is 590 ha with 68 ha of rice harvested. All operations are mechanized. Up to 900,000 t of rough rice are produced on 97,000 ha of irrigated riceland in the semiarid Riverine region around Yanco, NSW. Another 30,000 t are produced annually in Northern Queensland. Only a small amount of rice is produced in the state of Victoria.

The area sown to rice is unlikely to increase because available water is fully committed. Rice growing is strictly controlled on suitable (generally heavy) soils to minimize infiltration. A sizeable proportion of rice crops are established by aerial sowing. There is some drill seeding into the prepared fields and some no-tillage drill seeding into fallow pasture pods. The growth duration is 170-180 days.

Production constraints

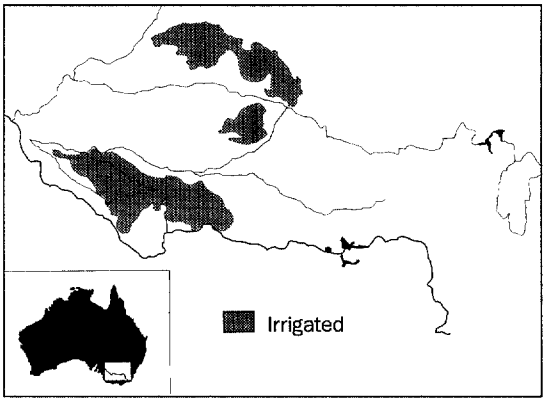
Rice yields have increased from 5-7 t/ha in the early 1970s to more than 9 t/ha in 1992, the highest in the world. That has been the result of improved varieties and better management at the farm level. Nitrogen is usually the only nutrient fertilizer applied to Australian rice crops. Typical application rates are 120 kg N/ha.

Concerns are now being raised about salinization of shallow groundwater due to rising water tables in the rice-growing areas. Other concerns about environmental effects are the vol-

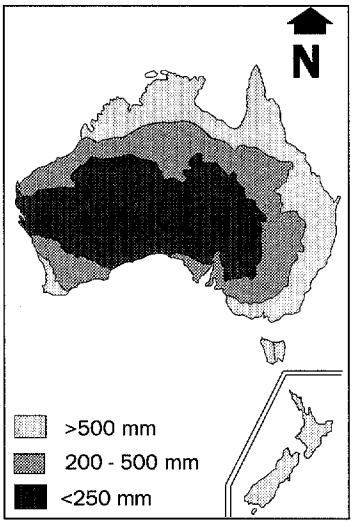
ume of drainage water and the chemical residues it contains, the breeding of mosquitos in irrigated ricelands, and bird control. Migratory ducks can cause heavy damage, with up to 30% of some farms having to be resown.

Production opportunities

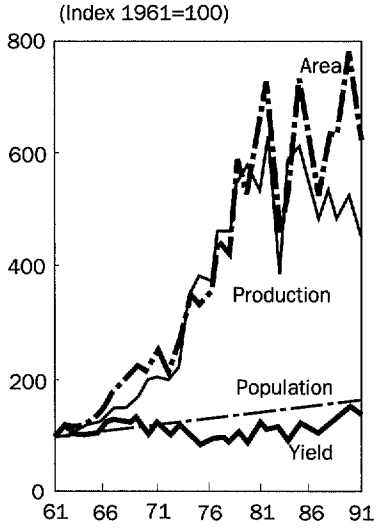
The NSW rice industry has long been a financial supporter of rice research in Australia. Intensive rice research is conducted at the Yanco Agricultural Institute, primarily in varietal improvement and production technology (nutrition, grain quality, weeds, water, rotations, pest control, crop establishment). To reduce water requirements of the rice crop, researchers are trying to reduce the growth duration to 140-150 days. Focus is now on maximizing yields to achieve the same output with a restricted rice-growing area. Maximum yields reported of some farms are more than 14 t/ha, indicating the possibilities for yield increases by further optimizing crop and water management.



Rice ecosystems.



Mean annual rainfall.

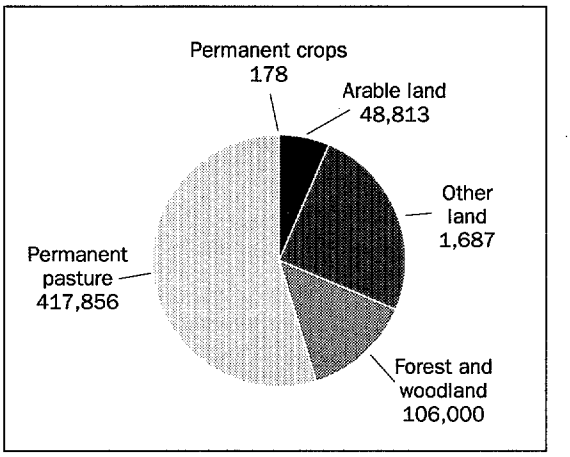


Trends in population, rice production, area, and yield.

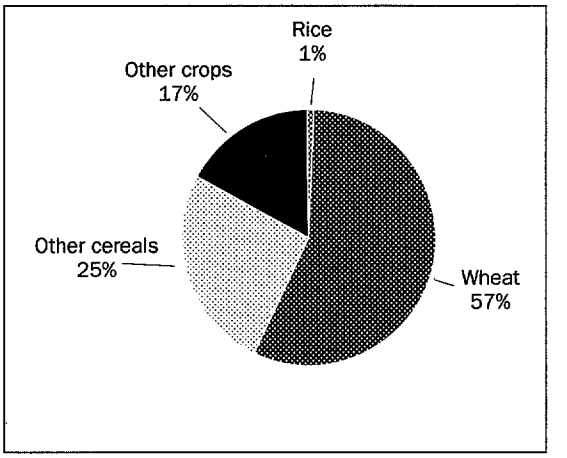
Australia

Land (km^2)[a]	
Total area	7713360
Population[a]	
Total population (no.× 10^3)	17013
Urban population	14631
Rural population	2382
Agricultural population	849
Agricultural labor force	406
Population density (no./km^2)	2.2
Annual growth rate (%)[b]	1.53
Gross domestic product (US$ × 10^6)[a]	296300
Agricultural share in GDP (%)[a]	4
Land use (ha × 10^3)	
Irrigated agricultural area[a]	1900
Harvested area,modern rice varieties[a]	-
Harvested area, traditional varieties[a]	-
Rice production (t × 10^3)	
Total rough rice	726
Irrigated area	726
Rainfed lowland area	0
Upland area	0
Flood-prone area	0
Yield (t/ha)	
Irrigated area	8.2
Rainfed lowland area	0.0
Upland area	0.0
Flood-prone area	0.0
Average yield[c]	8.2
Per capita rice use consumption (kg)[a]	
Milled	22
Rough rice equivalent	35
Per capita calorie supply (no.)	
Total calorie supply	3385
Calories supplied by rice	257
Rice trade (t × 10^2)	
Total imports	285
Total exports	2191
Fertilizer use, chemical sources (t × 10^3)[a]	
Total consumption (N,P,K)	815
N	439
P	255
K	121

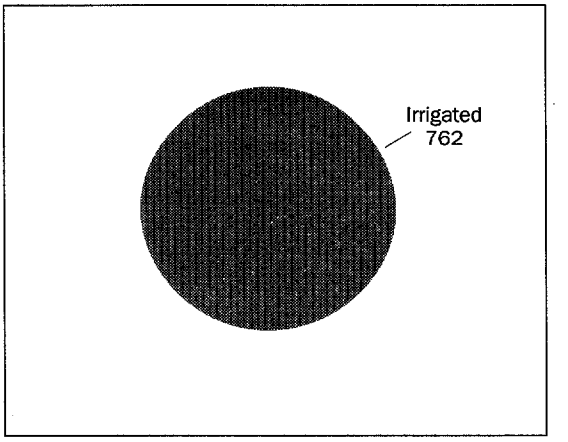
Data are for 1991 unless otherwise indicated. [a]1990. [b]1985-90. - = data not available. [c]Weighted average for all ecosystems.



Land use by physical area (ha × 10^3), 1990.

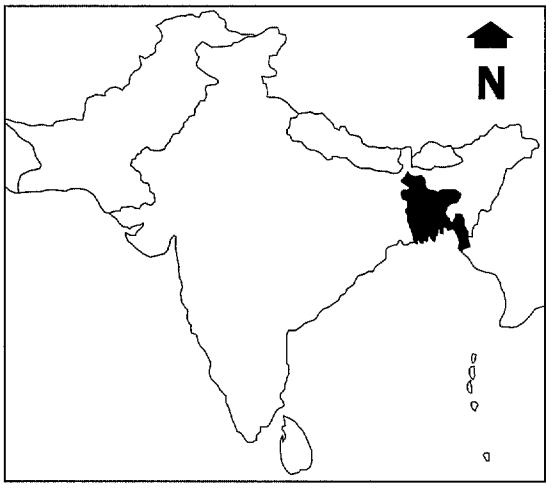


Area harvested, temporary crops, 1990.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)



Harvested rice area (ha × 10^3) by ecosystem, 1991.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)

Bangladesh



Bangladesh lies in the northeastern part of South Asia between 20° and 26° N latitude and between 88° and 92° E longitude. The country is bounded by India on the west, north, and northeast; by Myanmar on the southeast; and by the Bay of Bengal on the south.

Except for the hilly regions in the northeast and the southeast and some highlands in the north and northwest, Bangladesh for the most part consists of low, flat, fertile land. About 230 rivers and their tributaries, with a total length of about 24,140 km, flow across the country down to the Bay of Bengal. The alluvial soil is continuously enriched by heavy silt deposited by the rivers during the rainy season.

Bangladesh is in AEZ 3, characterized as warm humid tropics, with a length of growing period > 260 d for most parts of the country. The country enjoys a subtropical monsoon climate. Summer, monsoon, and winter are the most prominent of six distinct seasons. Winter, which is pleasant, extends from November to February, with minimum temperature ranges of 7-13 °C and maximum of 24-31 °C.

The monsoon starts in June and lasts until October. This period accounts for 80% of the total rainfall. Average annual rainfall varies from 1,200 to 2,500 mm. Maximum rainfall is recorded in the coastal areas of Chittagong and northern Sylhet district. Minimum rainfall is observed in the western and northern parts of the country.

Importance of rice

Nearly 70% of the land area of the country has been brought under crop cultivation. More than two-thirds of the land is double- or triple cropped. The harvested rice area is about 120% of the arable land.

Agriculture, the main occupation of the people, employs 55% of the labor force. It contributed 38% to GDP in 1990, two-thirds of which came from crop production. Rice accounts for about 80% of total cropped area and 70% of the value added in crop production. The emphasis of government policy and research has been on food grain production but with low input technology. Consequently there is considerable scope for increased production in both crop and noncrop agricultural activities.

Rice environment

The major rice ecosystems are upland (direct seeded aus), irrigated (mainly boro), rainfed lowland (mainly transplanted aman, 0-50 cm), medium deep stagnant (50-100 cm), deepwater (>100 cm-<180 cm), flooded (>180 cm), tidal saline, and tidal nonsaline.

The rice area is not expanding, but there is a major shift in rice cultivation. The boro area is increasing at the expense of deepwater aman (broadcast aman) and upland aus rice.

Modern varieties (MVs) make up about 90% of boro (irrigated) rice. Transplanted aman is about 40% MVs, aus about 20%. Deepwater rices are exclusively local varieties. Rice is not being replaced by any other crop at this time. The reallocation of land from traditional varieties to MVs is the main source of growth in rice production and yields. The average rice yield of about 2.6 t/ha increased at a rate of 2.6%/yr from 1980 to 1992.

Production constraints

Sustainability is always a problem wherever intensified cropping systems are practiced and crop residues are removed for fuel and feed. Cow dung, a traditional source of fertilizer, is being diverted to meet an acute shortage of fuel in rural areas. Chemical fertilizer use has increased rapidly along with the spread of MVs, from 11 kg NPK/ha in 1970 to 86 kg NPK/ha in 1991.

Drought is a frequent problem, but supplemental irrigation during the monsoon could alleviate it. Subsurface groundwater is available almost everywhere in the country. Irrigation by small-scale tubewells began in the late 1970s when

government control over the procurement and distribution of modern agricultural inputs was abolished. The spread of tubewells has increased more rapidly since the late 1980s when the import of agricultural machinery was liberalized. Nearly 22% of the rice area has irrigation facilities; 80% is irrigated by tubewells and power pumps.

Flooding occurs annually, but causes serious damage only about once in every 10 yr. Normal flooding is simply a part of the ecosystem and helps to maintain soil quality. The flood-prone areas are ideally suited to boro rice.

Soils in coastal areas are affected by salinity. Most soils are low in organic matter (many less than 1.0%) and consequently low in N. Zinc and S deficiencies are common; replacement amounts of P and K are sufficient.

Infrastructure is adequate for rice but inadequate for other agricultural commodities, especially perishables. The prices of both rice and nonrice crops fluctuate seasonally.

Bangladesh is faced with the choice of whether to be fully self-sufficient in food grains or to maintain a slight deficit. If it chooses the latter, then readily available public food aid targeted at the disadvantaged who lack employment and purchasing capacity could easily make up the shortfall. When food grain production approaches self-sufficiency, farm gate prices of rice go down quickly. A policy to routinely move stored grain into market channels and replace it with fresh stocks is needed to stabilize rice prices.

Population is a bigger problem than food production inasmuch as food production is basically keeping pace with population growth. Population density is 878 persons/km^2, one of the highest in the world. The government is seriously addressing the population problem.

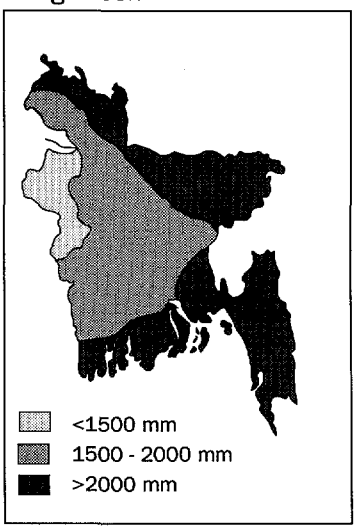
Production opportunities

Since the country has been basically self-sufficient in food grain production for the last 3 yr, the government is now encouraging research on crop diversification and the production of limited amounts of high-quality rice for export.

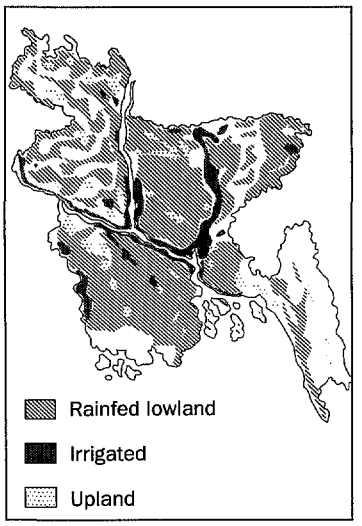
Rice research and development are effective, but could be streamlined with more effective linkages between research and extension. IRRI country projects as well as scientist-to-scientist collaboration are useful in this respect.

Among the measures that would help stabilize rice supply and encourage agricultural growth are the spread of shorter duration MVs to intensify cropping, further development of drainage and irrigation facilities, development of salinity tolerant varieties to raise productivity in coastal areas, and raising rice yields in irrigated areas so that some riceland could be used to grow other high value crops that are currently imported.

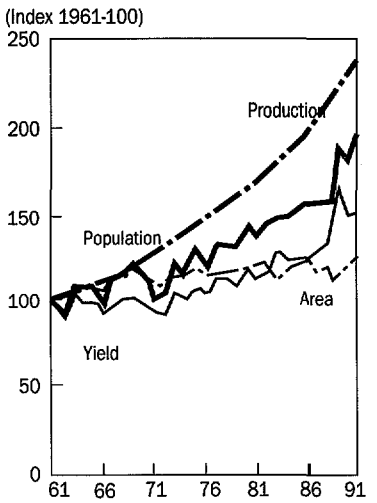
Bangladesh



Mean annual rainfall.



Rice ecosystems. Flood-prone areas are coterminous with irrigated areas.

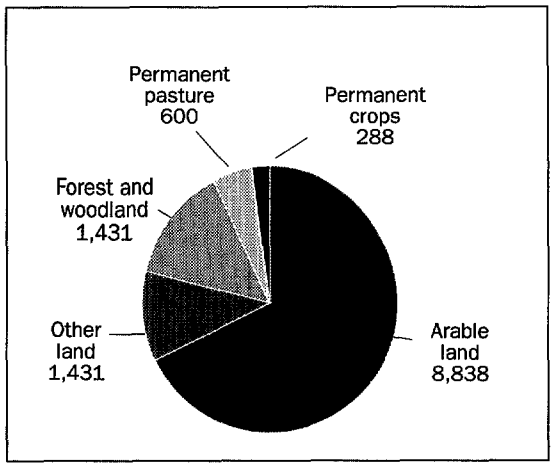


Trends in population, rice production, area, and yield.

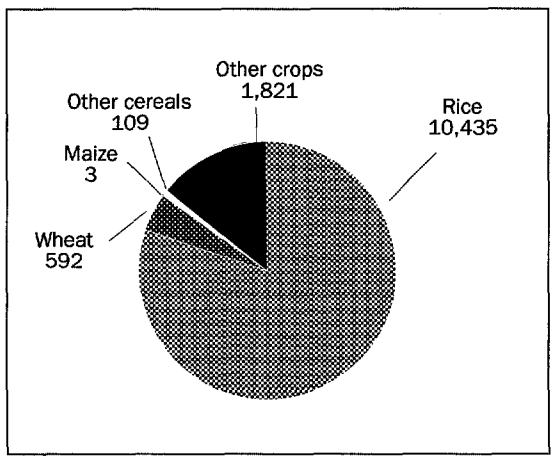
Bangladesh

Land (km²)[a]	
Total area	144000
Population[a]	
Total population (no. × 10³)	114403
Urban population	18304
Rural population	96099
Agricultural population	78366
Agricultural labor force	22949
Population density (no./km²)	878.9
Annual growth rate (%)[b]	2.57
Gross domestic product (US$ × 10⁶)[a]	22880
Agricultural share in GDP (%)[a]	38
Land use (ha × 10³)[a]	
Irrigated agricultural area	2933
Harvested area, modern rice varieties	5322
Harvested area, traditional varieties	5113
Rice production (t × 10³)	
Irrigated rice	10994
Rainfed lowland rice	12855
Upland rice	700
Flood-prone rice	4026
Total rough rice	28575
Yield (t/ha)	
Irrigated rice	4.6
Rainfed lowland rice	2.5
Upland rice	0.8
Flood-prone rice	1.6
Average yield[c]	2.6
Per capita rice consumption (kg)[a]	
Milled	155
Rough rice equivalent	238
Per capita calorie supply (no.)	
Daily total supply	2100
Calories supplied by rice	1580
Rice trade (t × 10²)	
Total imports	100
Total exports	0
Fertilizer use, chemical sources (t × 10³)[a]	
Total consumption (N,P,K)	786
N	609
P	104
K	73

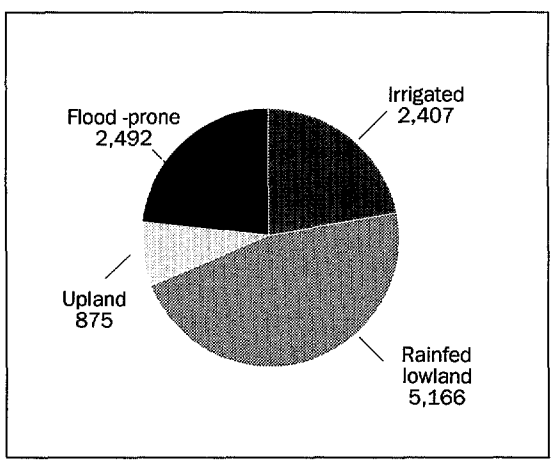
Data are for 1991 unless otherwise indicated. [a]1990. [b]1985-90. [c] Weighted average for all ecosystems.



Land use by physical area (ha × 10³), 1990.

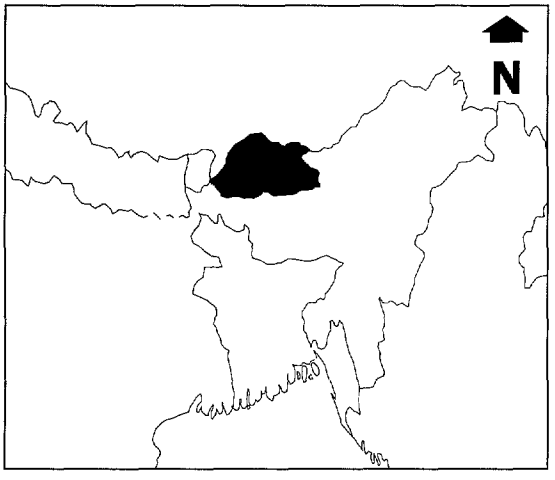


Area (ha × 10³) harvested, temporary crops, 1990.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)



Harvested rice area (ha × 10³) by ecosystem, 1991.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)

Bhutan



Bhutan lies in the eastern Himalayas between 26° and 28° N latitude and between 88° and 92° E longitude. It is a landlocked country bordered on the west, south, and east by the Indian states of Sikkim, West Bengal, Assam, and Arunachal Pradesh and to the north by the Tibet Autonomous Region of China.

Bhutan's terrain is extremely rugged, rising from 160 to more than 7,000 m within 100 km of the southern border. Much of Bhutan remains under natural forest, alpine pastures, or snow cover. Less than 4% of the land area is planted to crops.

Because of its mountainous terrain, most of Bhutan falls into AEZ 8, cool subtropics with summer rainfall. Lower altitude areas of southern Bhutan may be classified as warm humid subtropics with summer rainfall (AEZ 7). Annual rainfall varies from 600 mm in the mid- and high-altitude valleys to more than 5,000 mm on the low-altitude plains.

Importance of rice

Agriculture dominates the economy of Bhutan. Crop and livestock enterprises account for 41% of GDP and about 90% of employment. Bhutan has been historically self-sufficient in food grains, and at one time exported rice to Tibet. Population growth, urbanization, and increased consumption, however, led to food grain deficits beginning in the 1980s and continuing to the present.

Rice is Bhutan's main staple crop. It is grown on about 35,000 ha. In the late 1980s, Bhutan produced about 70% of its domestic requirement. Production has since dropped to less than 60% of self-sufficiency. Projected demand over the next 20 yr clearly indicates the need for rapid and sustainable productivity increases. Self-sufficiency in rice is no longer considered realistic, yet maintenance of a reasonable level of self-sufficiency remains a high priority.

Rice environment

Rice is grown at altitudes ranging from 160 to 2,400 m. There have been no systematic attempts to classify the rice environments. For research and development planning, however, three major rice-growing zones are delineated, based on altitude: high altitude, above 1,800 m; mid altitude, 600-1,800 m; and low altitude, below 600 m. The mid-altitude zone may be further divided into a humid zone (more than 1,200 mm annual rainfall) and a dry zone (less than 1,200 mm).

Irrigation is essential for most of the rice grown in the mid- and high-altitude zones, because of the low rainfall. Irrigation systems are generally gravity-fed from streams that form from melting and precipitation upstream. On the low-altitude southern plains, more than 50% of the rice is grown under rainfed condition. A small area of rice, probably less than 1,000 ha, is grown on hillsides using the slash-and-burn system.

Production constraints

The cool climate of Bhutan presents both a constraint and an opportunity. At higher altitudes, rice varieties must be cold tolerant; in the dry mid altitudes, varieties such as IR64 yield well, but take more than 150 days to mature. The cold night temperatures and high solar radiation in the dry mid-and high-altitude zones favor high yields, where water and nutrient supplies are adequate.

Apart from some alluvial soils in the low-altitude plains, most of Bhutan's soils are described as sedimentary, having been formed in situ on colluvial material. Most rice soils are loams or sandy loams. Limited analyses suggest that soils are generally low in N, sometines deficient in P, and frequently deficient in K (especially in southern Bhutan). The high rice yields that have been recorded for the high- and mid-altitude zones, with the application of farmyard manure and NPK, indicate that these soils are relatively free of serious micronutrient deficiencies or toxicities. Zinc, however, may be a limiting nutrient in southern Bhutan.

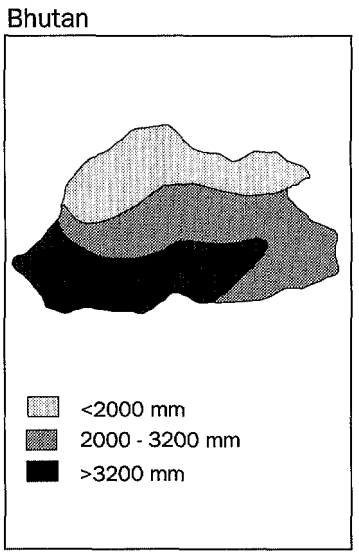
Insect pests and diseases are not considered to cause significant yield loss in the high- and mid-altitude zones. Insect pests are most serious in the humid low-altitude zone. Weeds are a constraint to rice production throughout Bhutan. In the high and mid altitudes, the most serious weed is *Potamogeton distinctus*. Weeds of rice in the low-altitude zone have not been surveyed systematically.

Cropping patterns are constrained by temperature, rainfall, irrigation water availability, food preferences, and market opportunities. In the high-altitude zone, rice - wheat is the dominant pattern; rice - potato, rice-buckwheat, and rice - barley are grown to a lesser extent. In the mid-altitude zone, the rice - wheat pattern is again dominant; rice - mustard, rice - vegetables, rice - buckwheat, and rice - barley are also found. A considerable part of the high and mid altitudes are not planted to winter crops because of the need to reserve land (15-30%) for rice seedbeds established in February, March, or April. In the low-altitude plains of southern Bhutan, the main cropping pattern is rice - fallow, with some farmers growing a maize crop before rice. In areas where irrigation is available, farmers grow rice followed by wheat. In a few limited areas, two crops of rice are grown.

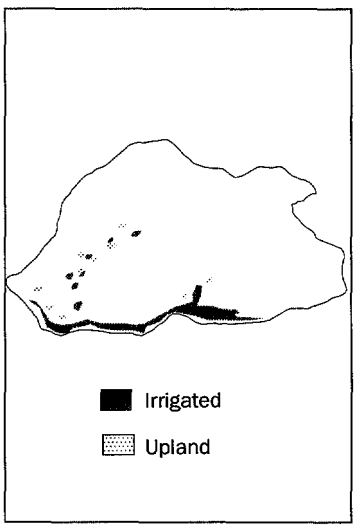
Production opportunities

Before 1982, virtually no agricultural research was undertaken in Bhutan. A Bhutan-IRRI project to develop national rice research capabilities began in 1984 with funding from the International Development Research Centre of Canada. Bhutanese scientists and technicians were trained at IRRI and in-country to provide the basis of a national research system that has since made considerable progress in demonstrating the potential for rice yield increases through varietal improvement, improved soil fertility, and better weed control. Greatest success has been achieved in the mid altitudes. Modern varieties (mainly IR64) have spread to over 30% of one important rice-growing area, the Wangdiphodrang-Punakha Valley.

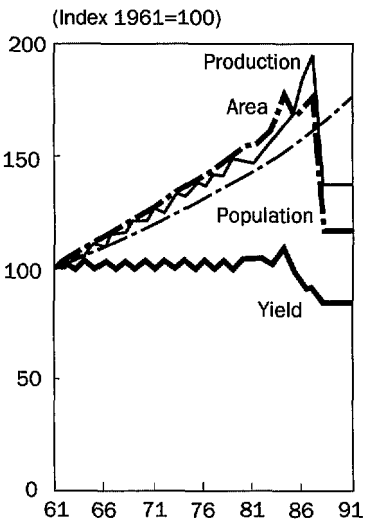
In phase 2, Bhutan's Ministry of Agriculture reorganized research into a Renewable Natural Resources (RNR) research sector. The RNR program aims to integrate agriculture, livestock, and forestry research to reflect the high degree to which these enterprises are integrated at the farm level.



Mean annual rainfall.



Rice ecosystems. Flood-prone areas are coterminous with irrigated areas.

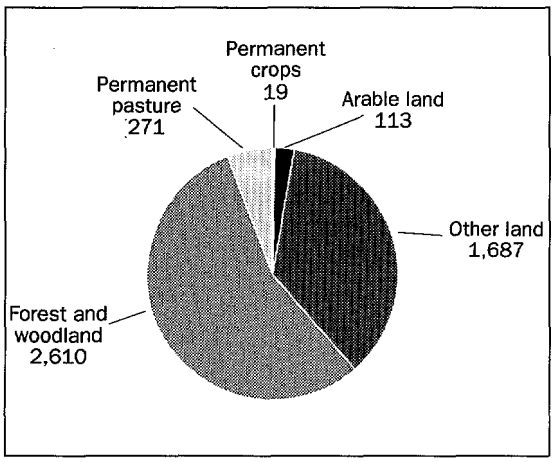


Trends in population, rice production, area, and yield.

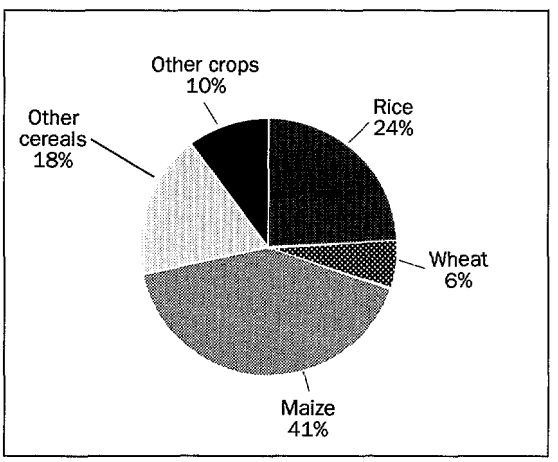
Bhutan

Land (km^2)[a]	
Total area	47000
Population[a]	
Total population (no. × 10^3)	1434
Urban population	73
Rural population	1362
Agricultural population	1302
Agricultural labor force	575
Population density (no./km^2)	30.5
Annual growth rate (%)[b]	2.18
Gross domestic product (US$ × 10^6)[a]	280
Agricultural share in GDP (%)[a]	54
Land use (ha × 10^3)	
Total irrigated agricultural area[a]	34
Area planted to modern rice varieties[a]	26
Area of traditional varieties[a]	0
Rice production (t × 10^3)	
Irrigated area	–
Rainfed lowland area	–
Upland area	–
Flood-prone area	–
Total rough rice	43
Yield (t/ha)	
Irrigated area	–
Rainfed lowland area	–
Upland area	–
Flood-prone area	–
Average yield[c]	1.7
Per capita rice consumption (kg)[a]	
Milled	–
Rough rice equivalent	–
Per capita rice supply (no.)	
Total calorie supply	–
Calories supplied by rice	–
Rice trade (t × 10^2)[a]	
Total imports	200
Total exports	0
Fertilizer use, chemical sources (t × 10^3)[a]	
Total consumption (N, P, K)	0.1
N	0.1
P	0
K	0

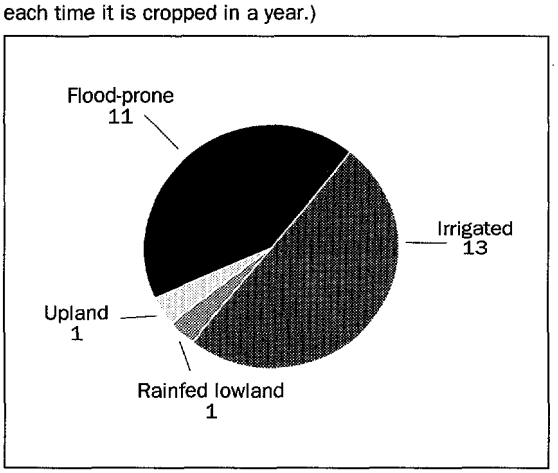
Data are for 1991 unless otherwise indicated. [a]1990. [b]1985-90. – = data not available. [c]Weighted average for all ecosystems.



Land use by physical area (ha × 10^3), 1990.



Area harvested, temporary crops, 1990.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)



Harvested rice area (ha × 10^3) by ecosystem, 1991.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)

Brazil

Brazil extends from 5° N latitude at its frontier with Guyana and Venezuela to as far south as 33° S latitude in the state of Rio Grande do Sul. The longitude limits are from 30° to 74° W.

It lies within several AEZs: AEZ 1, warm arid and semiarid tropics; AEZ 2, warm subhumid tropics, AEZ 3, warm humid tropics; AEZ 4, cool tropics; and AEZ 8, cool subtropics with summer rainfall. The climate varies from tropical to subtropical, the latter mainly in the southern coast.

Agriculture continues to be the main single user of labor, with 24% of the work force, although the percentage has declined from 60% in 1960. This sector contributed 10% to GDP in 1990, and was second to manufacturing with 26.2%. Agriculture represented 40% of Brazilian exports during 1988 and 1989. Brazil is the world's largest coffee producer, averaging 3 million t during the last 3 yr and contributing 4% to the total export earnings in 1990.

Other important agricultural export commodities include sugar, soybean, oranges, and cocoa. For domestic consumption, rice is the second largest commodity produced in the country, after cassava.

Importance of rice

Rice per capita consumption in Brazil was 43 kg in 1990, whereas cassava consumption was about 65 kg. Rice supplied 16% of the calories and 13% of the protein in the diet.

During the 1980s, rice production was stagnant, area decreased, and yields increased. Increased interest in soybean production in the central part of the country partly explains the reduction in upland rice area.

This stagnation in local rice supply resulted in the country going from being net exporter during the 1970s to importing an average of 470,000 t/year during 1981-1990. Average yield increases resulted from the larger proportion of irrigated rice in the overall rice crop and higher yields in that environment.

Rice environment

Environments where rice is grown in Brazil are classified as lowlands with controlled irrigation (irrigated), lowlands without irrigation control (rainfed lowland), and uplands without irrigation (upland). A variant of the upland system is rice under sprinkler irrigation, as rice has become part of the cropping sequence under central pivot systems.

Area estimates for recent years were 787,000 ha for irrigated rice, 246,000 ha for rainfed lowland, and 3.1 million ha for upland. Modern varieties have spread to 90% of the irrigated areas. Irrigated rice is concentrated in the southern states of Rio Grande do Sul and Santa Catarina. In the former state, with about 700,000 ha of irrigated rice, about 80% of the area is planted in rotation with pastures in a system of 2 yr of rice followed by 3 yr of pastures. Only one crop per year is established using dry seed in dry soil (55% broadcast, 30% in rows, and the rest following some system of minimum tillage). Minimum tillage allows farmers to increase machinery use efficiency, and control undesirable weeds.

Most irrigation water (75%) is pumped onto the field. In Santa Catarina, irrigated rice areas are planted once a year using pregerminated seed in puddled soil. Modern technologies such as fertilizer, chemical weed control, and machinery are used.

Production constraints

Most areas planted continuously with rice are infested with weedy rices (red rice) to some degree, significantly affecting yields of ricelands over time. Other production problems are yield potential, occurrence of low temperatures during flowering, and rice water weevil.

Rainfed lowlands are predominant in Minas Gerais (150,000 ha), Rio de Janeiro (32,000 ha), and Espiritu Santo (29,000 ha) and are found scattered

in the northeastern states of Bahia and Sergipe. About 10, 300 ha of rice is grown in the swamp lands in the Amazon region of Pará and Maranháo. Upland rice is grown mainly in the central and northeastern parts of the country and is also rotated with pastures and crops such as soybean. As rice is often used as a pioneer crop, very little inputs are used, with the exception of machinery for land preparation, planting and harvesting in most of the central region. In this region, the trend is to plant rice in areas with minimum risk of drought, and to incorporate rice in a system for pasture establishment and renewal.

In the northeastern state of Maranhao (1 million ha), rice farms are relatively small (1-4 ha), and intercropping is practiced in half of the area. Intercropping is done with maize and cassava, or maize and beans. Production constraints for upland rice include low soil pH, drought, and blast disease. Tall improved varieties developed by the Centro Nacional de Pesquisa de Arroz e Feijao (CNPAF) and the Instituto Agronomico de Campinas occupy most of the upland areas.

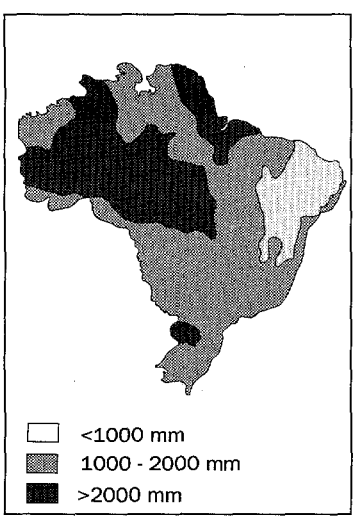
Where moisture is more favorable for upland rice, or where the central pivot irrigation system is used, available cultivars lodge and have low yield potential and undesirable grain quality.

Production opportunities

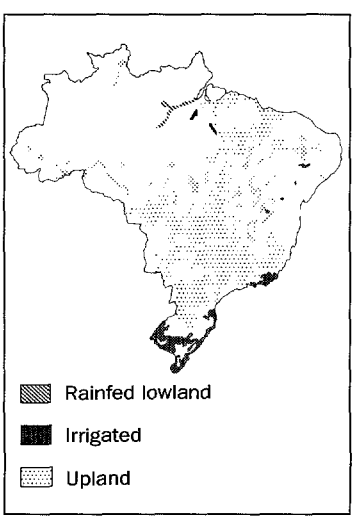
Rice research is organized at both the federal and state levels. Research at the federal level is coordinated by the Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA). CNPAF, located in the central region, conducts research on all aspects of upland rice and develops technology for the irrigated rice areas of central and northern Brazil. The rice program of the Centro de Pesquisa Agropecuaria de Terras Baixas de Clima Temperado, also part of the EMBRAPA system, conducts research on all aspects of irrigated rice for the southern states of Rio Grande do Sul and Santa Catarina. At the state level, rice research is organized under state agricultural research organizations.

All rice research resources are linked through an EMBRAPA-sponsored national rice network. During the last few years, the private sector has become interested in rice research, both as a donor and as a direct participant, opening up a new source of research resources.

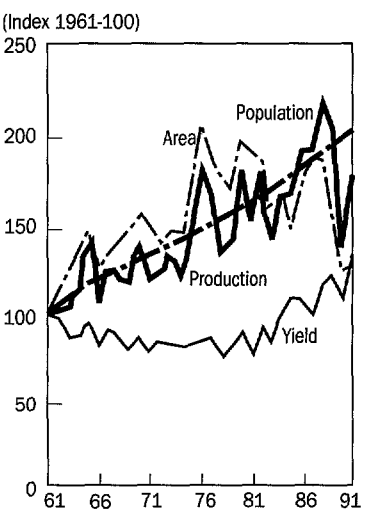
Brazil



Mean annual rainfall.



Rice ecosystems.

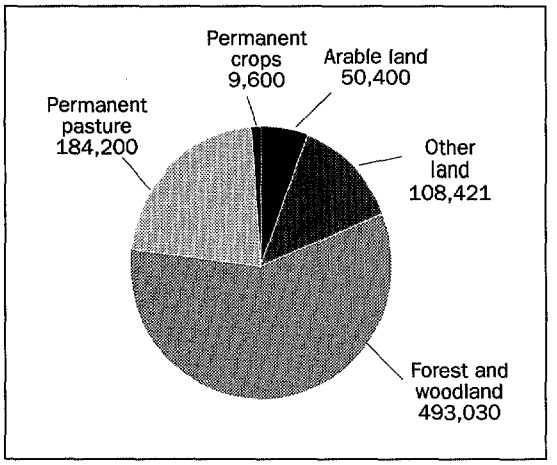


Trends in population, rice production, area, and yield.

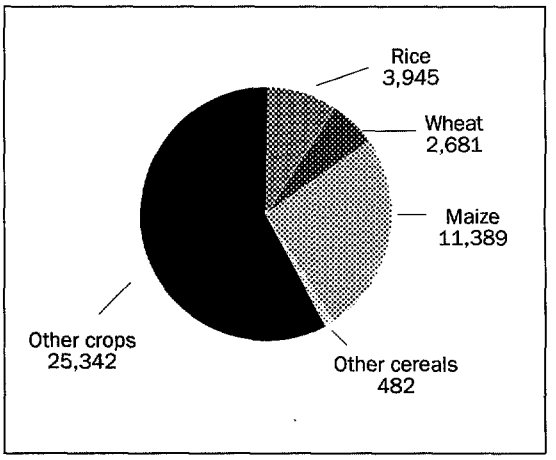
Brazil

Land (km^2)[a]	
Total area	8511970
Population[a]	
Total population (no. × 10^3)	150195
Urban population	112646
Rural population	37549
Agricultural population	36497
Agricultural labor force	13352
Population density (no./km^2)	17.76
Annual growth rate (%)[b]	2.05
Gross domestic product (US$ × 10^6)[a]	414060
Agricultural share in GDP (%)[a]	10
Land use (ha × 10^3)[a]	
Irrigated agricultural area	2700
Harvested area, modern rice varieties	907
Harvested area, traditional varieties	3038
Rice production (t × 10^3)	
Irrigated rice	3935
Rainfed lowland rice	663
Upland rice	4885
Flood-prone rice	20
Total rough rice	9503
Yield (t/ha)	
Irrigated area	5.0
Rainfed lowland area	2.7
Upland area	1.6
Flood-prone area	2.0
Average yield[c]	2.3
Per capita rice consumption (kg)[a]	
Milled	43
Rough rice equivalent	66
Per capita calorie supply (no.)	
Total calorie supply	2723
Calories supplied by rice	448
Rice trade (t × 10^2)	
Total imports	7284
Total exports	12
Fertilizer use, chemical sources (t × 10^3)[a]	
Total consumption (N,P,K)	2283
N	779
P	522
K	982

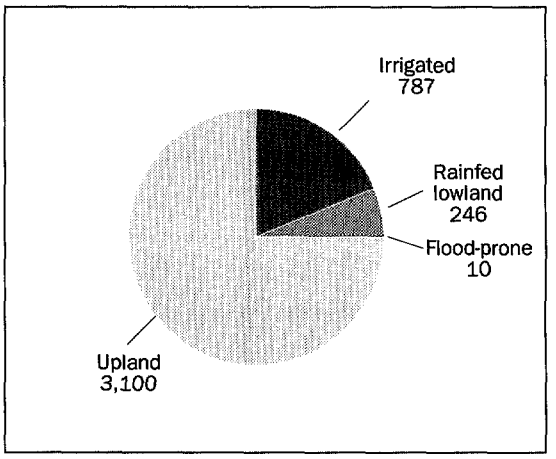
Data are for 1991 unless otherwise indicated. [a]1990. [b]1985-90. [c]Weighted average for all ecosystems.



Land use by physical area (ha × 10^3), 1990.

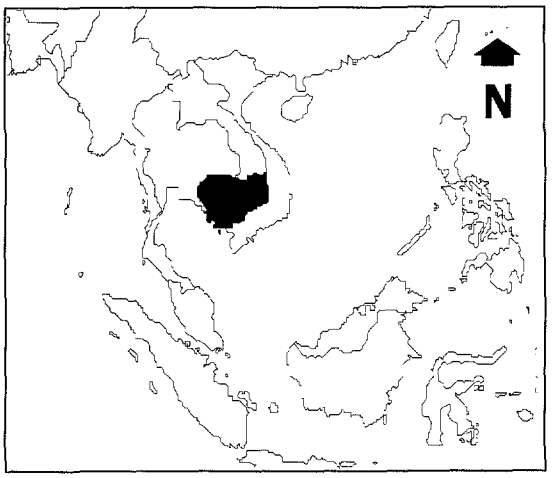


Area (ha × 10^3) harvested, temporary crops, 1990.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)



Harvested rice area (ha × 10^3) by ecosystem, 1991.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)

Cambodia



Cambodia lies between 10 and 15° N latitude and between 102 and 108° E longitude. The country is bordered by Thailand, Laos, Vietnam, and the Gulf of Thailand.

It is in AEZ 3, characterized as warm humid tropics. The climate is tropical monsoonal characterized by a short rainy season, prolonged dry season, and irregular occurrence of rainfall both from year to year and within years. Most rain falls between May and mid-November. Often a 10- to 15-day dry spell (called the short dry season) occurs in July or August. Total average annual rainfall varies greatly from province to province. While the annual rainfall in Phnom Penh and Battambang is 1,375 mm and 1,387 mm, respectively, Kampong Speu receives only 1,204 mm, and Kampong Som has 3,831 mm. Practically no rain falls during the long dry season between mid-November and May. Ambient temperature increases from December to April or May.

The population is estimated to be about 9 million. Eighty percent of the population is rural, 10% reside in Phnom Penh, and the remaining 10% occupy the provincial centers.

Primary produce is a major contributor to Cambodia's foreign trade. Agricultural exports include rubber, timber, fish, maize, soybean, sesame, and tobacco.

Importance of rice

Rice is by far the most important staple food of Cambodia. Rice occupies 90% of the total agricultural area and is the major agricultural item in terms of area, volume, and income. About 2.5 million ha were planted to rice in the 1960s. Currently, Cambodia cultivates approximately 1.8 million ha. There is considerable potential for increasing production through an expanded area. Food production is not keeping up with the population increase, especially with the recent repatriation of 350,000 refugees. The country imports approximately 20,000 t of rice annually.

Rice environment

The rice ecosystems in Cambodia are divided into four major types: 1) rainfed lowland (including areas with supplementary irrigation), 2) rainfed upland, 3) deepwater/floating, and 4) dry season irrigated.

More than 90% of the wet season rice area is rainfed lowland. Because of the large area (about 0.9 million ha) and widespread distribution of rainfed lowland, there is considerable variation in soil types and rainfall.

Upland rice occupies about 36,000 ha, which is about 2% of the total rice area. Rainfall throughout the area varies considerably, but sloping land (some of which is mountainous) is the common feature of the upland ecosystem.

Deepwater/floating rice is that grown in water depths of 0.5 to 4 m. The deepwater/floating ecosystem makes up about 42% of Cambodian ricelands.

Most of Cambodia's rice grows on extremely flat, poorly drained areas of infertile soil surrounding the Tonle Sap Lake basin and the upper reaches of the Mekong Delta.

Dry season irrigated rice is planted on about 144,000 ha or approximately 8% of the rice area. There are three major types of dry season rice culture: 1) a fully irrigated second crop at the end of the wet season, 2) a supplementary irrigated rice in deep flooded areas, and 3) a dry season rice crop in receding water around lakes and rivers.

Production constraints

The problems related to rice production are lack of infrastructure and access to inputs, erratic rainfall, drought, floods, and poor soils. The soils are similar in their sandiness, low cation exchange capacity, low pH, and low level of organic matter.

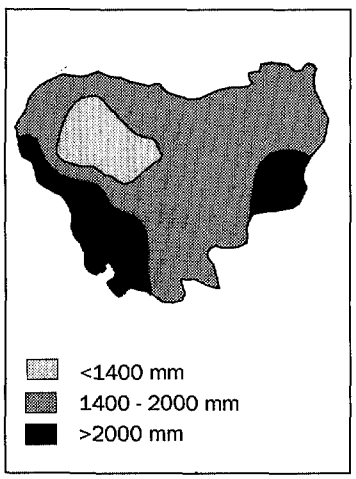
Production opportunities

Government research and development efforts are being supported by IRRI and other organizations. An excellent rice research program has been developed by the Cambodia-IRRI Rice Project supported by the Australian International Development Assistance Bureau (AIDAB).

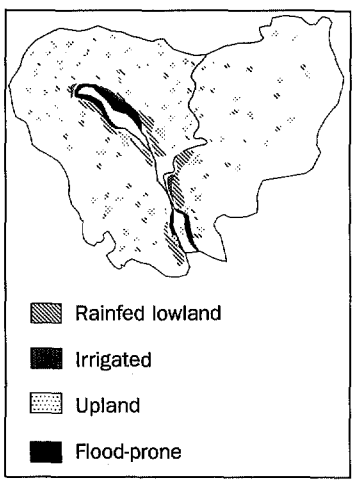
The project's major effort is to increase productivity of current riceland through the development of more productive varieties, improved seed, more efficient use of indigenous and imported fertilizer, better cropping systems, and improved water and pest control.

Future rice production in Cambodia could increase to a possible export level with the expansion of the rice area, increased use of fertilizer, and the increased adoption of high-yielding varieties.

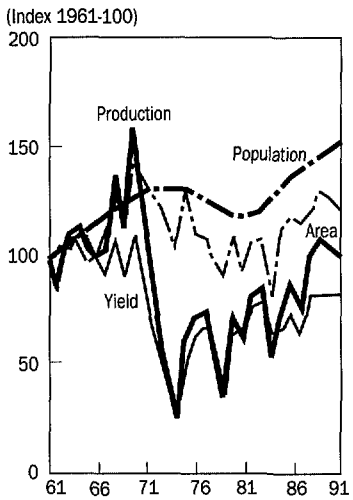
Cambodia



Mean annual rainfall.



Rice ecosystems.

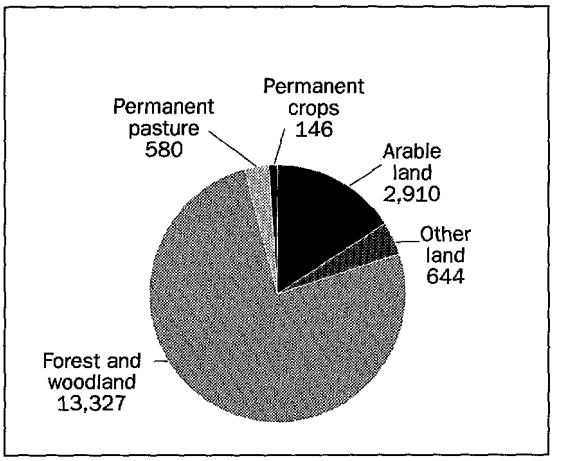


Trends in population, rice production, area, and yield.

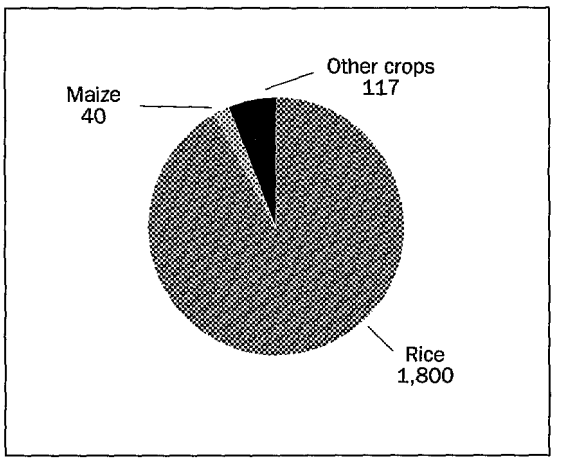
Cambodia

Land (km²)[a]	
Total area	181040
Population[a]	
Total population (no. × 10³)	8263
Urban population	992
Rural population	7271
Agricultural population	5784
Agricultural labor force	2635
Population density (no./km²)	46.81
Annual growth rate (%)[b]	2.52
Gross domestic product (US$ × 10⁶)[a]	
Agricultural share in GDP (%)[a]	
Land use (ha × 10³)[a]	
Irrigated agricultural area	92
Harvested area, modern rice varieties	198
Harvested area, traditional varieties	1602
Rice production (t × 10³)	
Irrigated rice	360
Rainfed lowland rice	1328
Upland rice	32
Flood-prone rice	680
Total rough rice	2400
Yield (t/ha)	
Irrigated rice	2.5
Rainfed lowland rice	1.5
Upland rice	0.9
Flood-prone rice	0.9
Average Yield[c]	1.3
Per capita rice consumption (kg)[a]	
Milled	167
Rough rice equivalent	257
Per capita calorie supply (no.)	
Daily total supply	2114
Calories supplied by rice	1696
Rice trade (t × 10²)	
Total imports	200
Total exports	0
Fertilizer use, chemical sources (t × 10³)[a]	
Total consumption (N,P,K)	5
N	2
P	3
K	0

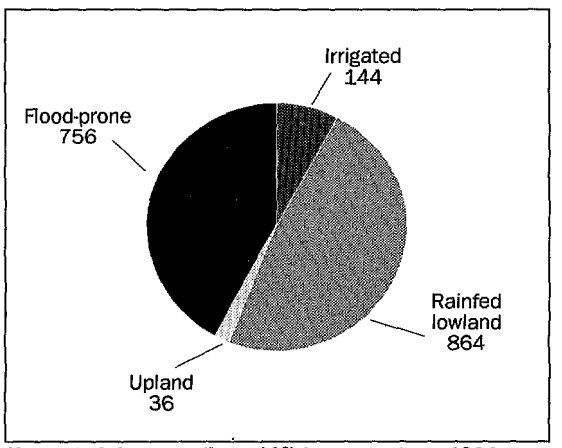
Data are for 1991 unless otherwise indicated.[a]1990. [b]1985-90. [c] Weighted average for all ecosystems.



Land use by physical area (ha × 10³), 1990.

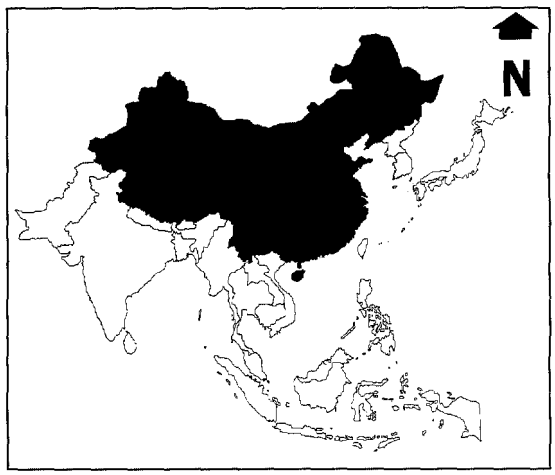


Area (ha × 10³) harvested, temporary crops, 1990.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)



Harvested rice area (ha × 10³) by ecosystem, 1991.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)

China



China is situated between 18° and 54° N latitude and 73° and 135° E longitude. Marked by topographical variety and complexity, China's landmass is made up of mountains (33%), plateaus (26%), basins (19%), plains (12%), and hills (10%).

China lies in four AEZs, all of which are subtropical and include some temperate areas. They are: AEZ 5, warm arid and semiarid subtropics with summer rainfall; AEZ 6, warm subhumid subtropics with summer rainfall; AEZ 7, warm\cool humid subtropics with summer rainfall; and AEZ 8, cool subtropics with summer rainfall. Rice is produced primarily in AEZs 6 and 7.

China's climatic features include a pronounced monsoon climate with a hot summer and a cool winter, marked seasonal variations in precipitation, and a distinctive continental climate with large annual temperature fluctuations. The climate types are so varied and complex that high rainfall, cold waves, and typhoons are important climatic phenomena. China can be divided from the coastal areas to the northwest interior into four regions according to moisture regime. They are 1) the humid region south of the Qinling Mountains and Huaihe River, comprising 32% of total land area; 2) the subhumid region including most of northeast and Central China, 15%; 3) the semiarid region, 22%; and 4) the arid region, 31%.

China is the most populous country in the world. The 1990 population of the 30 provinces, autonomous regions, and centrally administered municipalities on the mainland was nearly 1.14 billion. China's agricultural population in 1990 accounted for 66% of total population. Three-fourths are concentrated in the northern, northeastern, eastern, and south central areas, which make up only 44% of the nation's land area. The remaining one-fourth of the population are dispersed in the southwestern and northwestern parts, which account for 56% of the nation's total land. This gradually decreasing population density to the west reflects the nation's uneven regional natural features as well as socioeconomic development.

Importance of rice

Agriculture contributed 27% to China's 1990 GDP, which totaled $364.9 billion. Rice is the staple food of China. Chinese rice production accounts for about 35% of the world's total. Of China's total production, which has ranged from about 171 million to 191 million t annually for the past decade, less than 1% enters world trade. Because the domestic rice requirement will continue to rise over the long term, China concentrates on increased rice production to meet the growing needs of its population. Rice accounts for some 40% of total grain production, which was 452 million t in 1990.

The annual population growth rate averaged 1.56% between 1972 and 1990, while rice production rose an average of 2.8% annually over the same period.

Rice environment

The distribution of rice in China tends to be regional and discontinuous because of topography and weather. In southeast China, high temperature and adequate rainfall make an ideal environment for rice during a long growth period. The region south of the Qinling Mountains and the Huaihe River encompasses nearly 30 million ha, over 90% of the total rice area.

In northeastern China, low temperature, short growth period, little rainfall, and lack of water limit the rice area. South of the Huang Huaihai Plain is a larger rice area, but volatile rainfall between spring and summer often limits the area that can be planted. The Behai Bay region, the lower reaches of the Liaohe River, and the Songhua River basin are other large rice areas in the east high latitude region. There are some scattered rice areas in arid and semiarid regions of northwestern China.

Production constraints

A shrinking land base for agriculture is the primary production constraint. On the average, China's population is increasing by 17 million/yr while cultivated land is shrinking by some 300,000 ha/yr. In the last 40 yr, China's cultivated land per capita has shrunk from 0.18 ha to 0.085 ha, a decrease of 53%. Relatively serious water loss, soil erosion, expanding desertification and salinization, and decreasing organic matter pose grave difficulties for continued agricultural development.

At present there is not much land left for reclamation. China's increased demand for grain has to be met mainly by raising yields. There is great potential for raising yields, especially on some 26% of total rice area, which has medium-to-low productivity.

Droughts, floods, waterlogging, severe cold snaps, and insects affect 20-50 million ha of crops throughout the country. Salinity and toxicity affect some newer ricefields, but nutrient deficiency is the more general constraint. Water shortages often reduce the irrigated area and frequency of irrigation, resulting in rice production losses as high as 1-2 million t in some years.

Production opportunities

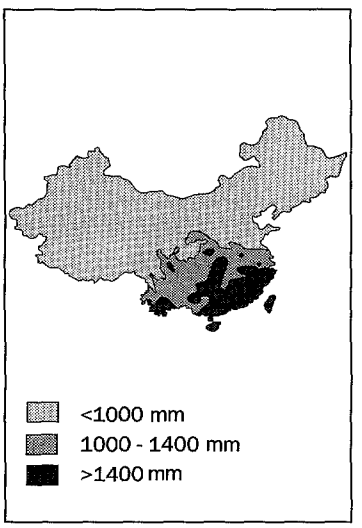
The main task of Chinese rice scientists in the near term is to ensure the sustainability of gains achieved thus far. Over the longer term, increased production is expected through varietal improvement, improved soil fertility and fertilizer use efficiency, integrated management of low- to medium-yielding ricefields, insect pest management and diseases and weed control, mechanization and improved postharvest processing, and improved irrigation and water conservation.

Since 1980, China and IRRI have cooperated on a number of research projects of mutual concern such as the exchange of rice germplasm to strengthen breeding programs; hybrid rice research to exploit heterosis in rice; and shuttle breeding to speed the development of rice varieties with high yield potential, good quality, multiple resistance to insects and diseases, and wide adaptability.

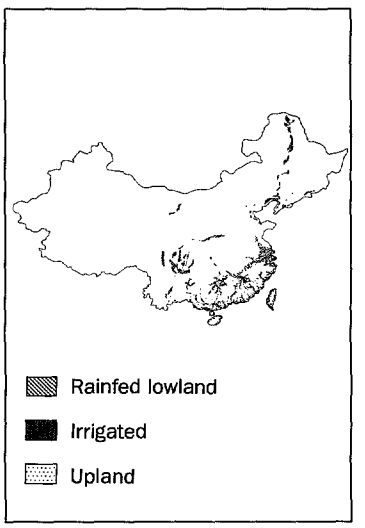
Other areas of cooperation include bacterial leaf blight research, tissue culture, integrated varietal resistance combined with biological methods to control insects and diseases, the chemical control and cytogenetics of brown planthopper and whitebacked planthopper, monitoring susceptibility of rice pests to insecticides, and economics of agricultural mechanization.

China expects to open a new phase of rice production through expanding the area planted to hybrid rice, and applying biotechnology techniques to varietal improvement.

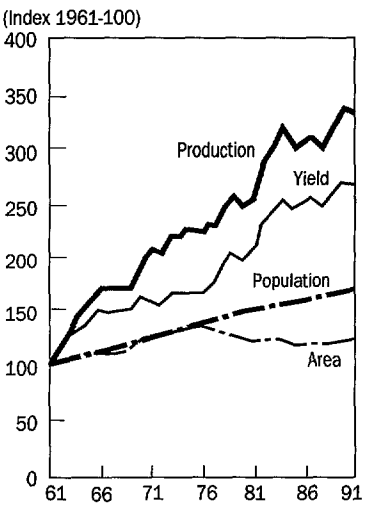
China



Mean annual rainfall.



Rice ecosystems.

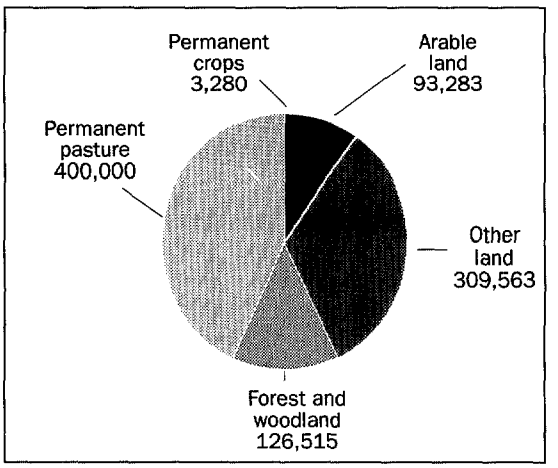


Trends in population, rice production, area, and yield.

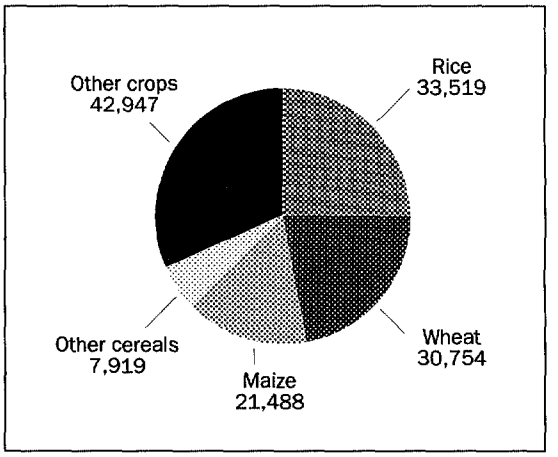
China

Land (km^2)[a]	
Total area	959696
Population[a]	
Total population (no. × 10^3)	1138000
Urban population	637280
Rural population	500720
Agricultural population	753976
Agricultural labor force	449593
Population density (no./km^2)	122.02
Annual growth rate (%)[b]	1.43
Gross domestic product (US$ × 10^6)[a]	364900
Agricultural share in GDP (%)[a]	27
Land use (ha × 10^3)[a]	
Irrigated agricultural area	47837
Harvested area, modern rice varieties	33519
Harvested area, hybrid rice	15928
Harvested area, traditional varieties	0
Rice production (t × 10^3)	
Irrigated rice	180830
Rainfed lowland rice	4965
Upland rice	1655
Flood-prone rice	0
Total rough rice	187450
Yield (t/ha)	
Irrigated rice	5.9
Rainfed lowland rice	3.0
Upland rice	2.5
Flood-prone rice	0.0
Average yield[c]	5.7
Per capita rice consumption (kg)[a]	
Milled	94
Rough rice equivalent	145
Per capita calorie supply (no.)	
Total supply	2703
Calories supplied by rice	977
Rice trade (t × 10^2)	
Total imports	1455
Total exports	8175
Fertilizer use, chemical sources (t × 10^3)[a]	
Total consumption (N,P,K)	23488
N	19450
P	2587
K	1451

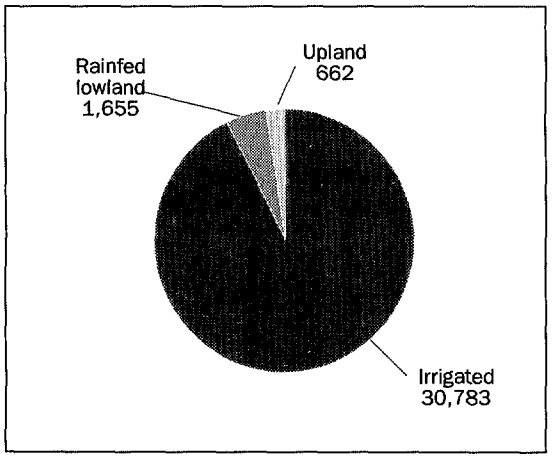
Data are for 1991 unless otherwise indicated. [a]1990. [b]1985-90. [c]Weighted average for all ecosystems. Data include Taiwan.



Land use by physical area (ha × 10^3), 1990.

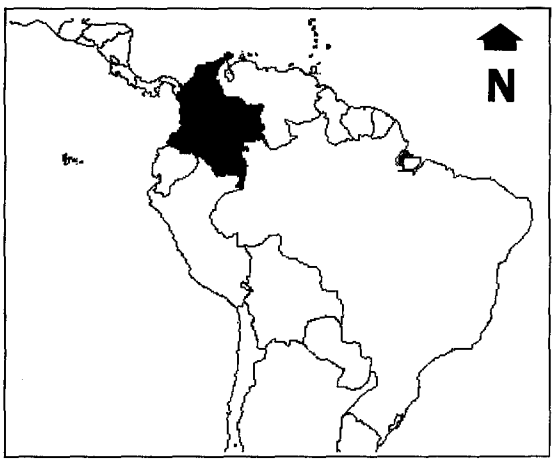


Area (ha × 10^3) harvested, temporary crops, 1990.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)



Harvested rice area (ha × 10^3) by ecosystem, 1991.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)

Colombia



Colombia has coasts on both the Pacific Ocean and the Caribbean Sea. It is located between 4° S and 12° N latitude and 68° and 78° W longitude. Colombia spans four AEZs: AEZ 1, warm arid and semiarid tropics; AEZ 2, warm subhumid tropics; AEZ 3, warm humid tropics; and AEZ 4, cool tropics. The climate in the coastal lands is tropical with high rainfall; the Pacific coast represents one of the most humid regions of the world. The highlands, where major cities are located, show a rather temperate climate.

Population in 1990 was estimated at 31 million, 69% of whom live in urban areas. Employment follows the same trend as population distribution, with 70% of the labor force being urban. Major sources of employment are agriculture, forestry or fishing (30%), and manufacturing (13%).

Importance of rice

The contribution of agriculture to the gross domestic product was 21.5% in 1989, followed by industry, which contributed 21.4%. The major crop in Colombia is coffee; it occupies an area of slightly over 1 million ha and contributed over 20% to the country's export earnings in 1990. Among the food crops, rice ranks second in volume with 2.1 million t produced in 1989; potato production for the same year was 2.9 million t. In area planted, rice is second to maize among the food crops. The value of rice production is the highest of annual food crops in Colombia. As rice is grown mainly for human consumption, it is the most important source of calories for the Colombian population. It provides 13.3% of the calories and 12.7% of the protein to the diet. In summary, rice represents 16% of the area planted, 30% of the area in cereals, 8.5% of the value of agricultural production, and 49% of the value of cereals.

Rice production increased from 689,000 t in 1969 to 2.1 million t in 1989. Area harvested in 1991 were 435,000 ha with a yield of 4.0 t/ha. During the 1980s, production, area, and yield were stagnant, while per capita consumption decreased slightly. Depending on the relative profitability of soybean, cotton, and sorghum, there have been shifts in area from these crops to rice and vice versa. Modern rice varieties were first released in 1968, spreading rapidly throughout the irrigated areas to occupy 99% of the area in 1974. In the first semester of 1988, 96% of the 300,000 ha included in the rice census of that year were planted to improved varieties.

Rice environment

Practically all rice is grown under favorable moisture regimes. Irrigated rice with favorable temperature represents two-thirds of the area and 84% of production. For this ecosystem, most of the crop is established by broadcasting dry seed in dry soil, as only 7% of the area is puddled.

In the central zone of the country, representing nearly 25% of the national rice area, light textured soils and relatively higher slopes make it necessary to continuously apply irrigation water to the ricefields. The rainfed areas can be classified as rainfed shallow, favorable (10% of the total area), and favorable upland with long growing season (23%).

The level of mechanization is used to classify the rainfed rice-growing environments into two classes: 1) mechanized upland, and 2) manual upland. The former includes farms with an average size of 25 ha where modern varieties and purchased inputs are used. The latter represents farms of 1.5 ha with limited use of modern inputs. This group represents 5% of the area and 2% of production. Regardless of the ecosystem, mechanization level, or farm size, Colombian rice farmers are market oriented.

Production constraints

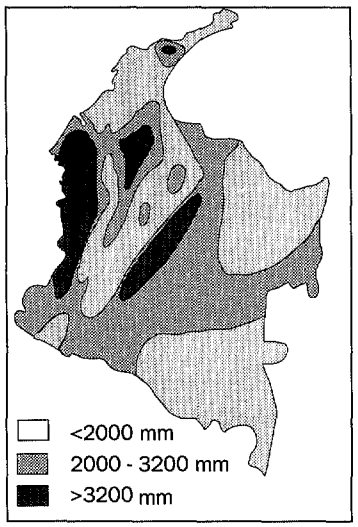
Major problems for the irrigated areas are yield potential (as current genetic yield potential is similar to commercial yields on the best farms), water management, weed control, and marketing. Disease severity, mainly blast, is high in the rainfed ecosystem. Red rice problems are emerging as seed quality has deteriorated, probably as a result of price increases. The opening of the economies is putting pressure on farmers to reduce costs, as good quality imported rice might enter the local market at competitive prices in the future. International competition will reduce the profitability of rice cultivation which may limit expansion of rice area.

Production opportunites

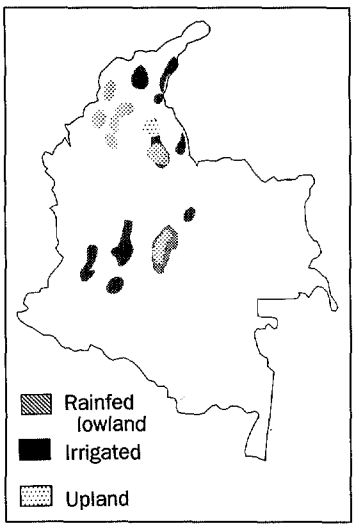
Rice research has traditionally been done jointly by the Instituto Colombiano Agropecuario (ICA), a government funded autonomous institution, and the Colombian Federation of Rice Farmers (FEDEARROZ) with the support of the Centro Internacional de Agricultura Tropical (CIAT) and IRRI. The wave of privatization affecting the Colombian economy has changed ICA's structure, turning it into a research corporation with the Colombian Government as its major shareholder.

FEDEARROZ is also increasing its direct involvement in rice research and is trying to assess the potential of hybrid rice in the country, a line of research pursued by neither ICA nor CIAT. The participation of the private sector in rice research is expected to increase in the near future, both as ICA shareholders as well as in the form of direct investments. These developments will initially increase the pressure on research to come up with new advances, leading to the hope that research resources will also increase. Although there is plenty of land to increase rice area, lack of infrastructure will delay further investments in the expansion of the rice frontier. There is also the possibility that marginal areas might not receive adequate research attention.

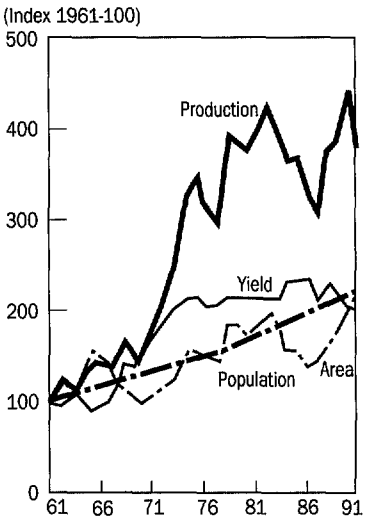
Colombia



Mean annual rainfall.



Rice ecosystems.

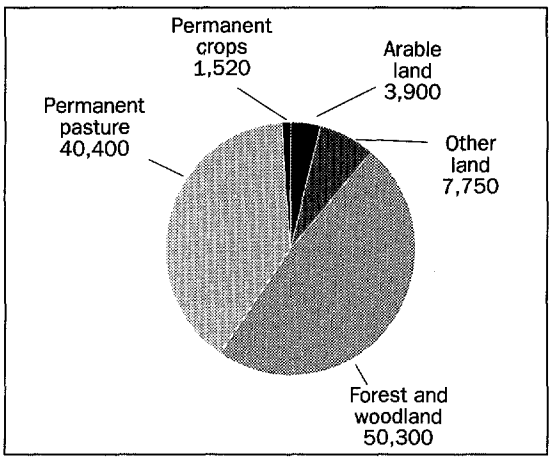


Trends in population, rice production, area, and yield.

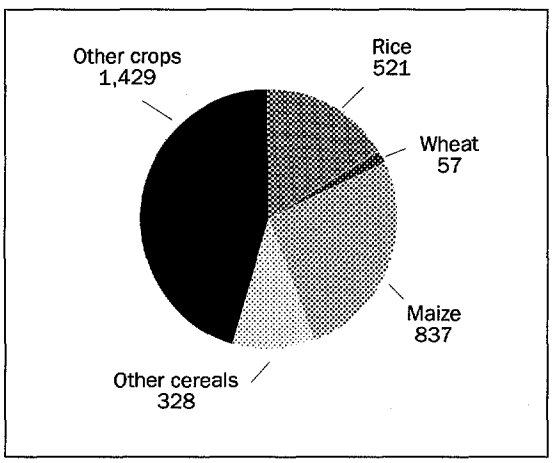
Colombia

Land (km²)[a]	
Total area	1138910
Population[a]	
Total population (no. × 10³)	31105
Urban population	21774
Rural population	9332
Agricultural population	8585
Agricultural labor force	2722
Population density (no./km²)	29.95
Annual growth rate (%)[b]	1.81
Gross domestic product (US$ × 10⁶)[a]	41120
Agricultural share in GDP (%)[a]	17
Land use (ha × 10³)[a]	
Irrigated agricultural area	520
Harvested area, modern rice varieties	453
Harvested area, traditional varieties	68
Rice production (t × 10³)	
Irrigated rice	1469
Rainfed lowland rice	110
Upland rice	160
Flood-prone rice	0
Total rough rice	1739
Yield (t/ha)	
Irrigated rice	5.0
Rainfed lowland rice	2.5
Upland rice	1.6
Flood-prone rice	0.0
Average yield[c]	4.0
Per capita rice consumption (kg)[a]	
Milled	32
Rough rice equivalent	49
Per capita calorie supply (no.)	
Total supply	2492
Calories supplied by rice	332
Rice trade (t × 10²)[a]	
Total imports	3
Total exports	847
Fertilizer use, chemical sources (t × 10³)[a]	
Total consumption (N,P,K)	504
N	312
P	56
K	136

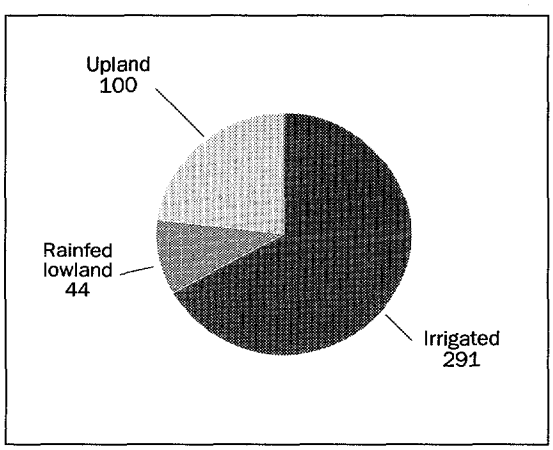
Data are for 1991 unless otherwise indicated.[a]1990. [b]1985-90. [c]Weighted average for all ecosystems.



Land use by physical area (ha × 10³), 1990.

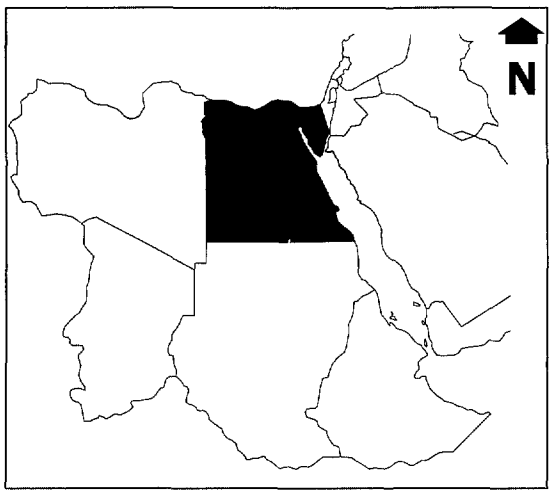


Area (ha × 10³) harvested, temporary crops, 1990.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)



Harvested rice area (ha × 10³) by ecosystem, 1991.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)

Egypt



Egypt is located in the northeast corner of Africa between 22° and 32° N latitude and 25° and 36° E longitude. Rice is concentrated in the northern Nile Delta above the 30th parallel.

It is in AEZ 9, characterized as subtropical arid with winter rains, which in reality in Egypt is no rain—certainly none during the rice-growing season.

The population numbered 53.7 million in 1990, with 25% residing in metropolitan Cairo and more than 50% in rural areas dependent on agriculture.

Importance of rice

Rice is grown during the summer season on about 433,000 of 2.6 million ha of irrigated agricultural lands. Short-grained japonica varieties make up most of the rice crop.

Rice was introduced in the latter part of the 19th century as a reclamation crop on saline soils in the northern Nile Delta after the construction of the Delta Barrage allowed the introduction of perennial irrigation. Rice is a staple crop only in the areas in which it is grown. Outside the area of production, it is consumed as a preferred but nonessential staple food, with 159,000 t exported in 1991. Most of the exports are to other Arabic countries with a sizable expatriate Egyptian community that prefers the short-grained varieties. There is also some potential for exporting long-grained varieties to the European Community countries.

In the areas it is grown, rice is the farmers' preferred summer crop and usually occupies over half the cultivated area. For that reason the area has been expanding with the liberalization of acreage and price controls. The yields have also been increasing yearly with the progressive adoption of new, high-yielding, pest-resistant varieties.

Rice environment

Rice in Egypt represents the fully irrigated ecosystem or the nontropical subdivision of this ecosystem. High levels of solar radiation, along with adequate irrigation water, contribute to high yields. Rice is grown in sequence with winter crops—of which berseem is the most important—but wheat, broadbeans, sugarbeets, etc. are also included in the cropping sequence. It is also grown in sequence with summer crops of cotton and maize.

Production constraints

When irrigation water is available, Egypt has one of the most favorable climates for rice production. The national average yield was 7.3 t/ha in 1991. Research yields have exceeded 13 t/ha. Having berseem as a winter forage legume helps maintain the high yield potential. With the rice area being fully irrigated, there are no real problems of drought or flooding.

The only adverse problem is soil salinity and occasional alkalinity that to varying degrees affect about 30% of the rice area. Other problems are limited micronutrient availability, particularly that of Zn.

As with most of Egypt's agriculture, rice has been supported by an extensive, subsidized public sector infrastructure. In response to external pressures, however, Egypt is currently undergoing a privatization and liberalization program throughout the agricultural sector. This program will remove most of the input subsidies for rice as well as for cotton and maize, and reduce the requirement to deliver a portion of the rice to public milling companies at a reduced price. The impact of these structural changes on rice and companion crops production is yet to be determined. So far it appears to have stimulated an increase in rice production, with a corresponding decline in cotton and maize.

Production opportunities

The Ministry of Agriculture has a comprehensive agriculture research program that works on agri-

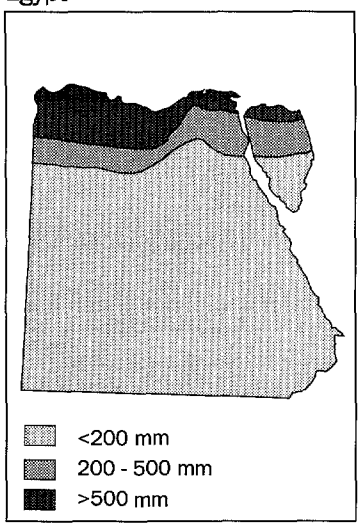
cultural commodities in proportion to their standing on the list of government agricultural production priorities. It includes the Rice Research and Training Center at Sakha, in the middle of the Delta and rice-growing area. The center deals exclusively with rice research. It has a staff of 18 Ph D scientists. The rice research program is divided into three components.

- Plant breeding: works on continuing to increase the yield potential through new varieties that are high yielding, short statured, resistant to pests and diseases, and have good grain quality. The breeding program also produces all the breeder and foundation rice seed each year.
- Agronomy: works on production recommendations for both transplanted and direct seeded rice.
- Plant protection: works on disease resistance, particularly blast, and weed and insect management.

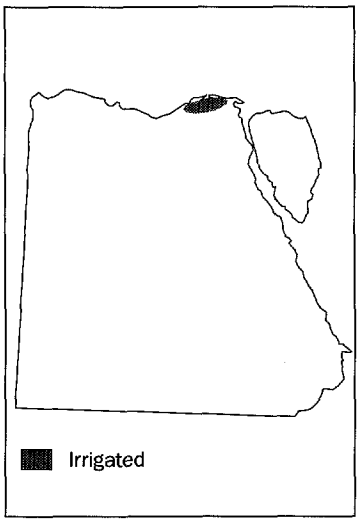
In addition to the research program, Egypt has a technology transfer program specific to rice. This program annually conducts more than 60 farm demonstrations distributed throughout the rice-producing area, a limited number of verification trials, and a yearly production campaign.

IRRI has collaborated with this program for over 20 yr and currently has 3 IRRI staff members posted to Egypt under a contract funded through USAID.

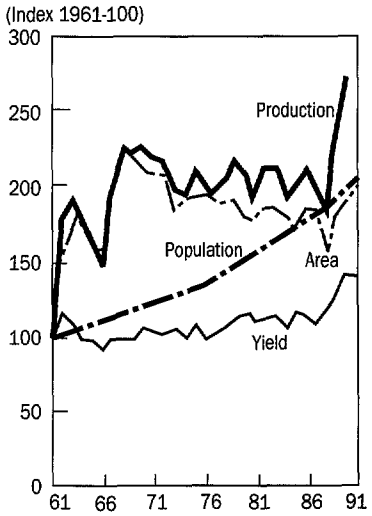
Egypt



Mean annual rainfall.



Rice ecosystems.

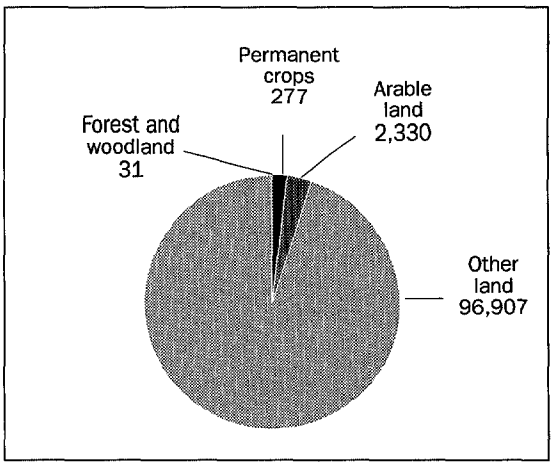


Trends in population, rice production, area, and yield.

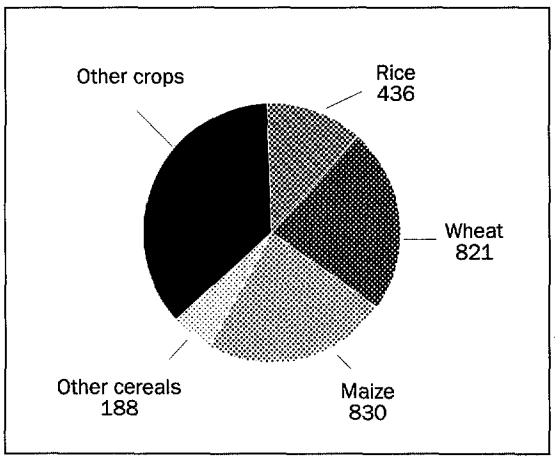
Egypt

Land (km^2)[a]	
Total area	1001450
Population[a]	
Total population (no. × 10^3)	53686
Urban population	25232
Rural population	28454
Agricultural population	21743
Agricultural labor force	6024
Population density (no./km^2)	53.93
Annual growth rate (%)[b]	2.42
Gross domestic product (US$ × 10^6)[a]	33210
Agricultural share in GDP (%)[a]	17
Land use (ha × 10^3)[a]	
Irrigated agricultural area	2607
Harvested area, modern rice varieties	433
Harvested area, traditional varieties	0
Rice production (t × 10^3)	
Irrigated rice	3152
Rainfed lowland rice	0
Upland rice	0
Flood-prone rice	0
Total rough rice	3152
Yield (t/ha)	
Irrigated rice	7.3
Rainfed lowland rice	0.0
Upland rice	0.0
Flood-prone rice	0.0
Average yield[c]	7.3
Per capita rice consumption (kg)[a]	
Milled	28
Rough rice equivalent	43
Per capita calorie supply (no.)	
Daily total supply	3318
Calories supplied by rice	300
Rice trade (t × 10^2)	
Total imports	38
Total exports	1590
Fertilizer use, chemical sources (t × 10^3)[a]	
Total consumption (N, P, K)	**860**
N	745
P	81
K	34

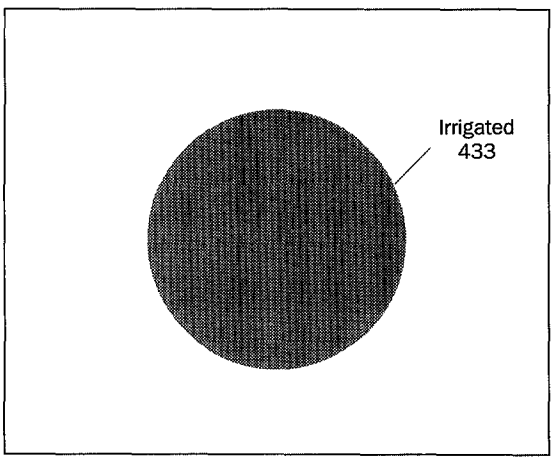
Data are for 1991 unless otherwise indicated.[a]1990. [b]1985-90. [c]Weighted average for all ecosystems.



Land use by physical area (ha × 10^3), 1990.

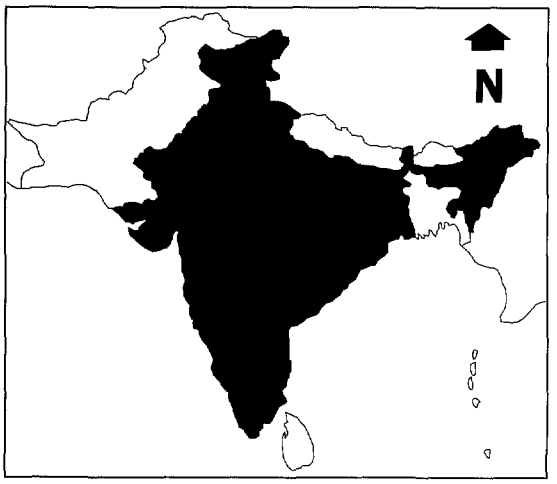


Area (ha × 10^3) harvested, temporary crops, 1990.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)



Harvested rice area (ha × 10^3) by ecosystem, 1991.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)

India



The mainland of India extends between 8° and 37° N latitude and 68° and 97° E longitude. On its northern frontiers India is bounded by the Great Himalayas. To the south, beyond the tropic of Cancer, it narrows to form the Great Indian Peninsula. which ends at the Indian Ocean at its southmost tip. On the east of peninsular India is the Bay of Bengal; on the west is the Arabian Sea

The mainland consists of four well-defined regions: 1) the great mountain zone; 2) the Indo-Gangetic plain, 3) the desert region, and 4) the Southern Peninsula. India lies in five agroecological zones: AEZ 1, characterized by warm and semiarid tropics; AEZ 2, warm subhumid tropics; AEZ 5, warm arid and semiarid subtropics with summer rainfall; AEZ 6, warm subhumid tropics with summer rainfall; and AEZ 8, cool subtropics with summer rainfall. Most rice is grown in AEZs 1, 2, and 6.

There are four distinct seasons: 1) cold (December-February), 2) hot (March-May), 3) rainy (June-September), and 4) retreating southwest monsoon (October-November).

Four broad climatic regions are identified based on rainfall. Practically the whole of Assam and west coast of India lying at the foot of the Western Ghats and extending from the north of Bombay to Trivandrum are areas of very heavy rainfall. In contrast, the Rajasthan desert extending westward to Gilgit are regions of low precipitation. In between are two areas of moderately high and low rainfall. The area of high rainfall is a broad belt in the part of the peninsula merging northward with the Indian plains and southward with coastal plains. The low rainfall area is a belt extending from the Punjab plains across the Vindhya mountains into the western part of the Deccan, widening considerably in the Mysore plateau.

India is the world's second most populous nation, with a population of 848 million in 1990, a growth rate of 2.0%, an infant mortality rate of 92/1000 live births, and a life expectancy of 59 yr. Though it is still a predominantly rural country, India's urban population of 229 million exceeds the total populations of most developing nations.

Importance of rice

Agriculture is the backbone of India's economy, providing direct employment to about 70% of working people in the country. It forms the basis of many premier industries of India, including the cotton textile, jute, and sugar industries. Agriculture contributes about 31% to GDP; about 25% of India's exports are agricultural products.

Rice is the staple food of 65% of the total population in India. It constitutes about 43% of the total foodgrain production and 47% of total cereal production.

Both food and nonfood crops are grown. Foodgrains consists of cereals such as rice, wheat, jowar, bajra, and maize as well as pulses. Food crops grow on nearly 70% of the gross sown area. Total foodgrain production was 170.6 million t in 1989-90. Important nonfood crops are cotton, jute and tobacco.

India became self sufficient in rice in 1977. That was achieved through a combination of increasing the area under cultivation and increasing cropping intensity. With the adoption of modern varieties (MVs) in 1966, an average annual increase of 2% in rice yield has been attained. About 55% of the rice area was planted to MVs in 1985. Rough rice production has exceeded 100 million t annually since 1988; total production in 1991 was almost 111 million t, with an average yield of 2.6 t/ha. India exports a small amount of high quality *basmati* (aromatic) rice.

Rice environments

Rice environments in India are extremely diverse. India has the largest area under rice in the world. Of the 42 million ha of harvested rice area, about 33% are rainfed lowland, 45% irrigated, 15%

rainfed upland, and 7% flood-prone. In some areas, such as Punjab, Haryana, and Tamil Nadu, yields have increased by 55-98% in the past two decades. Much of these areas are irrigated and the farmers have higher per capita income, due to higher input use.

Production constraints

Since the major portion (55%) of the area under rice in India is rainfed; production is strongly tied to the distribution of rainfall. In some of the states, erratic rainfall leads to drought during the vegetative period, but later on the crop may be damaged by submergence due to high rainfall. In the eastern states, damage due to flash floods is quite high.

Other constraints relate to the land and soil. On the one hand extreme soil acidity is a problem in southern and eastern India, whereas in northern India soil salinity and alkalinity is a problem. Nitrogen, P, and Zn deficiency is widespread.

Nearly all of the rainfed area suffers from the lack of infrastructure. Moreover, most farmers cannot afford the inputs necessary for maximum production.

Production opportunities

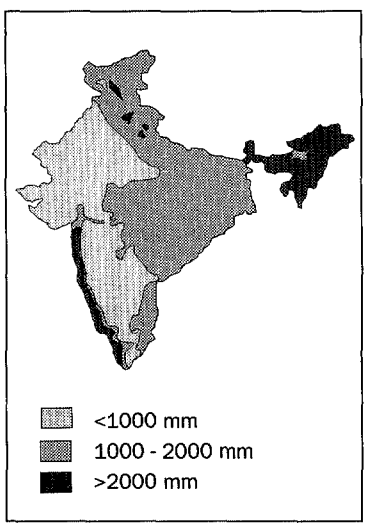
Much of India's agricultural growth, particularly in major cereals, can be traced to an agricultural strategy adopted in the late 1960s. The strategy included

- a package of inputs consisting of short-duration, high-yielding modern varieties, fertilizers, and improved agricultural practices in areas of assured water supply,
- timely credit, and
- announcing minimum price supports before planting.

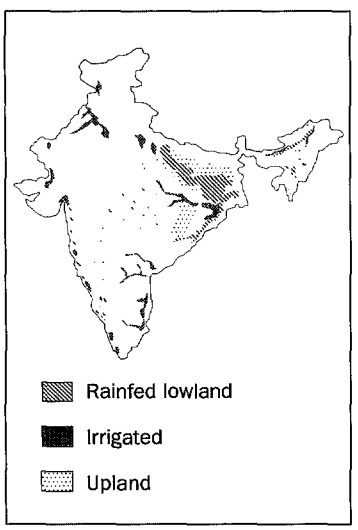
To extend the production package to less favored areas, agroclimatic zonal planning is applied to achieve more balanced regional growth. India has been divided into 15 agroclimatic regions based on homogeneity in rainfall, temperature, soil, topography, and water resources.

On such area encompasses six states in eastern India where strategic research to increase the productivity of rainfed rice is done in collaboration with the International Fund for Agricultural Development and IRRI.

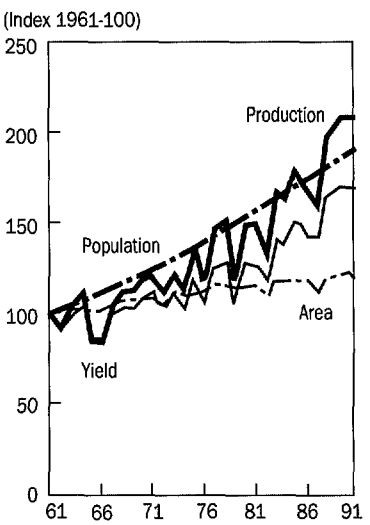
India



Mean annual rainfall.



Rice ecosystems. Flood-prone areas are coterminous with irrigated areas.

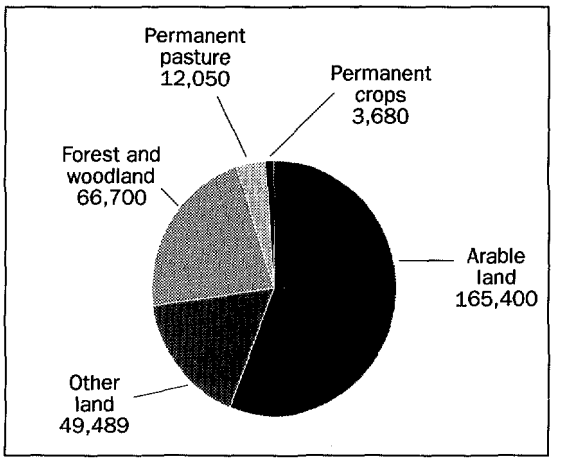


Trends in population, rice production, area, and yield.

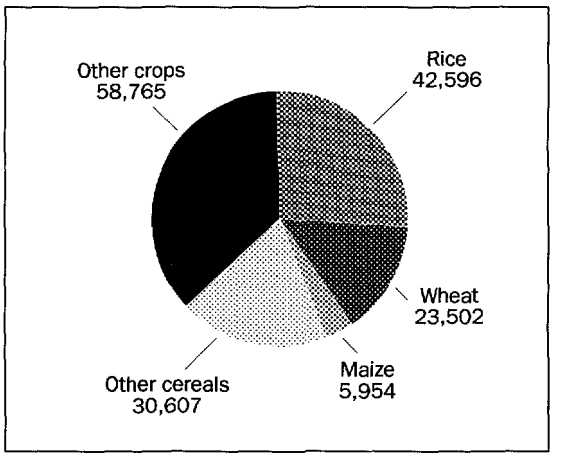
India

Land (km^2)[a]	
Total area	3287590
Population[a]	
Total population (no. × 10^3)	847728
Urban population	228887
Rural population	618841
Agricultural population	532373
Agricultural labor force	213288
Population density (no./km^2)	285.12
Annual growth rate (%)[b]	2.05
Gross domestic product (US$ × 10^6)[a]	254540
Agricultural share in GDP (%)[a]	31
Land use (ha × 10^3)[a]	
Irrigated agricultural area	43050
Harvested area, modern rice varieties	28113
Harvested area, traditional varieties	14483
Rice production (t × 10^3)	
Total rough rice	110945
Irrigated area	63028
Rainfed lowland areas	33422
Upland area	5064
Flood-prone area	4431
Yield (t/ha)	
Total rough rice	2.6
Irrigated area	3.6
Rainfed lowland areas	2.4
Upland area	0.8
Flood-prone area	1.5
Average yield	2.6
Per capita rice consumption (kg)[a]	
Milled	66
Rough rice equivalent	102
Per capita calorie supply (no.)	
Daily total supply	**2243**
Calories supplied by rice	673
Rice trade (t ×10^2)	
Total imports	180
Total exports	4500
Fertilizer use, chemical sources (t × 10^3)[a]	
Total consumption (N,P,K)	10537
N	8021
P	1412
K	1104

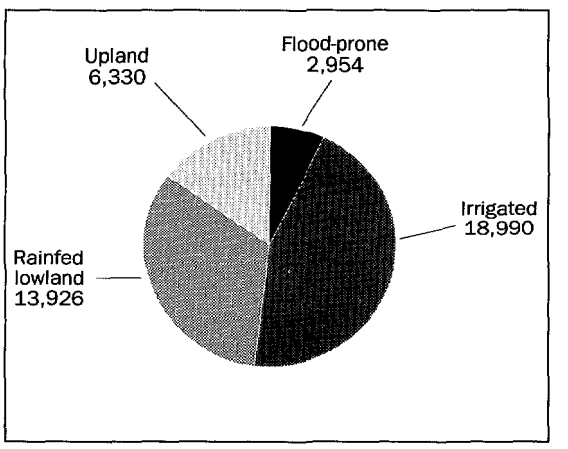
Data are for 1991 unless otherwise indicated.[a]1990.[b]1985-90. [c]Weighted average for all ecosystems.



Land use by physical area (ha × 10^3), 1990.

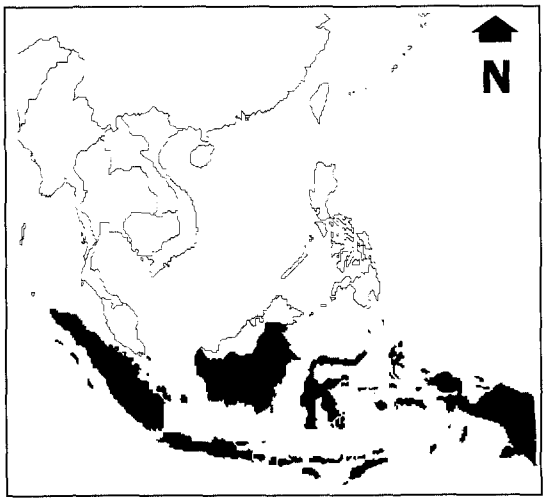


Area (ha × 10^3) harvested, temporary crops, 1990.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)



Harvested rice area (ha × 10^3) by ecosystem, 1991.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)

Indonesia



The Indonesian archipelago extends from 6° N to 11° S latitude and from 95° to 141° E longitude or about 2,000 km north to south and 5,000 km east to west. There are 13,667 islands, which include five of the world's largest namely: Sumatra, Kalimantan (Indonesian part of Borneo), Irian Jaya (Western New Guinea), Sulawesi (Celebes), and Java.

Indonesia lies within AEZ 3, characterized as warm humid tropics. Most of Indonesia has a moist tropical climate, with abundant rains and high temperatures. Annual rainfall ranges from 1,000 to more than 5,000 mm/yr, with more than 90% of the country receiving average rainfall of more than 1,500 mm. December, January, and February are the months with highest rainfall.

The 1990 population was 182 million; the projected population by year 2000 is 214 million with a growth rate of 1.6%. The mean population density is 100/km^2, but on Java where 61% of the people reside, the population density in 1990 was 790/km^2. The urban population was 31%, with the remainder in the rural areas. Fifty two percent of the work force was in agriculture, 18% in industry, and 30% in services.

Importance of rice

Agriculture contributed 22% to GDP in 1990. Rice is an important commodity and is subsidized by the government through inputs and price support. As a result, the country attained self-sufficiency in 1984 and has remained self-sufficient since. Indonesia used to import 25% of the rice in the world market in the 1960s and early 1970s, but now exports rice. Rice production increased at the rate of 4.6% annually from 1969 to 1988, but this rate has declined recently.

Rice is the staple food of the people. In rice-growing areas, it is a major source of income for the farmers. With diversification programs, however, other commodities included in the farming systems supplement the income from rice.

Rice area increased by 1.2% between 1969 and 1990. But many ricelands are being converted into nonagricultural use such as housing and industry.

Rice environment

Rice is grown in a wide range of environments: irrigated lowland, rainfed lowland, tidal swamp, and upland. About 72% of the rice area is irrigated, 7% rainfed lowland, 10% flood-prone, and 11% upland. About 70% of the irrigated rice area can be planted to two crops of rice a year; in the other rice ecosystems, only one rice crop can be grown. Dryland crops, however, usually follow the rice crop in rainfed lowland areas. The average cropping intensity is about 140%. On Java, however, cropping intensity is more than 200%, especially in irrigated and favorable rainfed ecosystems.

Most irrigated lowland rice areas are located in floodplains. However, they can also be found on mountainsides wherever there is water. Rainfed lands are on both floodplains and undulating landscapes. Uplands are mostly on undulating landscape. Most of the flood-prone areas are tidal swamps affected by the rise and fall of tides.

The use of modern rice varieties has increased markedly. Current estimates are that over 85% of riceland is planted to modern varieties. Production of other food crops such as maize, soybean, peanut, and mungbean has been increasing at about the same rate as rice. The area covered by these crops has increased at an even higher rate than rice, averaging about 4.3% annually.

Production constraints

Long-term sustainability is a primary concern, particularly in the uplands. Weather, topography, and poor soils are the chief production constraints.

Weather. Rainfed lowland, and upland rice ecosystems are most prone to drought stress. However, some irrigated lowlands are also prone to drought, especially in the dry season when

irrigation water is in short supply. Others, especially those in low-lying areas, as well as the tidal swamps are subject to flooding.

Topography. Erosion is a serious problem in upland rice areas because on steep slopes the fields are neither bunded nor terraced. That is causing serious sedimentation problems in lowland irrigation systems. Alley cropping as well as terracing are being introduced in some areas, but these cultural practices have not as yet been widely adopted by farmers.

Soils. In irrigated and favorable rainfed lowlands, the relatively heavy application of fertilizers plus the fairly high yields make nutrient imbalance a serious problem.

In the upland ecosystem, where soils are more weathered and leached, acidity, Al toxicity, P and other nutrient deficiencies combine to reduce yields. Soil acidity is serious in tidal swamps because of acid sulfate soils. That is accompanied by Fe toxicity, as well as some deficiencies of P and micronutrients.

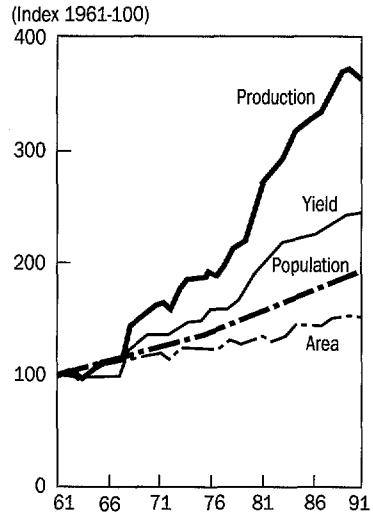
Farm-to-market roads are generally inadequate outside Java. The same holds true for other communication facilities. As a result, marketing of farm products is slow, especially for commodities other than rice, which require further processing before being consumed. The movement of inputs to the farm is also slow.

Production opportunities

The government has been allocating a sizable amount of its budget to the agricultural sector. For fiscal 1993-1994, agriculture and irrigation combined were one of five sectors that were allocated 72% of the available development budget.

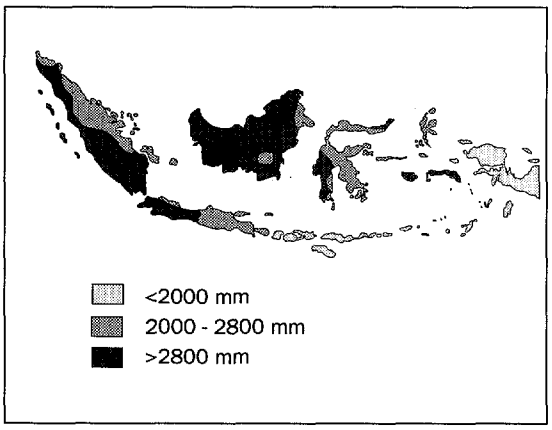
Although research on other food crops is increasing, the level of rice research is being maintained. The main research goal is to sustain a dynamic self-sufficiency in rice. To attain this, four strategies have been proposed: 1) increase the efficient use of current infrastructure, 2) expand the land area for rice production, 3) reduce the yield gap, and 4) reduce postharvest losses. All four strategies require sustained research activities.

During the last decade Indonesia has developed a cadre of researchers capable of undertaking rice research and collaborating with colleagues in other countries. Over 500 Indonesian researchers have trained at IRRI over the past 20 yr. Collaboration between the Agency for Agricultural Research and Development, specifically the Central Research Institute for Food Crops (CRIFC),

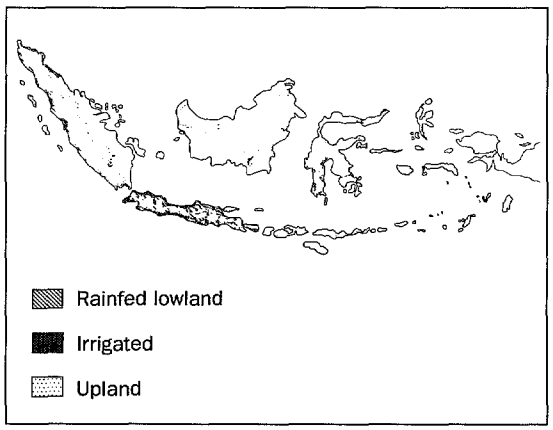


Trends in population, rice production, area, and yield.

Indonesia



Mean annual rainfall.



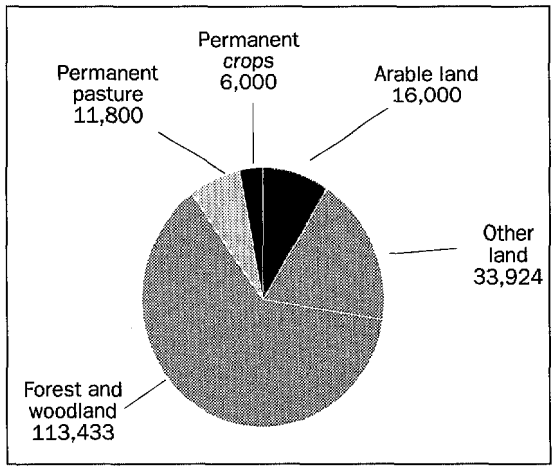
Rice ecosystems. Flood-prone areas are coterminous with irrigated areas.

and IRRI has also increased. Two CRIFC research stations are consortium sites for rainfed lowland and upland rice.

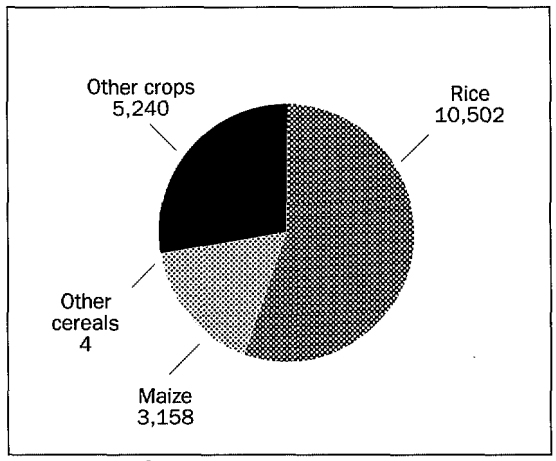
Indonesia

Land (km^2)[a]	
Total area	1904570
Population[a]	
Total population (no. × 10^3)	181593
Urban population	56294
Rural population	125299
Agricultural population	80627
Agricultural labor force	34557
Population density (no./km^2)	100.24
Annual growth rate (%)[b]	1.96
Gross domestic product (US$ × 10^6)[a]	107290
Agricultural share in GDP (%)[a]	22
Land use (ha × 10^3)[a]	
Irrigated agricultural area	7600
Harvested area, modern rice varieties	8087
Harvested area, traditional varieties	2415
Rice production (t × 10^3)	
Irrigated rice	38656
Rainfed lowland rice	2140
Upland rice	1793
Flood-prone rice	1732
Total rough rice	44321
Yield (t/ha)	
Irrigated rice	5.3
Rainfed lowland rice	3.0
Upland rice	1.6
Flood-prone rice	1.7
Average yield[c]	4.4
Per capita rice consumption(kg)[a]	
Milled	138
Rough rice equivalent	212
Per capita calorie supply (no.)	
Daily total supply	2631
Calories supplied by rice	1519
Rice trade (t × 10^2)	
Total imports	1710
Total exports	6
Fertilizer use, chemical sources (t × 10^3)[a]	
Total consumption (N,P,K)	2129
N	1610
P	257
K	261

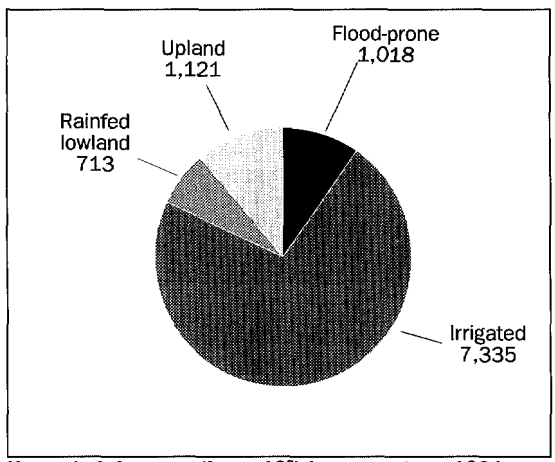
Data are for 1991 unless otherwise indicated.[a]1990. [b]1985-90. [c]Weighted average for all ecosystems.



Land use by physical area (ha × 10^3), 1990.

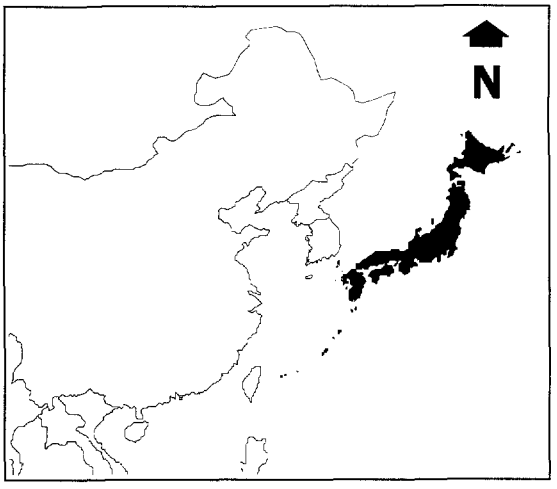


Area (ha × 10^3) harvested, temporary crops, 1990.
(In determining harvested area, land unit is counted each time it is cropped in a year.)



Harvested rice area (ha × 10^3) by ecosystem, 1991.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)

Japan



The Japanese islands are located between 20° and 45° N latitude, and 123° and 146° E longitude. They lie off the eastern coast of the Eurasian continent, roughly in a crescent shape. The country consists of four main islands with about 4,000 smaller ones. The northern limit of rice cultivation is 44° N latitude. Rice is grown up to 1,400 m altitude in the central region of the main island.

Japan is in AEZ 8, characterized as cool subtropics with summer rainfall. The climate is humid temperate and oceanic with four distinct seasons. Rainfall during the rainy season in June and July is indispensable to rice cultivation. Temperature and solar radiation from April to October are ideal for rice growing.

The population in 1990 was over 120 million. The agricultural population is about 7.5 million. Thirty percent of the population works for secondary industry and 60% in tertiary industry.

Importance of rice

Agriculture contributes about 3% to GDP. Although the percentage is small, agricultural production is important to feed the population.

Rice is the staple food. Japan is self-sufficient in rice, but 86% of wheat is imported.

Although rice consumption has declined, and more livestock and other horticultural products are raised, rice is still the most important agricultural product. Rice provides about one-fourth of the daily calorie intake per person.

Japan has more than a 2,000 yr history in rice cultivation. Rice cultivation has influenced the politics, economy, and culture of the country.

Potential rice production now exceeds the demand for rice, and ricefields have been planted to other crops. To prevent the overproduction of rice, a policy aiming at the alternative use of ricefields has been promoted. Of 2.8 million ha of ricefields, 0.8 million ha (30%) were planted to other crops in 1990.

The share of rice in gross agricultural production in 1990 was 28%. The distribution of rice is partially controlled by the government. In 1991, 21% of the rice was distributed by the government and 79% by the agricultural cooperatives.

Rice environment

Rice ecosystems in Japan are characterized by wide ranges of latitude, including the subtropical, temperate, and subfrigid zones. Almost 100% of ricefields are irrigated and grown to rice in the summer.

Rice cultivation in the higher latitudes is a distinguishing characteristic of Japanese rice culture. To cope with cold weather in the northern part of Japan, early-maturing varieties resistant to cold weather were developed. Rice growing in the cold district is characterized by the use of good quality older seedlings for early transplanting, deep water irrigation to protect the crop from low night temperature, windbreak nets, and application of organic matter to improve soil fertility.

Production constraints

Irrigated fields act as a reservoir for rainwater and as catchments to protect steep slopes from flooding and soil erosion. Irrigated fields have the advantage of higher yield and continuous cropping compared with upland fields.

Rice is occasionally damaged by drought, but the injury is not so serious in the irrigated fields. Cold damage experienced in summer is serious in some years in northern Japan. Usually, there is severe incidence of rice blast disease in cool summer weather. Heavy rainfall at the end of the rainy season causes local flooding. Rice is sometimes damaged by typhoons, especially in the southern regions. Early season culture has been established to avoid typhoons in the southwestern part of the country.

Most ricefields are in the plains of the major river basins. A large number of ricefields are also found in terraces and valleys.

Soil fertility has been gradually declining because of the increase of part-time farming. The decline in soil fertility is the result of shallow plowing by a rotary tiller and the reliance on chemical fertilizers. Deep plowing and the application of organic matter are important for improving soil fertility.

To cope with the changing crop pattern, multipurpose use of ricefields for crops other than rice is required. Agricultural infrastructure should be improved for the alternative use of irrigated ricefields as lowland and upland fields. The percentage of irrigated fields with separate irrigation and drainage system is 44%. The systems should be promoted.

In spite of substantial farm subsidies and price support provided by the government, rice farming cannot compete with other economic activities, and income from it is lower than nonagricultural earnings. Farming operations have been fully mechanized. In 1991, 98% of the rice seedlings were transplanted using mechanical transplanters. But the production cost is many times higher than in tropical Asia due to exorbitant land prices and the high opportunity cost of farm labor. Young people are not interested in rice cultivation; this is carried out mainly by older people. Many Japanese consumers now want "environment-friendly" rice grown without heavy use of agrochemicals. Some farmes have started producing rice through organic farming to meet the demand.

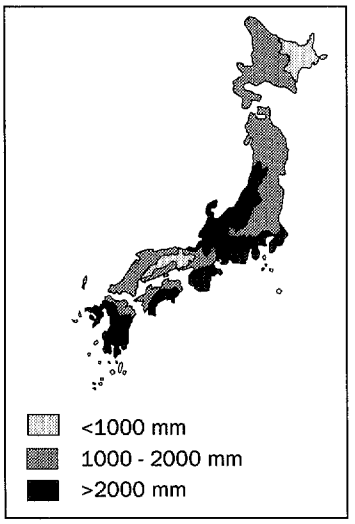
Production opportunities

The Ministry of Agriculture, Forestry and Fisheries (MAFF) has set a policy for the diversified use of ricefields in agriculture.

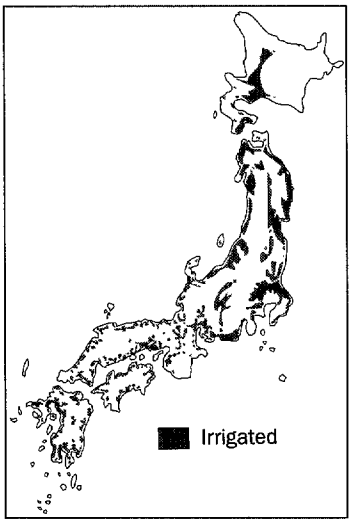
Research on breeding, plant physiology, soil, fertilizer, plant pathology, and entomology are conducted in research institutes and experiment stations affiliated with prefectural governments as well as with MAFF. The rice genome research program (RGP), begun in 1991, aims to establish a comprehensive DNA map of rice. Its eventual goal is to isolate genes with useful agronomic traits and use them for human welfare. The RGP is funded by MAFF and the Japan Racing Association. As some of the problems encountered in Japan are shared by other Asian countries, cooperation with IRRI is often essential for their solution.

Reduced production cost, increased productivity through the application of advanced technology, and multipurpose use of ricefields in agriculture are important in sustaining rice cultivation in Japan.

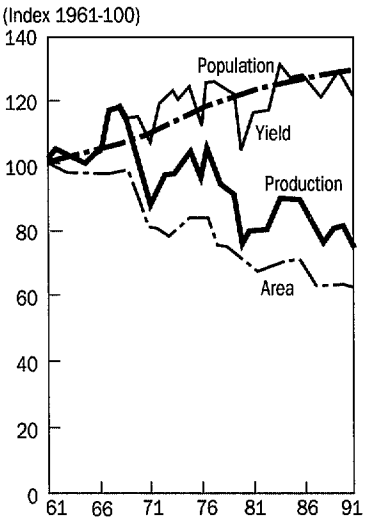
Japan



Mean annual rainfall.



Rice ecosystems.

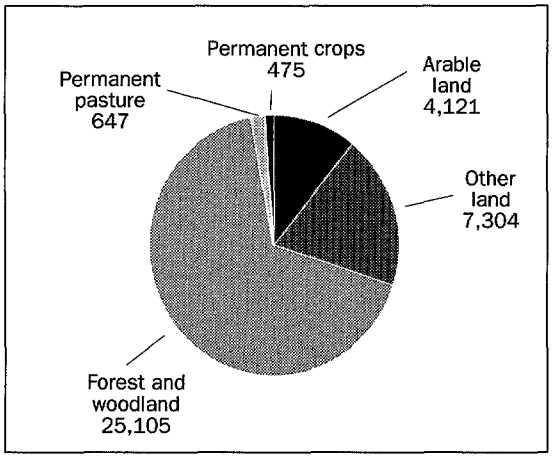


Trends in population, rice production, area, and yield.

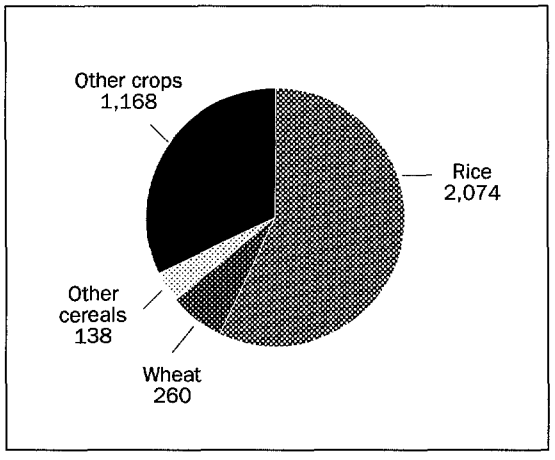
Japan

Land (km^2)[a]	
Total area	377800
Population[a]	
Total population (no. × 10^3)	123343
Urban population	94974
Rural population	28369
Agricultural population	7524
Agricultural labor force	4009
Population density (no./km^2)	327.59
Annual growth rate (%)[b]	0.42
Gross domestic product (US$ × 10^6)[a]	2942890
Agricultural share in GDP (%)[a]	3
Land use (ha × 10^3)[a]	
Irrigated agricultural area	2847
Harvested area, modern rice varieties	2049
Harvested area, traditional varieties	0
Rice production (t × 10^3)	
Irrigated rice	11956
Rainfed lowland rice	0
Upland rice	49
Flood-prone rice	0
Total rough rice	12005
Yield (t/ha)	
Irrigated rice	5.9
Rainfed lowland rice	0
Upland rice	3.0
Flood-prone rice	0
Average yield[c]	5.9
Per capita rice consumption (kg)[a]	
Milled	62
Rough rice equivalent	95
Per capita calorie supply (no.)	
Daily total supply	2926
Calories supplied by rice	699
Rice trade (t × 10^2)	
Total imports	176
Total exports	0
Fertilizer use, chemical sources (t × 10^3)[a]	
Total consumption (N,P,K)	1361
N	612
P	304
K	446

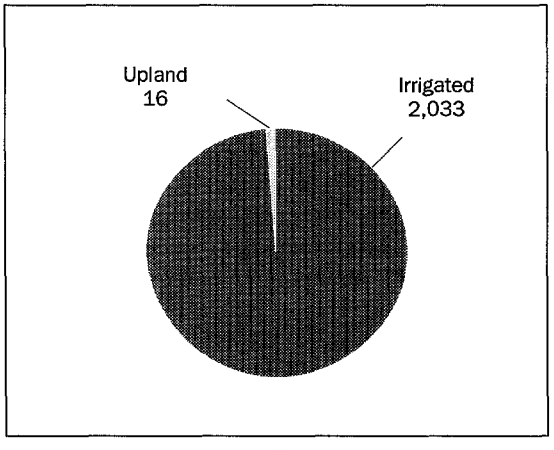
Data are for 1991 unless otherwise indicated. [a]1990. [b]1985-90. [c]Weighted average for all ecosystems.



Land use by physical area (ha × 10^3), 1990.

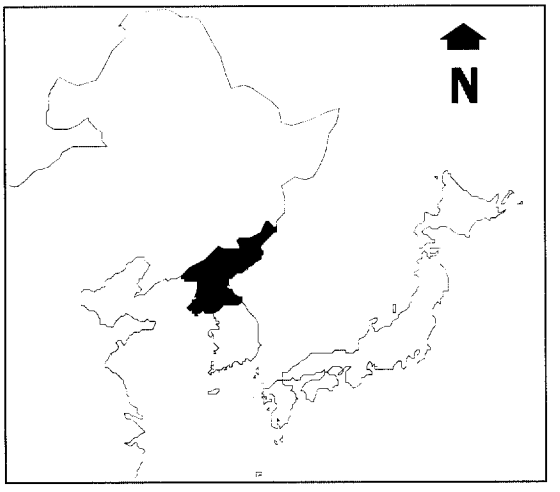


Area (ha × 10^3) harvested, temporary crops, 1991.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)



Harvested rice area (ha × 10^3) by ecosystem, 1991.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)

Democratic People's Republic of Korea (DPRK)



The Democratic People's Republic of Korea (DPRK) occupies the northern part of the Korean Peninsula. It extends from 38° to 43° N latitude and from 124° to 131° E longitude. It is bordered by the Republic of Korea to the south and the People's Republic of China to the north. At the extreme northeastern corner, DPRK shares a short border of about 18 km with Russia.

The country is largely mountainous, with about 65% of the total area composed of mountains and hills less than 1,000 m high. Only 15% of the area is higher than 1,000 m. The remaining 20% of the land area is made up of plains and lowlands. Lack of precipitation combined with poor soil fertility makes land at elevations higher than 400 m unsuited for agriculture other than grazing.

The climate is generally temperate oceanic, but changes to continental in the northwest where the country connects with the Asian landmass. Summers are warm and humid and of relatively short duration. Winters tend to be cold and dry, and in the northernmost provinces last for up to 5 months. Rainfall is geographically and seasonally irregular. In most of the country, up to half of the annual rainfall occurs during the three summer months. DPRK lies in AEZ 6, characterized as warm subhumid subtropical with summer rainfall.

The population of 22.8 million is mostly urban (about 60%), with the remainder living in rural areas. About 33% of the population, or about 7.6 million are dependent on agriculture. The population is concentrated in the coastal plains and in the river valleys, where agriculture can be practiced.

Importance of rice

Rice has been cultivated in the DPRK for about 3,000 years. It is the main and staple crop. Rice production ranks first among the cereal crops, followed by maize, barley, and wheat. Rice is grown on approximately 600,000 ha, which is about 35% of the total cultivable area of the country.

Traditionally, sticky varieties are preferred; therefore short-grained, japonica varieties make up all of the rice crop. All of the rice area is grown to modern varieties.

Rice environment

The rice crop in DPRK is all basin irrigated and transplanted. Of the approximately 1.5 million ha of relatively flat land, 1.4 million ha are capable of being supplied with supplementary irrigation. The extensive development of irrigation has overcome the problem of crop establishment in a dry spring season and allowed the use of longer duration, higher yielding varieties.

Although sowing and harvest dates differ because of weather patterns, the farming system itself is remarkably uniform over the entire country. Because of the relatively short growing season, protected nurseries are sown with pregerminated seed in April. Transplanting is usually done from the first week in May to late May. Delay beyond that time subjects the crop to risk of cold damage at flowering. Rainfall during April and May is sometimes low and unreliable.

Heavy rains and storms in July and August, high night temperatures, and high humidity favor pest and disease outbreaks and physical damage to the crop. September and October, with mild, sunny, and dry weather, are excellent for crop maturation and crop drying is easy. The rapid onset of cool weather reduces the incidence of storage pests and molds in the harvested crop.

Production constraints

The dry period from April to June and from September to October and the heavy rains (700-800 mm) during July and August do not favor rice production. The amount of total rainfall is generally greater in the western regions than elsewhere in the country, but the uneven precipitation has made extensive irrigation necessary. These constraints have been largely offset by basin irrigation systems, which protect the crop from these weather

extremes. Large investments in crop science and land development have brought average yields in the DPRK to among the world's highest. Stable and high yields of 7.6 t/ha have prevailed since the early 1980s.

The limited inventory of arable land and the high cost of the labor-intensive, highly mechanized rice farming system are additional constraints. The high national average yields, however, offset the high cost of production.

The only real physical problems are low soil fertility in most areas, particularly in valleys and on hillsides, and occasional salinity in newly reclaimed tidal lands. Other problems are associated with high acidity (pH 4-5) in mountain areas.

Production opportunities

The strictly limited inventory of irrigable arable land in the DPRK has dictated an increasing use of intensive production methods. National policy has established programs to ensure continued increases in rice production. A major program has been the reclamation of shallow marine sediments on the east coast, with about 300,000 ha targeted for reclamation.

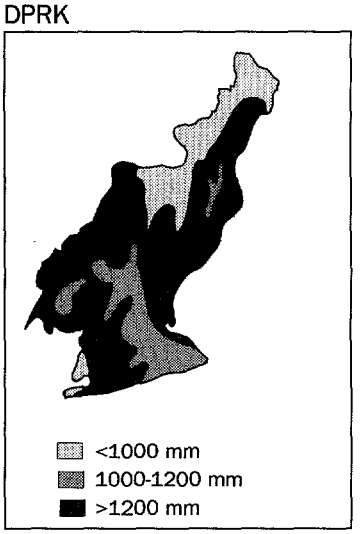
Like other countries that have achieved high yields, DPRK is facing a yield plateau. Varieties such as Pyongyang 15, which sometimes produce 10 t/ha under ideal conditions, have become difficult to replace with higher yielding varieties.

The Academy of Agricultural Sciences (AAS) administers the comprehensive agricultural research program according to government agricultural production priorities. Among the many specialized research organization under the AAS is the Rice Research Institute (RRI).

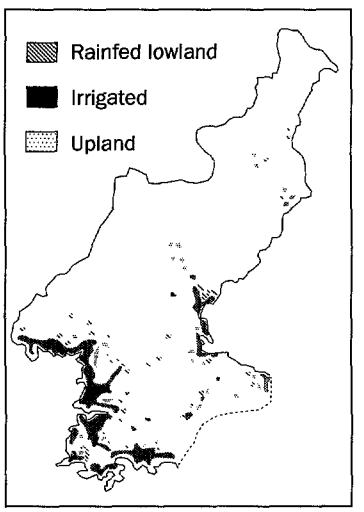
RRI specializes in rice breeding. Soil and crop management, pest and disease control, and mechanization are carried out in other research institutes, but all have intensive programs devoted to the rice crop. The AAS also operate Branch Academies, which are responsible for regional agriculture in different climatic regions of the country.

The rice breeding program in RRI involves mutation breeding; japonica × indica crosses and backcrossing to japonica; wides crosses with millet, reed, maize, barnyard grass, and Indian millet; hybrid rice (male sterile lines have been identified); cytoplasmic fusion; and anther culture.

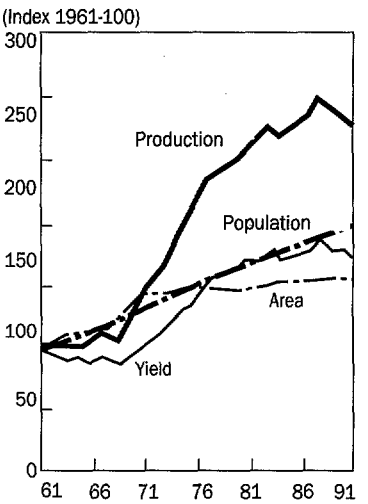
DPRK



Mean annual rainfall.



Rice ecosystems.

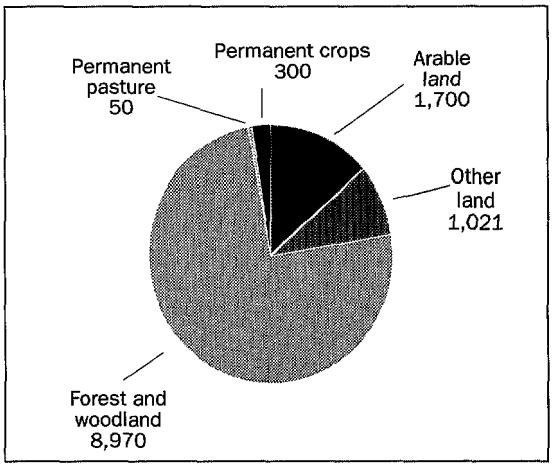


Trends in population, rice production, area, and yield.

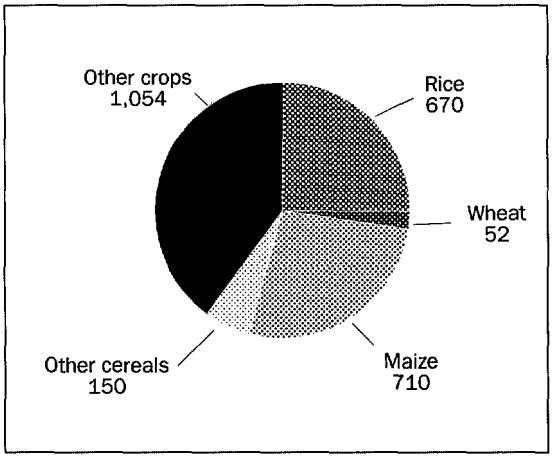
DPRK

Land (km^2)[a]	
Total area	120540
Population[a]	
Total population (no. × 10^3)	22876
Urban population	13726
Rural population	9150
Agricultural population	7663
Agricultural labor force	3969
Population density (no./km^2)	189.98
Annual growth rate (%)[b]	2.31
Gross domestic product (US$ × 10^6)[a]	
Agricultural share in GDP (%)[a]	
Land use (ha × 10^3)[a]	
Irrigated agricultural area	1420
Harvested area, modern rice varieties	680
Harvestedz area, traditional varieties	0
Rice production (t × 10^3)	
Total rough rice	5100
Irrigated area	4146
Rainfed lowland area	620
Upland area	334
Flood-prone area	0
Yield (t/ha)	
Irrigated area	9.1
Rainfed lowland area	4.6
Upland area	3.8
Flood-prone area	0
Average yield[c]	7.5
Per capita rice consumption (kg)[a]	
Milled	125
Rough rice equivalent	192
Per capita calorie supply (no.)	
Total calorie supply	2860
Calories supplied by rice	1331
Rice trade (t × 10^2)	
Total imports	1600
Total exports	110
Fertilizer use, chemical sources (t × 10^3)[a]	
Total consumption (N,P,K)	740
N	655
P	70
K	15

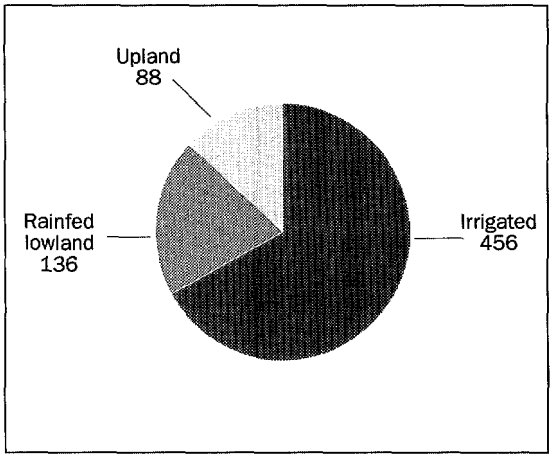
Data are for 1991 unless otherwise indicated.[a]1990. [b]1985-90. [c]Weighted average for all ecosystems.



Land use by physical area (ha × 10^3), 1990.

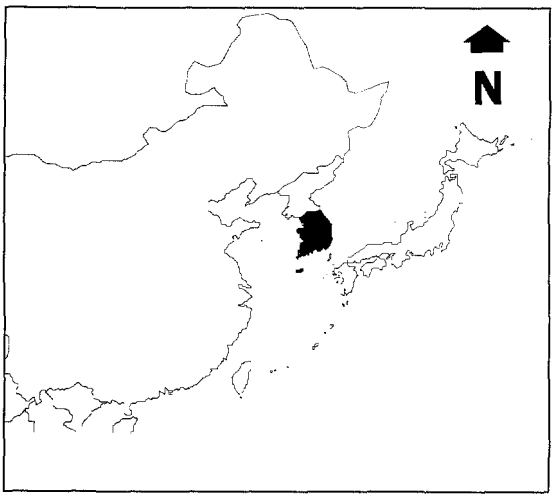


Area (ha × 10^3) harvested, temporary crops, 1990.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)



Harvested rice area (ha × 10^3) by ecosystem, 1991.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)

Republic of Korea (ROK)



The Republic of Korea is located between 33° and 38° N latitude and extends from east to west from 124° to 132° E longitude.

It is considered to be in AEZ 6, characterized as warm subhumid subtropical with summer rainfall. However, the Korean Peninsula has a continental weather pattern with temperature extremes of up to 40 °C in summer and as low as -40 °C in winter. Precipitation tends to vary by topography, ranging from 800 to 1,300 mm annually.

ROK is still in the process of industrializing, and most of the urban people have some rural ties, either having come from the rural area themselves or having relatives in the countryside. The main occupations are in industry and services; farmers number about 8 million, or less than 20% of the population.

Importance of rice

Thirty years ago, more than 70% of the population was rural and farming was the main occupation of the majority. By 1990, only 28% of the population remained in rural areas.

The agricultural population makes up about 80% of total rural population. Agriculture remains important politically and socially even though its contribution to GDP is less than 10%.

Rice is more important than any other food crop or any other agricultural commodity. Rice is the staple food and the main source of carbohydrate in the diet of the people.

The government limits farm size to 3 ha/household and rice is the major source of farm income. ROK farmers have very low nonfarm income compared with those in other developed or developing countries. Rice accounts for about 45% of total income, providing fully 50% of the income from farming. The entire lowland is grown to modern varieties of rice.

The country now experiences rice surpluses, and per capita consumption is gradually decreasing. The rice area is decreasing yearly as a result of industrialization and expanding urban areas. Farmers now concentrate on quality to maintain the domestic consumption level and do not rely on export markets.

Although it is self-sufficient in rice, ROK produces only 35% of its domestic demand for other cereals. Annual cereal imports include 6 million t maize, 4 million t wheat, and 1 million t soybeans and other cereals for animal feed. Imports will increase, even though the population growth rate is only 1.27% per year.

More than 60% of annual precipitation is received from July to September. Soils in the plains area are wet and muddy during the crop season, making rice the only crop choice.

Barley and wheat are no longer grown as winter crops because of their high production cost and relatively low return.

Rice environment

Rice has been grown in ROK for more than 3,000 years. More than 70% of the ricefields have stable irrigation systems; the rest are rainfed, but most of them have groundwater pumping facilities. At one time more than half of the ricefields were double-cropped with barley or wheat. But now rice is single-cropped because wheat is imported.

Rice culture is distinctly different from that of other countries. The land ownership limitation of 3 ha/household means that agriculture is structured for a small-scale farmer. ROK has no alternative crops besides rice. Except for the southwest part of the country, most ricefields lie in valleys between mountains with steep slopes. Ricefields are frequently subjected to drought and submergence.

Production constraints

ROK farmers achieve the world's highest yields. However, many biotic and abiotic constraints limit yields.

Drought comes once in about 3 yr, especially during seedling growth and transplanting. Reliable irrigation systems and facilities have minimized losses due to drought stress. Heavy rainfall from July to September causes flooding. The soil and stones from destroyed stream banks frequently cover the ricefields because of the sharp gradient of the streams. The continuous rainfall in early September sometimes causes rice grains to germinate in the panicles.

Most fields are located between small mountains, which makes it hard to enlarge the block size. Full mechanization with big machinery is difficult because of the steep slopes. Coastal ricefields are affected by seawater intrusion, but that is minimized by reservoirs.

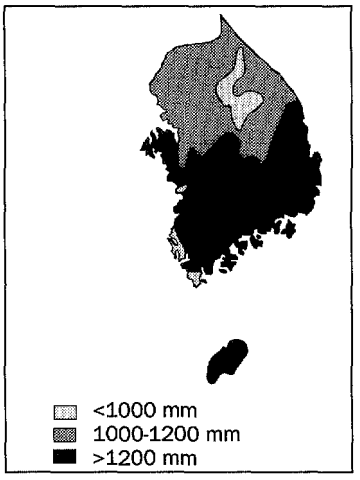
Except for salinity in the coastal area, soil toxicity is rare.

Nutrient deficiency is experienced nationwide, especially in minor elements such as Fe, Mg, Zn, Bo, etc. Soil amendments such as foreign clay soil, zeolite, limestone, calcium-silicate, etc. help alleviate the problem.

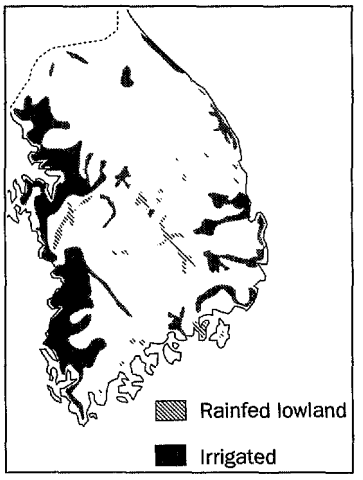
Production opportunities

The strategy for improving the structure of the agricultural system is under study. Agriculture is deeply rooted in the political and social life and changes in the structure of agriculture are sensitive issues. Major considerations are increasing the landholding limit beyond 3 ha/household, and rearranging land into larger blocks for eventual mechanization.

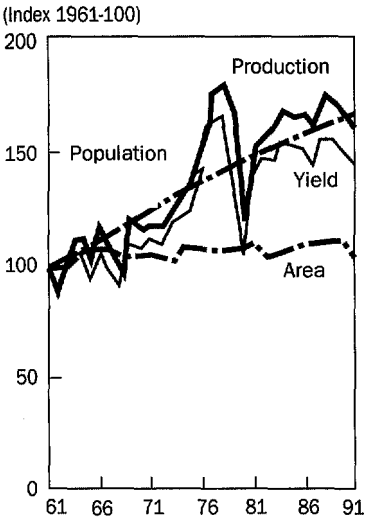
ROK



Mean annual rainfall.



Rice ecosystems.

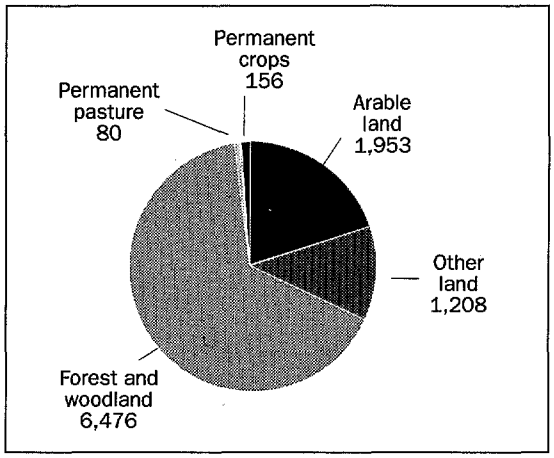


Trends in population, rice production, and yield.

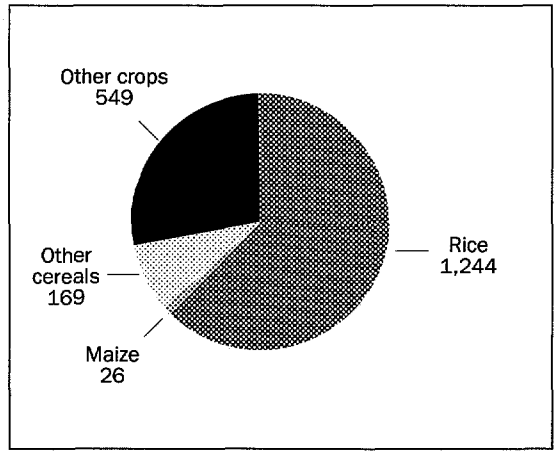
ROK

Land (km^2)[a]	
Total area	99820
Population[a]	
Total population (no. × 10^3)	43749
Urban population	31499
Rural population	12250
Agricultural population	9800
Agricultural labor force	4738
Population density (no./km^2)	443.12
Annual growth rate (%)[b]	1.27
Gross domestic product (US$ × 10^6)[a]	236400
Agricultural share in GDP (%)[a]	9
Land use (ha × 10^3)[a]	
Irrigated agricultural area	1355
Harvested area, modern rice varieties	1244
Harvested area, traditional varieties	0
Rice production (t × 10^3)	
Irrigated rice	7157
Rainfed lowland rice	291
Upland rice	30
Flood-prone rice	0
Total rough rice	7478
Yield (t/ha)	
Irrigated rice	6.5
Rainfed lowland rice	3.0
Upland rice	2.5
Flood-prone rice	0
Average yield[c]	6.2
Per capita rice consumption (kg)[a]	
Milled	92
Rough rice equivalent	142
Per capita calorie supply (no.)	
Daily total supply (no.)	2840
Calories supplied by rice (no.)	1023
Rice trade (t × 10^2)	
Total imports	35
Total exports	20
Fertilizer use, chemical sources (t × 10^3)[a]	
Total consumption (N,P,K)	795
N	465
P	100
K	230

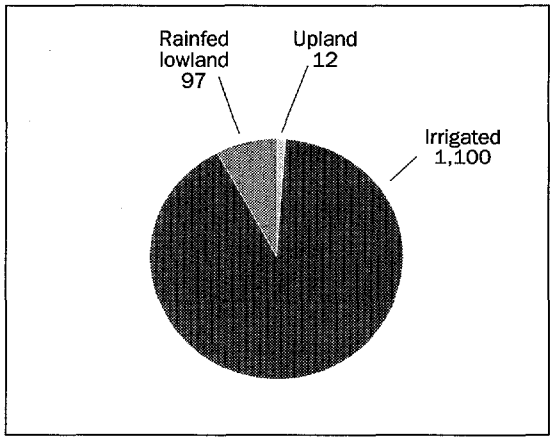
Data are for 1991 unless otherwise indicated.[a]1990. [b]1985-90. [c]Weighted average for all ecosystems.



Land use by physical area (ha × 10^3), 1990.

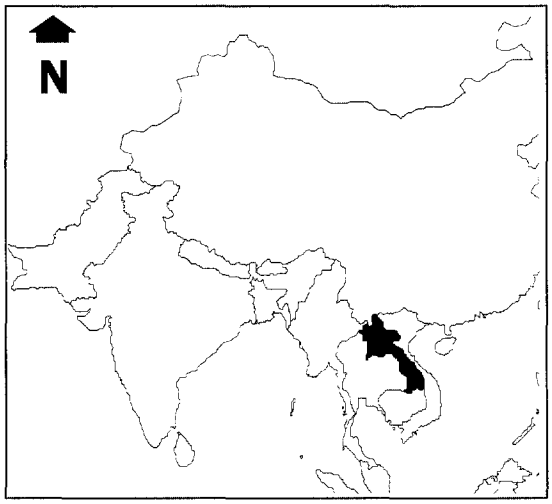


Area (ha × 10^3) harvested, temporary crops, 1990.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)



Harvested rice area (ha × 10^3) by ecosystem, 1991.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)

Lao PDR



The Lao People's Democratic Republic (Lao PDR) is a landlocked country located between 14° and 20° N latitude and 100° and 108° W longitude. It stretches more than 1,700 km from north to south and between 100 to 400 km from east to west. Laos is bordered on the east by Vietnam, on the west by Thailand, on the south by Cambodia, and on the north by China and Myanmar.

Some 75% of the country is hilly to mountainous. In the north and northeast, elevations of 1,000 to 1,500 m are not uncommon. The rest of the country consists of flat to gently undulating lowland and alluvial plains and terraces adjacent to the Mekong River at an elevation of 250-300 m.

Laos is in AEZ 3, characterized as warm humid tropics. The climate is tropical, dominated by the monsoons, especially the southwest monsoon from May to October, which brings up to 75% of the annual rainfall. The average annual rainfall for much of the country is between 1,300 and 1,500 mm. Rainfall exceeding 3,000 mm is not uncommon at higher elevations in the south. Temperatures are highest in April and early May. The period October or November to February or March is coolest, depending on location. Frost is sometimes recorded at higher elevations.

The 1990 population was approximately 4 million, with an annual growth rate of about 2.5%. Agriculture is the principal economic sector in Laos, involving about 70% of the population and accounting for about 60% of GDP. More than 90% of the farmers are subsistence oriented. There has been a move toward a market-based economy in the agricultural sector since 1988, in line with a general change from a centrally planned to a market-oriented economy.

Importance of rice

Rice is the single most important crop, accounting for about 72% of the cultivated area. The harvested rice area in 1990 was approximately 640,000 ha. More than 85% of the rice produced is of the waxy or glutinous type.

Total rice production in an average year ranges between 1.4 and 1.6 million t, all consumed domestically. That amount would meet domestic requirements if distribution problems could be overcome. But drought in the major rice-producing areas can quickly bring about a national rice deficit. Less than 5% of total production is traded within the country.

More than 60% of rice producers in the uplands are estimated to suffer rice deficits. A lower but still significant percentage of rainfed lowland producers also have rice deficits. Most rainfed rice cultivation is based on a single wet season crop, with little or no associated cultivation of other crops either before or after the rice crop.

An increase in the irrigated area could be achieved through the development of small irrigation systems. Stable yields are the goal in the uplands.

Rice environment

Rainfed lowland rice accounts for approximately 56% of the rice area and 69% of production; the rainfed uplands account for approximately 41% of the area and 28% of production. Irrigated rice production accounts for less than 2% of the area and less than 3% of production. The majority of rice producers have net cash incomes well below the annual per capita income of about $200.

There has been very little adoption of improved technologies in the rice-based ecosystems. Traditional varieties dominate in more than 85% of the area of rainfed lowland production and all of rainfed upland production. Fertilizer use is limited. Organic fertilizer usually is applied only in seedbeds, while inorganic fertilizer use is limited to the relatively small area of irrigated production.

Production constraints

The greatest constraint to rice production is the dependence on a rainfed rice-based system. More than 98% of the area is rainfed, of which 56% is rainfed lowlands. The government has targeted these areas for increased production to achieve self-sufficiency.

Problems of rainfed production are aggravated by the relatively sandy and infertile soils that prevail in most of the rainfed lowlands. Phosphorus deficiency appears to be general in almost all areas of rainfed lowland cultivation; K deficiency has also been widely demonstrated. Between 10 and 15% of the rainfed lowlands have salinity problems. Appropriate fertilizer formulations and recommendations are not yet available. The lack of a developed marketing infrastructure system also means that most farmers do not have ready access to fertilizer or credit to purchase it.

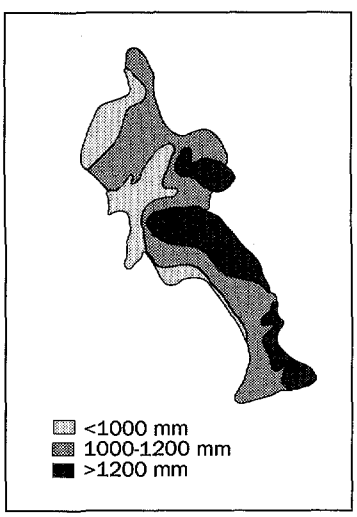
In addition to the problem of periodic droughts in the rainfed lowlands, large areas of rice production along tributaries of the Mekong River are affected by periodic flooding.

Production opportunities

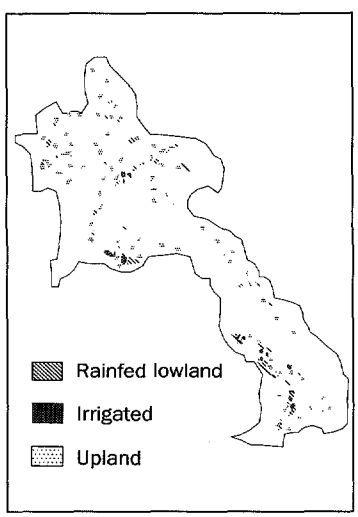
Before 1990 there was no national research network, nor were there accurate national soil maps and baseline meteorological information for many regions. In the later part of 1990, with the support of IRRI and funding from the Swiss Development Cooperation, a national rice research program and network was initiated. By the end of 1992 the network covered 13 of the 17 provinces in the country.

Research emphasis in this network is on the rainfed lowlands. The development of the research and technical skills of the approximately 70 scientists and technicians working in the network is also a priority. Significant improvements can be expected in the rainfed lowland and irrigated lowland rice-based ecosystems within the next 5 yr. Improvements in general infrastructure (roads, marketing, and credit), however, are also urgently needed. With the move to a more market-based economy, the government has focused attention on infrastructure development within both the short- and medium-term development plans.

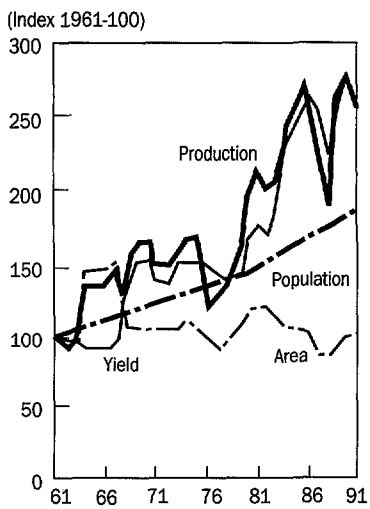
Lao PDR



Mean annual rainfall.



Rice ecosystems.

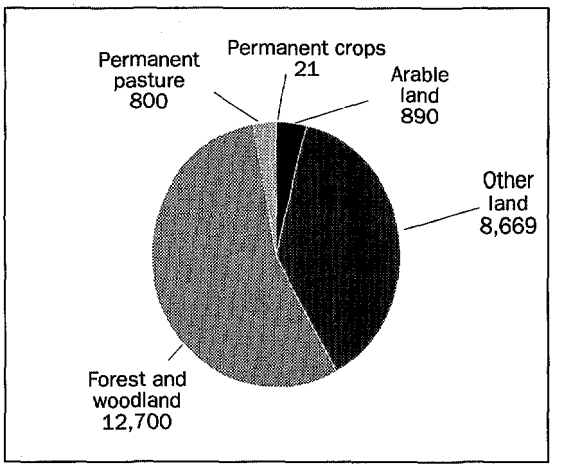


Trends in population, rice production, area, and yield.

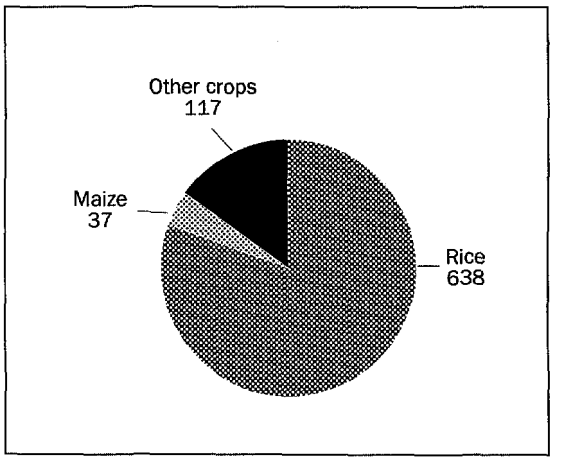
Lao PDR

Land (km^2)[a]	
Total area	236800
Population[a]	
Total population (no. × 10^3)	4073
Urban population	774
Rural population	3299
Agricultural population	2912
Agricultural labor force	1358
Population density (no./km^2	17.65
Annual growth rate (%)[b]	2.50
Gross domestic product (US$ × 10^6)[a]	870
Agricultural share in GDP (%)[a]	60
Land use (ha × 10^3)[a]	
Irrigated agricultural area	122
Harvested area, modern rice varieties	13
Harvested area, traditional varieties	625
Rice production (t × 10^3)	
Total rough rice	1224
Irrigated area	44
Rainfed lowland area	842
Upland area	338
Flood-prone area	0
Yield (t/ha)	
Total rough rice	2.2
Irrigated rice	3.4
Rainfed lowland rice	2.1
Upland rice	1.4
Flood-prone rice	0
Per capita rice consumption (kg)[a]	
Milled	190
Rough rice equivalent	292
Per capita calorie supply (no.)	
Daily total supply	2475
Calories supplied by rice	1723
Rice trade (t × 10^2)	
Total imports	300
Total exports	0
Fertilizer use, chemical sources (t × 10^3)[a]	
Total consumption (N,P,K)	1
N	1
P	0
K	0

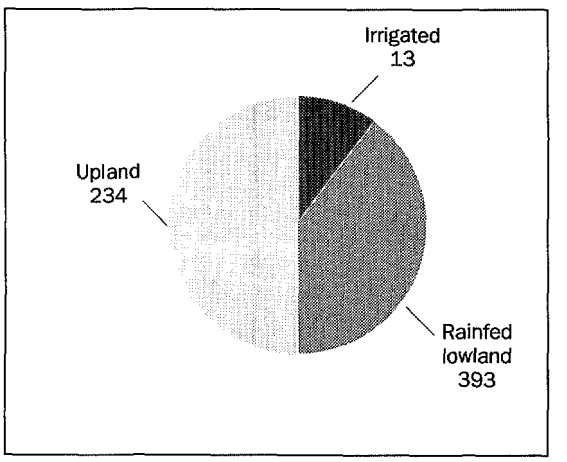
Data are for 1991 unless otherwise indicated.[a]1990. [b]1985-90. [c]Weighted average for all ecosystems.



Land use by physical area (ha × 10^3), 1990.

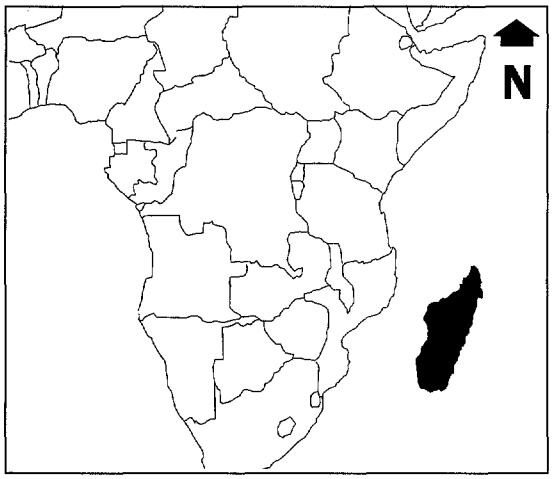


Area (ha × 10^3) harvested, temporary crops, 1990. (In determining harvested area, a land unit is counted each time it is cropped in a year.)



Harvested rice area (ha × 10^3) by ecosystem, 1991. (In determining harvested area, a land unit is counted each time it is cropped in a year.)

Madagascar



Madagascar is a large island, located east of the African continent between 11° and 25° S latitude. It lies within AEZ 1, warm arid and semiarid tropics; AEZ 2, warm subhumid tropics; and AEZ 3, warm humid tropics. It is the second largest rice producer in the African-Indian Ocean region. Agriculture is essentially rice-based. Rice is the preferred staple, a major ingredient in every meal, and is culturally important for the Malagasy people.

About 75% of the population of 12 million is involved in rice cultivation over an area of about 1.7 million ha, producing about 2.2 million t of rough rice annually. Reported per capita rice consumption has declined from a high of 175 kg/person per year in the 1970s to the present level of about 118 kg/year. Increased rice production is vital to feed the growing population.

Rice environments

About 50% of Madagascar is at an altitude of >500 m. The great variability in climate, soils, and topography contributes to the diversity of growing environments: narrow inland valleys and small floodplains, as well as large basins at higher altitudes, and large alluvial plains in the coastal areas. Important rice-growing zones are: the Central Highland, Middle West, Lac Alaotra, Northwest, North, and Southwest. Of the total rice area, about 74% is rainfed lowland, 10% irrigated, 14% upland, and 2% flood-prone.

Most of the rice is grown in the highlands (800 -1,000 m altitude) where the topography is rolling to undulating and the climate is not so favorable for rice cultivation. Mean annual temperatures range from 15 to 19 °C while annual rainfall varies from 1,200 mm to 1,500 mm. Wetland soils are primarily Oxisols, Ultisols, Entisols, Inceptisols, and to some extent, Histosols with varying levels of organic matter, low base status, and high contents of soluble iron.

Based on time of seeding and harvest, three rice growing seasons are recognized: early season (September to January, 5% of area); intermediate season (November to March, 5%); and main season (December/January to April, 90%). During the dry winter season (May to September), nonrice crops such as wheat, triticale, potato, tomato, beans, and other vegetables may be cultivated on the ricefields. Rice double-cropping is not common primarily because of low temperature and lack of irrigation water. Eucalyptus, cassava, taro, beans, and maize are grown on the slopes above ricefields.

In the coastal areas, favorable temperature regimes (mean temperature of 25-30 °C) and abundant sunlight allow year-round cultivation of rice where water is available. Usually, however, fields cultivable in the dry season are flooded in the rainy season. Irrigation schemes are mainly found in alluvial floodplains. Annual rainfall exceeds 3,000 mm on the steep eastern slopes, is 1,500 mm in the northwest plains, and less than 500 mm in the southwest. Periodic flooding is common in the northwest; drought destroys crops both there and in the southwest. Alluvial, sandy, and Oxisols support rice in these areas. Cotton, tobacco, manioc, maize, and legumes are grown in addition to rice.

Upland rice is commonly cultivated in the East by the slash and burn method, and in the Middle West, North, and Northwest by permanent cultivation with fallowing. Maize, beans, peanut, and cassava are alternate upland crops. Rich or young volcanic soils occur only in limited areas; most of the upland is covered by poor and erosion-prone ferrallitic soils. Upland cultivation aggravates soil erosion.

Production constraints

Low temperature, dependence on variable rains, poor water control, low soil fertility, diseases (blast, sheath rot, glume discoloration), and insects (hispa, white stem borer) limit rice yields in the highlands.

In the coastal areas, the short rainy season that results in water shortages, salinity in some areas, low soil fertility, insects (stem borers, hispa), diseases (blast, rice yellow mottle virus), and weeds are some important constraints to rice production. Early varieties can reduce end-of-season drought risk and encourage rice double-cropping in a few favorable areas.

In the uplands, declining soil fertility, soil erosion, insects, and parasitic (Striga) and other weeds seriously affect upland rice.

Socioeconomic constraints include unavailability of inputs, lack of credit, high input prices relative to rice prices, scarcity of simple agricultural machines and draft animals, poor roads and other rural infrastructure, lack of irrigation maintenance and erosion control, and high transportation costs. Added constraints on the coasts are the high cost of land preparation and labor shortages at critical periods.

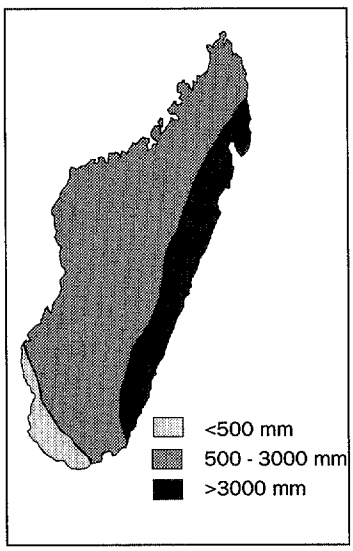
Production opportunities

Rice research is carried out primarily under the Rice Research Department of the National Center for Applied Research on Rural Development (FOFIFA). The program encompasses rice breeding, agronomy (including plant physiology and soil science), entomology, and pathology. A total of 44 researchers and technicians (14 of them women) are involved in rice and rice-related research and technology development. They work with the departments of research and development and other disciplines of FOFIFA, extension agents, and development organizations for on-farm testing and transfer of technologies to rice farmers.

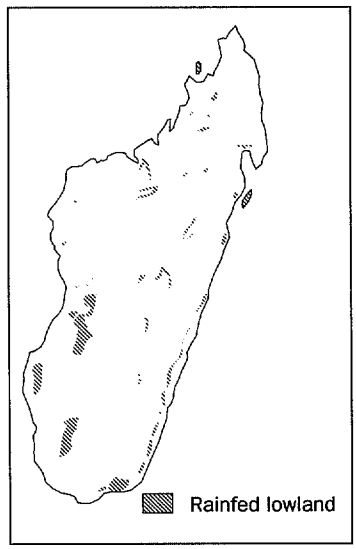
The Madagascar-IRRI collaborative Rice Research program, begun in 1984 with funding from USAID, is now in its third phase. With the expansion of the IRRI team in Madagascar from two to four staff members, soil science and socioeconomic research have been added to rice breeding and agronomic research.

Since the inception of the project in 1984, research has been conducted on rice varietal improvement, fertilizer management, cultural practices, and potential off-season crops for rice-based cropping systems. IRRI machinery has also been introduced and tested. Some is now manufactured locally. A farming systems approach has been introduced, emphasizing multidisciplinary, problem-solving, farmer collaborative research, and low-cost technologies that resource-poor farmers can adopt. Rice research is also being organized regionally to more sharply focus on the needs of the different ecologies and populations.

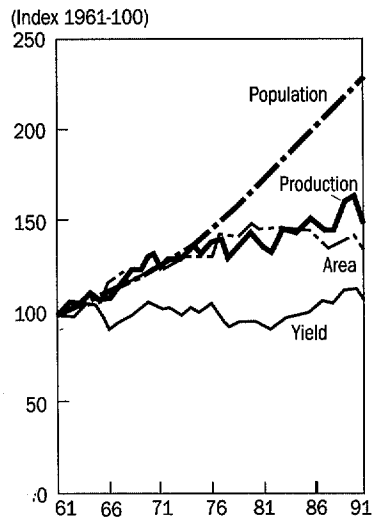
Madagascar



Mean annual rainfall.



Rice ecosystems.

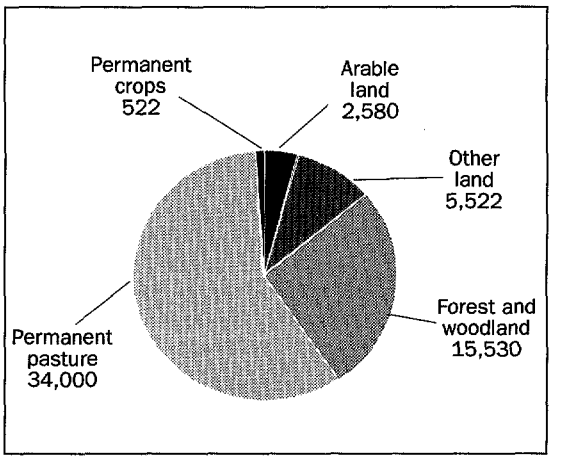


Trends in population, rice production, area, and yield.

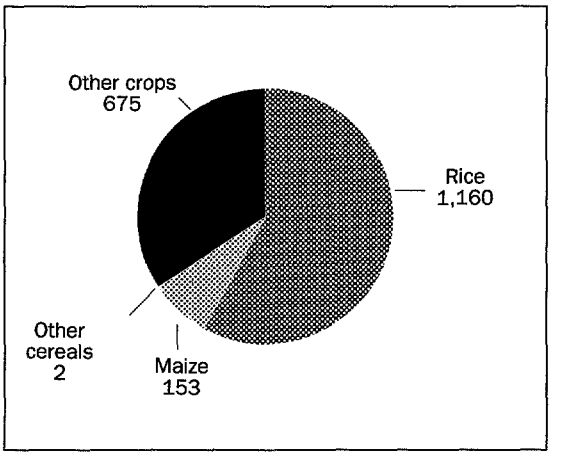
Madagascar

Land (km^2)[a]	
Total area	587040
Population[a]	
Total population (no. × 10^3)	11983
Urban population	2996
Rural population	8987
Agricultural population	9167
Agricultural labor force	3946
Population density (no./km^2)	20.61
Annual growth rate (%)[b]	3.0
Gross domestic product (US$ × 10^6)[a]	2750
Agricultural share in GDP (%)[a]	33
Land use (ha × 10^3)[a]	
Irrigated agricultural area	920
Harvested area, modern rice varieties	
Harvested area, traditional varieties	
Rice production (t × 10^3)	
Irrigated rice	440
Rainfed lowland rice	1591
Upland rice	154
Flood-prone rice	15
Total rough rice	2200
Yield (t/ha)	
Irrigated rice	4.0
Rainfed lowland rice	2.0
Upland rice	1.0
Flood-prone rice	0.7
Average yield[c]	2.0
Per capita rice consumption (kg)[a]	
Milled	118
Rough rice equivalent	182
Per capita calorie supply (no.)	
Daily total supply	2162
Calories supplied by rice	1091
Rice trade (t × 10^2)	
Total imports	313
Total exports	0
Fertilizer use, chemical sources (t × 10^3)[a]	
Total consumption (N,P,K)	6
N	3
P	1
K	2

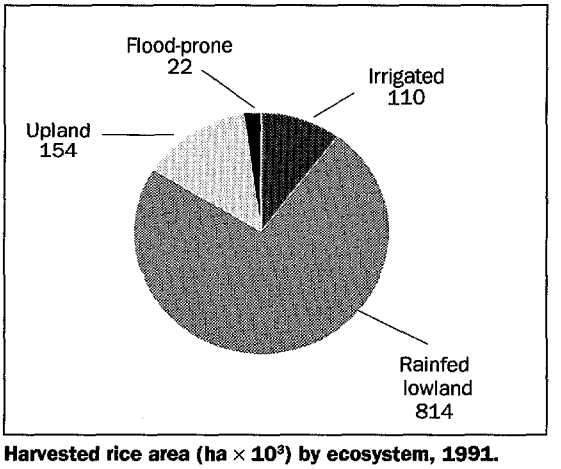
Data are for 1991 unless otherwise indicated.[a]1990. [b]1985-90. [c]Weighted average for all ecosystems.



Land use by physical area (ha × 10^3), 1990.

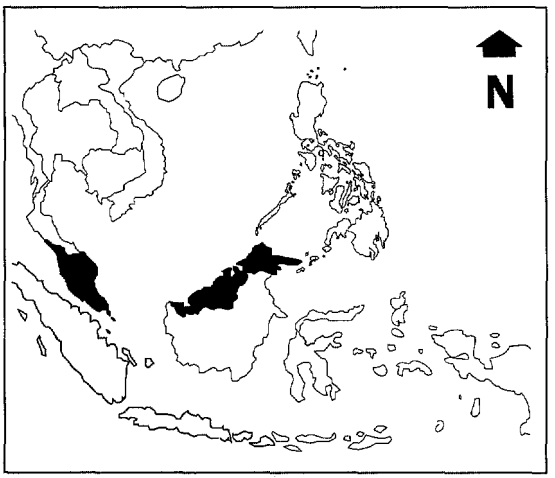


Area (ha × 10^3) harvested, temporary crops, 1990.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)



Harvested rice area (ha × 10^3) by ecosystem, 1991.
(In determining havested area, a land unit is counted each time it is cropped in a year.)

Malaysia



Malaysia in the Malay Archipelago comprises the Malay Peninsula, Sabah, and Sarawak. It is located between 1° and 7° N latitude and 100° and 120° E longitude. Peninsular Malaysia extends from the Thailand border in the north to Singapore in the south, with a peninsular coastline of some 1,930 km. Sarawak and Sabah on the northern part of Kalimantan have a coastline of about 2,253 km.

Malaysia is in AEZ 3, characterized as warm humid tropics. It lies entirely in the equatorial zone. The climate is governed by the northeast and southwest monsoons. The northeast monsoon extends from October until March, and the southwest monsoon runs from May to September. Intermonsoon periods are marked by heavy rainfall.

The northeast monsoon from the South China Sea brings heavy rains to the east coast of Peninsular Malaysia, occasionally causing widespread floods particularly from December to February. The period of the northeast monsoon is the wettest season in Sabah and Sarawak. The southwest monsoon period is drier, particularly for the west coast of the Peninsula, which is sheltered by the landmass of Sumatra.

Temperature averages a constant high of 26 °C with a diurnal range of 7 °C; the annual range is 1 °C. The humidity is high at 80% and rainfall heavy at 2,500 mm annually. Convectional rainfall is not uncommon. In general, Sabah and Sarawak experience greater rainfall than does Peninsular Malaysia.

The population is approximately 18 million, with nearly half residing in the rapidly urbanizing areas. Agriculture contributes 16% to GDP. Services contribute 44%, and manufacturing 29%.

Importance of rice

Oil palm from a little over 2.1 million ha, rubber at 1.75 million ha, and cocoa over 0.45 million ha are primary export earners. About two-thirds of the 400,000 ha of rice in Peninsular Malaysia is irrigated and double-cropped. Not much of the 50,000 ha in Sabah are fully irrigated; most of the 150,000 ha in Sarawak are rainfed and upland. Indica varieties are most common.

Malaysia is about 65% self-sufficient in rice. Rice is imported mainly from trading partners. There is increasingly more demand for high quality, fragrant rice. Rice remains the staple food although per capita consumption has dropped from 100 to 79 kg over the past 20 yr. Despite a population growth that exceeds 2% annually, the national requirement for rice has increased less drastically because of declining per capita consumption. Wheat is consumed mainly as bread and pastries.

Rice production is heavily subsidized through input supplies (seeds, fertilizers, machinery), price supports, and on-farm infrastructure. More than half of the rice area is planted to modern varieties. This trend is increasing.

The cultivated area had a net decrease of more than 5% over the past 5 yr.

More riceland is simply abandoned and left idle, rather than used for other short-term food crops.

Rice environment

The four main rice environments in Malaysia are classified as irrigated, partially irrigated, rainfed lowland, and upland. The irrigated lowland predominates in Peninsular Malaysia; rainfed rice is more common in Sabah and Sarawak where upland rice prevails.

Crop establishment in the irrigated areas is by manual or mechanical transplanting; direct seeding, usually broadcast and only seldom row-sown or drilled; and a double nursery technique. Machine harvesting is common in some irrigated areas such as the Muda irrigation system in Kedah. In the partially irrigated (upgraded rainfed lowland) area, rice is mostly direct seeded instead of transplanted.

Rice is mainly transplanted in the rainfed lowlands, and drill seeded in the uplands.

Production constraints

One of the main production constraints is fluctuating yield, with strong indication of a gradual decline over time. The shrinking of the areas for rice production overrides any advantage that might be expected from higher yields.

An extreme labor shortage has prompted steps to expedite farm mechanization. Still, the shortage of affordable farm labor has caused a consistent decline in rice area.

Periodic drought, irregular rainfall, and seasonal monsoon floods are a threat to the rice crop. Malaysia also experiences shortages of irrigation water.

Topography also plays a role in overall rice production. The intrusion of coastal seawater into areas below sea level is a continuing problem. Ineffective terracing of upland slopes and inefficient, gravity-fed irrigation systems lead to water deficits.

Soil-related constraints include suspected nutrient imbalance and deficiency and low cation exchange capacity. The use of organic materials is limited in favor of the blanket application of chemical fertilizers.

Production opportunities

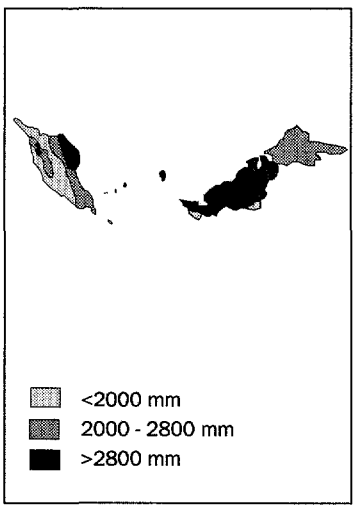
The rice research division in the Malaysia Agricultural Research and Development Institute (MARDI) facilitates research and development in Peninsular Malaysia. It is working to develop efficient management practices, production systems, and superior rice varieties with higher yield potential. Rice research at the state level concentrates on reducing the yield gap and increasing productivity, improving grain quality and postharvest management, and developing rice-based farming systems in rainfed areas.

MARDI is also working to reduce ricefield losses, improve rice-based farming systems, and maintain long-term stability while increasing rice yields.

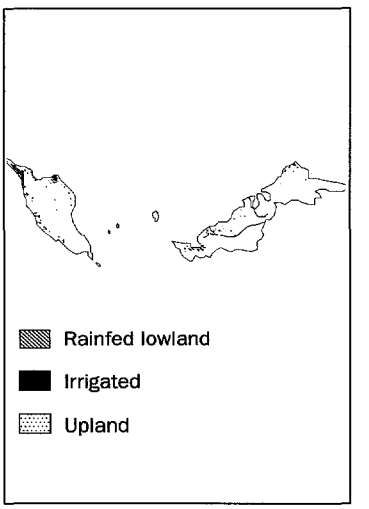
Extension is carried out by the federal government; the departments of agriculture in Sabah and Sarawak deal with all aspects of research and development for each state.

Over the long term, farm yields need be raised by almost twofold to maintain imports at one-third the national requirement or lower. Cropping intensity must be maintained at 175% or higher considering the shrinkage of the area planted to rice.

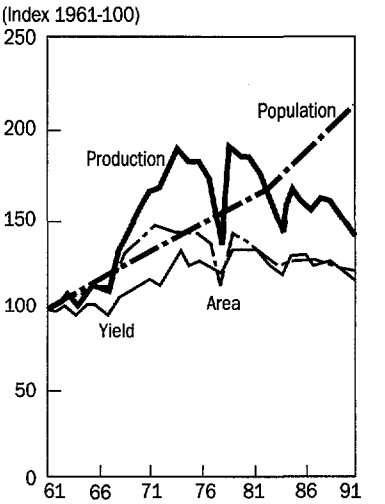
Malaysia



Mean annual rainfall.



Rice ecosystems.

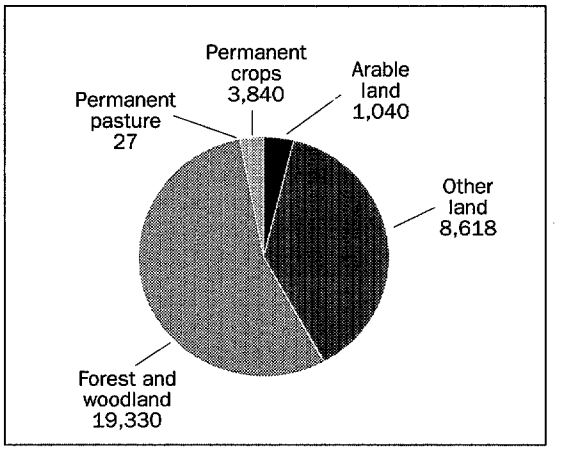


Trends in population, rice production, area, and yield.

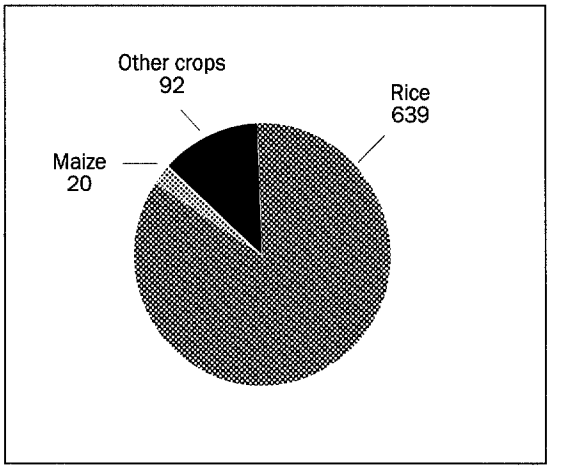
Malaysia

Land (km^2)[a]	
Total area	329750
Population[a]	
Total population (no. × 10^3)	17780
Urban population	7645
Rural population	10135
Agricultural population	5387
Agricultural labor force	2240
Population density (no./km^2)	54.12
Annual growth rate (%)[b]	2.51
Gross domestic product (US$ × 10^6)[a]	42400
Agricultural share in GDP (%)[a]	16
Land use (ha × 10^3)[a]	
Irrigated agricultural area	342
Harvested area, modern rice varieties	575
Harvested area, traditional varieties	64
Rice production (t × 10^3)	
Irrigated rice	1257
Rainfed lowland rice	206
Upland rice	76
Flood-prone rice	11
Total rough rice	1550
Yield (t/ha)	
Irrigated rice	3.0
Rainfed lowland rice	1.5
Upland rice	1.0
Flood-prone rice	1.7
Average yield[c]	2.4
Per capita rice consumption (kg)[a]	
Milled	79
Rough rice equivalent	122
Per capita calorie supply (no.)	
Daily total supply	2697
Calories supplied by rice	791
Rice trade (t × 10^2)	
Total imports	4003
Total exports	0
Fertilizer use, chemical sources (t × 10^3)[a]	
Total consumption (N,P,K)	779
N	313
P	72
K	394

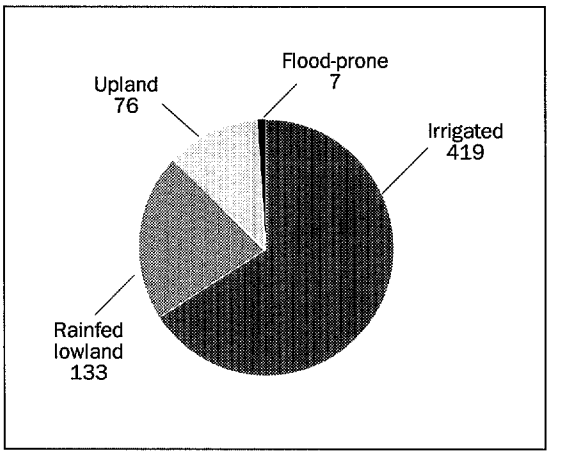
Data are for 1991 unless otherwise indicated. [a]1990. [b]1985-90. [c]Weighted average for all ecosystems.



Land use by physical area (ha × 10^3), 1990.

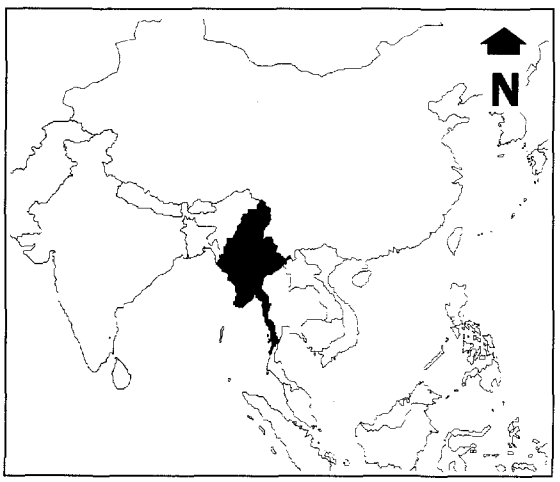


Area (ha × 10^3) harvested, temporary crops, 1990. (In determining harvested area, a land unit is counted each time it is cropped in a year.)



Harvested rice area (ha × 10^3) by ecosystem, 1991. (In determining harvested area, a land unit is counted each time it is cropped in a year.)

Myanmar



Myanmar is the largest country of the Southeast Asia mainland. It is between 10° and 29° N latitude and 92° and 101° E longitude. Myanmar has a common boundary with Bangladesh, India, China, Laos, and Thailand. There are six distinct regions: the western, northern, and eastern mountain ranges; the delta area of the Ayeyarwady and Sittaung Rivers; the coastal strips; and the central plain or dry zone. The cultivable area is 17 million ha, but so far only 8 million ha are under cultivation.

Myanmar is in AEZ 2, characterized as warm subhumid tropics. Generally, the country receives rain from the southwest monsoon, which normally starts in May and ends in October. Being on the windward side, coastal strips and deltaic regions receive heavy rains, ranging from 2,560 to 6,150 mm annually. The leeward central plain or dry zone receives lower and erratic rainfall, ranging from 700 to 1,200 mm annually.

About 75% of the 42 million population live in the rural area and most of them are engaged in agriculture.

Importance of rice

Myanmar has a predominantly agricultural economy based on rice production. The agriculture sector, including livestock and fisheries, accounts for 55% of the country's GDP. Rice is the single most important crop, grown on 4.8 million ha or 60% of the country's total cultivated area. Rice production employs 40% of the total labor force and consumes 70% of total commercial fertilizers. In turn, rice maintains its position as the main staple food crop, accounting for 97% of total food grain production. The importance of rice as a major foreign exchange earner has, however, declined over time. In 1991, rice accounted for only 9% of total export earnings.

The suitable area for rice in Myanmar is estimated at 6 million ha. To meet the increasing demand for rice of the growing population and to sustain exports, Myanmar has embarked on a program to increase rice production through area expansion, yield increase, and crop intensification.

Rice environment

The rice ecosystems of Myanmar include irrigated lowland, rainfed lowland (including late sown and mayin areas), deepwater, and upland. Late sown rainfed lowland is the area sown during monsoon; madin areas can be transplanted only after the monsoon when floodwater recedes. The rainfed lowland area is by far the largest, accounting for 52% of total ricelands. Irrigated lowland accounts for about 18%. Deepwater rice is planted on about 24% of riceland; upland rice makes up only about 6%.

Rainfed lowland and deepwater rice are confined to the delta region and coastal strip of Rakhine State. Irrigated lowlands are mainly in Mandalay, Sagaing, and Bago Divisions. The upland area is mostly in Mandalay, Sagaing, and Shan States. Some upland area in Shan State occupies sloping land and is exposed to cold starting in November.

Production constraints

Problems in rainfed lowland production include inadequate labor for transplanting, inadequate supply and high cost of fertilizer, and flooding in low areas. Farmers who wet seed face problems of insect pests, poor crop establishment, and weeds in upper fields.

In the upland areas at Aungban and Kyaukme (hilly regions), problems are weeds, insect pests (stem borer and white grub), low soil fertility, soil erosion, poor crop establishment, drought, and reduced fallow period.

Problems encountered in deepwater rice are unfavorable water conditions, weeds (particularly wild rice), soil physical problems, and pests (stem borer and white grub). High cost of labor, declining rice yield, excess water, and low soil fertility are the main problems in irrigated rice ecosystems.

In the hilly region the problems are mainly related to infrastructure—lack of good roads for rice transport, and in main rice-growing areas inadequate storage and postharvest facilities, which lower grain quality, particularly for export. The high cost of imported fertilizers and low rice prices have reduced fertilizer consumption and rice production since 1986. A record production of 13.9 million tons of rice in 1990 was only 4% higher than the level reached in 1982.

Production opportunities

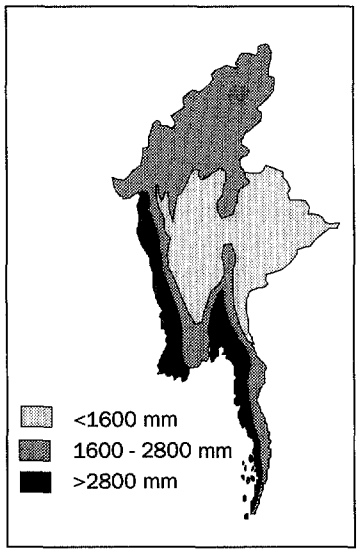
The significant yield increases recorded during the past 30 yr are attributed to a number of factors. Foremost is the introduction of high-yielding, modern varieties (MVs) and technologies developed at the Central Agricultural Research Institute, including those generated through Myanmar-IRRI collaborative research. Fifty MVs were released in Myanmar between 1966 and 1990. Of these, 11 were produced by Myanmar scientists using selected genetic materials from the International Network for Genetic Evaluation of Rice (INGER), and from local rice germplasm collections. The rest were direct selections from INGER nurseries conducted in Myanmar. Increased plant densities and increased fertilizer usage, particularly for MVs, also had a significant impact on production. Rice farming research has helped to increase the country's cropping intensity substantially. It is up to 200% in most ricelands in the delta, particularly through sowing of food legumes and oil seed crops after rice.

To solve the problem of inadequate and expensive labor for transplanting, farmers wet seed rice, transplant later using overaged seedlings, exchange labor, and grow cash crops. They substitute gypsum and farmyard manure for expensive fertilizers, fertilize selectively, and wet seed the crop or change cultivars.

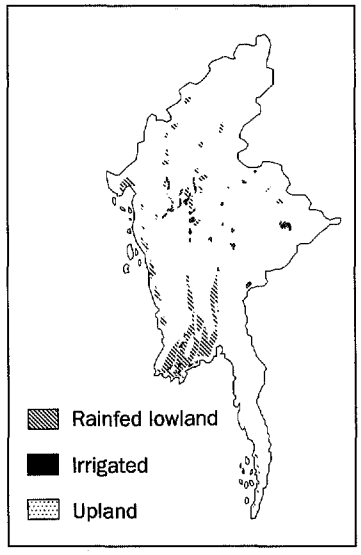
Choosing suitable cultivars and constructing fishponds are the solutions to the problem of excess water in lower areas. To control soil erosion, farmers construct erosion control structures above fields and drainage and diversion canals around fields.

The production gains achieved by improved rice technology in the rainfed lowlands must be maintained. The government also considers it important to develop new technology for the coastal and saline rice environment and for the upland ecosystem, which experiences drought, erosion, weeds, insect pests, nematodes, and low temperature. These technology needs are being addressed in part through the Myanmar-IRRI collaborative research program.

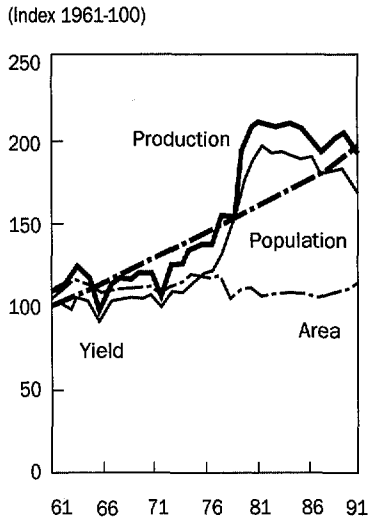
Myanmar



Mean annual rainfall.



Rice ecosystems. Flood-prone areas are coterminous with irrigated areas.

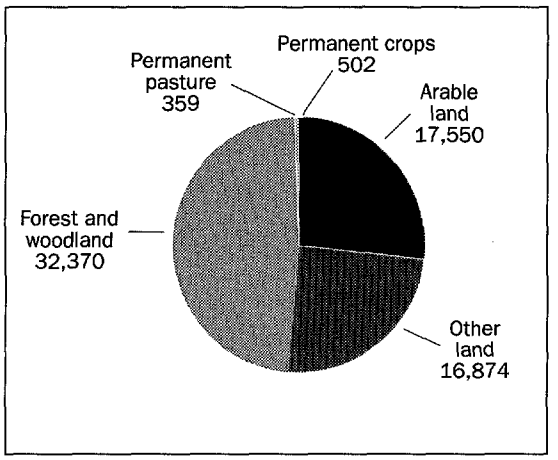


Trends in population, rice production, area, and yield.

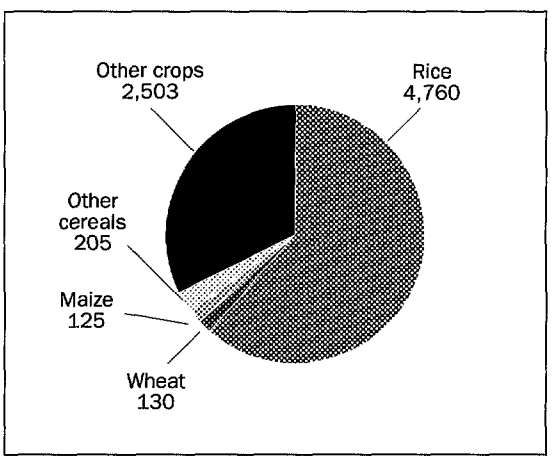
Myanmar

Land (km^2)[a]	
Total area	676550
Population[a]	
Total population (no. × 10^3)	41979
Urban population	10495
Rural population	31484
Agricultural population	19688
Agricultural labor force	8564
Population density (no./km^2)	63.84
Annual growth rate (%)[b]	2.23
Gross domestic product (US$ × 10^6)[a]	21793
Agricultural share in GDP (%)[a]	55
Land use (ha × 10^3)[a]	
Irrigated agricultural area	1008
Harvested area, modern rice varieties	2623
Harvested area, traditional varieties	2207
Rice production (t × 10^3)	
Irrigated rice	3636
Rainfed lowland rice	7536
Upland rice	290
Flood-prone rice	1739
Total rough rice	13201
Yield (t/ha)	
Irrigated rice	4.2
Rainfed lowland rice	3.0
Upland rice	1.0
Flood-prone rice	1.5
Average Yield[c]	2.7
Per capita rice consumption (kg)[a]	
Milled	190
Rough rice equivalent	292
Per capita calorie supply (no.)	
Daily total supply	2448
Calories supplied by rice	1893
Rice trade (t × 10^2)	
Total imports	0
Total exports	1763
Fertilizer use, chemical sources (t × 10^3)[a]	
Total consumption (N,P,K)	62
N	53
P	7
K	2

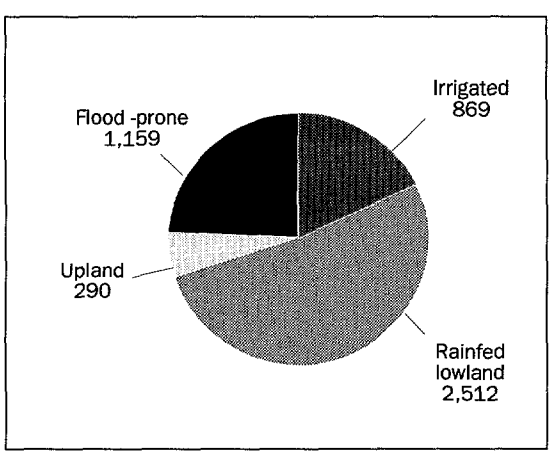
Data are for 1991 unless otherwise indicated. [a]1990. [b]1985-90. [c]Weighted average for all ecosystems.



Land use by physical area (ha × 10^3).

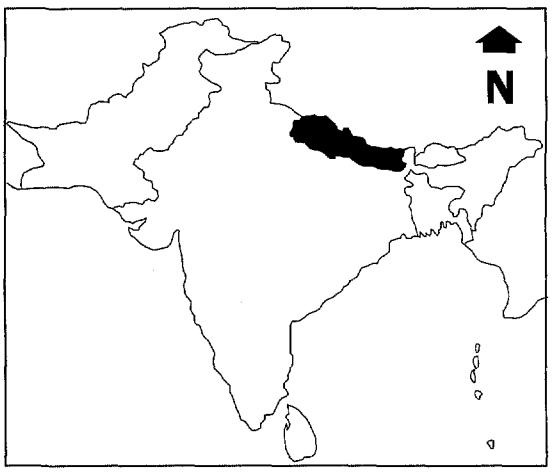


Area (ha × 10^3) harvested, temporary crops, 1990.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)



Harvested rice area (ha × 10^3) by ecosystem, 1991.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)

Nepal



Nepal is a small, landlocked country wedged between China and India. It lies between 27° and 30° N latitude and 30° and 88° E longitude. Its rectangular shape covers a length of roughly 800 km and a width of from 130-140 km.

Nepal is in AEZ 6, characterized as warm subhumid subtropics with summer rainfall. However, within the short span of its width can be found all varieties of climate and topography. The topography varies from the plains of the terai (the narrow band of plains adjacent to the foothills of the Himalayas) to the deep valleys of high mountains of the north.

The country can be broadly divided into three parallel geographic regions based on topography. Proceeding from the east to the west is the terai, or lower elevation fringe of the Gangetic plain in the southern border at 100-500 m elevation; the middle hills at altitudes between 500 m and the forest line at 4,000 m; and the high mountains of the Himalayas in the north, extending above the forest line as high as 8,000 m. With more than 50% of the cultivated land in the country, the terai is the granary of Nepal. Mountain regions cover only 5% of the cultivated area.

The population of the country is more than 19 million. The economy is largely rural, with almost 90% of the population engaged in agriculture.

Importance of rice

Agriculture contributes about 60% to GDP, provides employment to over 38% of the total population, and produces 80% of the value of exports.

Rice, maize, and wheat are the three most important crops, occupying about 55%, 29%, and 23% of the cultivated area, respectively, while millet and oil seeds cover about 10% of the area. Rice (65% of the cultivated plains area) and wheat (25%) are dominant in the terai. Maize (38%), rice (28%), and millet (18%) are the most important crops in the hills.

Rice is the most important food crop of Nepal. The main diet of the Nepalese is also rice. Almost all people in the terai and river basins depend on this crop.

Rice farming dominates the agricultural sector of Nepal, which itself dominates the economy. It is, therefore, the single most important industry in the country, contributing approximately one-fourth of the GDP and occupying approximately 1.4 million ha. From 1966 to 1991, production has increased at about 2.4% per year, below the annual population growth rate of 2.6%.

Virtually all of the increase in total rice production came from increases in the area cropped. It is estimated that more than 100,000 ha of riceland (roughly 7% of the total) are double-cropped.

Recently, there has been a substantial shift (from 2% in 1965-70 to 36% in 1987) to the use of higher yielding varieties. Adoption of modern varieties has induced farmers to apply commercial fertilizers to rice, a practice not followed when local varieties are grown.

Rice environment

Rice is grown under a wide range of ecological conditions. Of the total area, 88% is in the subtropical climatic region of the terai, inner terai, and equivalent regions of foothills and river basins of valleys up to 900 m altitude. Similarly, 10% is found in the warm temperature regions from 1,000 to 1,400 m, and 2% in the cold tropical regions between 1,500 and 3,050 m, which is the highest altitude in the world for rice cultivation.

In the inner and outer terai, temperatures are similar, but the rainfall regimes vary dramatically from east to west. Rainfall, soil, and topographic variation produce a range of field water regimes, which cause major differences in the rice production potential in different areas.

In the middle hills, lower air and water temperature dictate different rice varieties, production practices, and cropping systems from those prevalent in the terai. The vast range in elevations, soils, and slopes in this region results in a diversity of rice microenvironments.

Three major rice cultural types are recognized in Nepal rice cultivation: irrigated, rainfed wetland (lowland), and dryland (upland). All are found in both the terai and the middle hills.

Rainfed wetland rice is the dominant rice cultural type, occupying about 66% of the rice area. Fertilizer use in the rainfed area is very low. Nearly all nutrients applied to rice are used in the irrigated area.

Irrigated rice has the greatest elevation range, from about 100 m to 2,500 m. Temperature, length of time of irrigation availability per year, dependability of water supply, and soil fertility are the major determinants of production potential and cropping intensity.

Upland rice is grown on about 3% of the total riceland, and is more concentrated in the western part of the country. Local varieties are grown in the entire area without fertilizer applications.

Production constraints

Constraints to rice production in Nepal fall into four broad categories: those associated with irrigation, credit and input supply, soils, and pests and diseases.

Irrigated ricelands make up about 23% of the total harvested area. However, the area is considered as only partially irrigated because of an undependable water supply, which limits yields. The lack of improved technologies for the rainfed lowland and the partially irrigated areas also keeps yields low.

Rice producers have to deal with low price incentives and the lack of credit. In addition there is a shortage of inputs such as fertilizers. Labor shortages occur during peak periods.

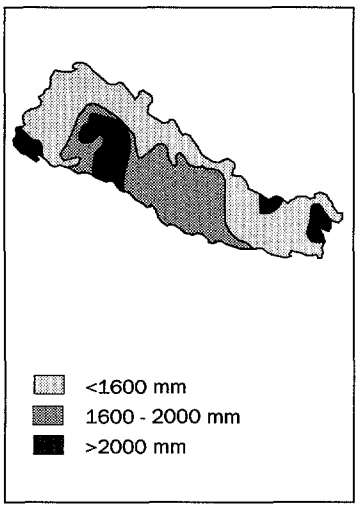
Siltation and flooding affect the terai plains; soil erosion is a problem in the middle hills. There is also declining soil fertility because of environmental degradation and the increasing cultivation of marginal lands.

Production opportunities

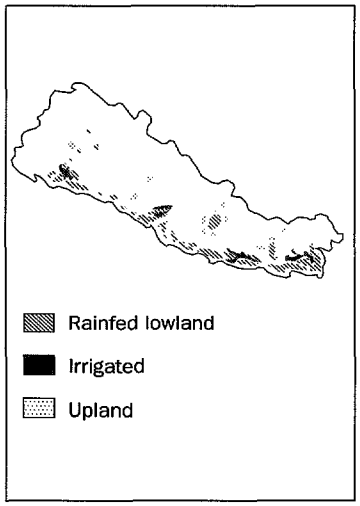
Nepal has set for itself the goal of doubling rice production by the year 2000 and elevating the income and nutritional status of small farm households. Meeting those goals depends on raising yields and intensifying cropping.

With technical change in rice production and increased inputs, rice yields are expected to increase from 2.5 to 3.5 t/ha.

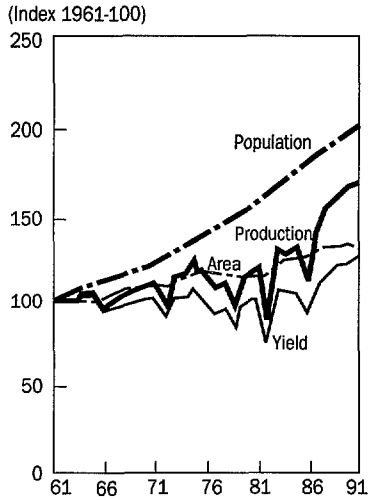
Nepal



Mean annual rainfall.



Rice ecosystems. Flood-prone areas are coterminous with irrigated areas.

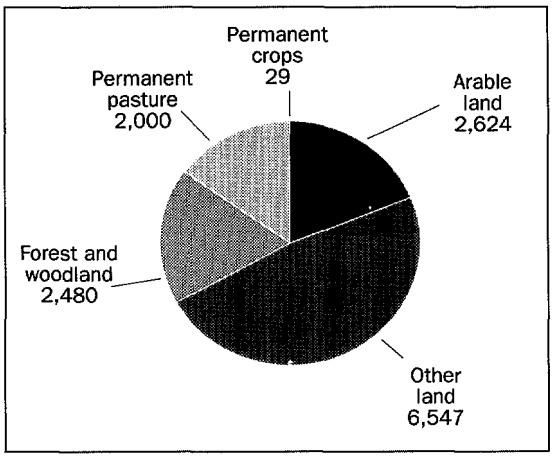


Trends in population, rice production, area, and yield.

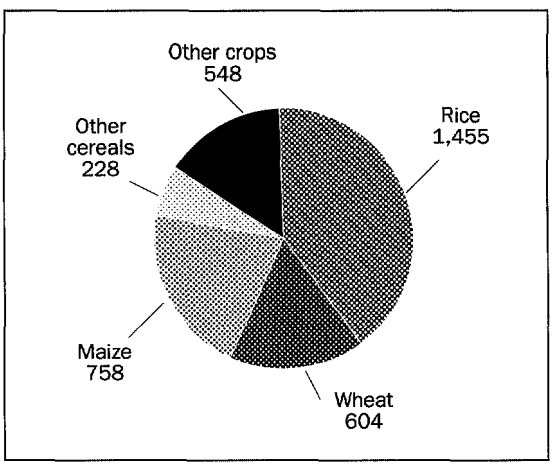
Nepal

Land (km^2)[a]	
Total area	140800
Population[a]	
Total population (no.×10^3)	19004
Urban population	1900
Rural population	17104
Agricultural population	17427
Agricultural labor force	7223
Population density (no./km^2)	138.92
Annual growth rate (%)[b]	2.60
Gross domestic product (US$ × 10^6)[a]	**2890**
Agricultural share in GDP (%)[a]	60
Land use (ha × 10^3)[a]	
Irrigated agricultural area	1000
Harvested area, modern rice varieties	524
Harvested area, traditional varieties	931
Rice production (t × 10^3)	
Irrigated rice	1385
Rainfed lowland rice	2080
Upland rice	43
Flood-prone rice	92
Total rough rice	3600
Yield (t/ha)	
Irrigated rice	4.2
Rainfed lowland rice	2.2
Upland rice	1.0
Flood-prone rice	0.8
Average yield[c]	2.5
Per capita rice consumption (kg)[a]	
Milled	102
Rough rice equivalent	157
Per capita calorie supply (no.)	
Daily total supply	2246
Calories supplied by rice	954
Rice trade (t × 10^2)	
Total imports	48
Total exports	0
Fertilizer use, chemical sources (t × 10^3)[a]	
Total consumption (N,P,K)	62
N	52
P	8
K	2

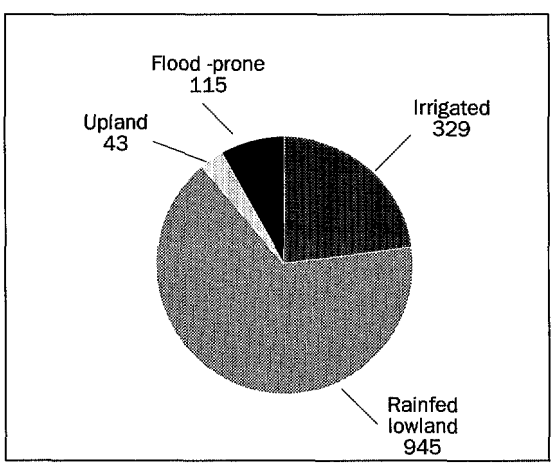
Data are for 1991 unless otherwise indicated.[a]1990. [b]1985-90. [c]Weighted average for all ecosystems.



Land use by physical area (ha × 10^3), 1990.

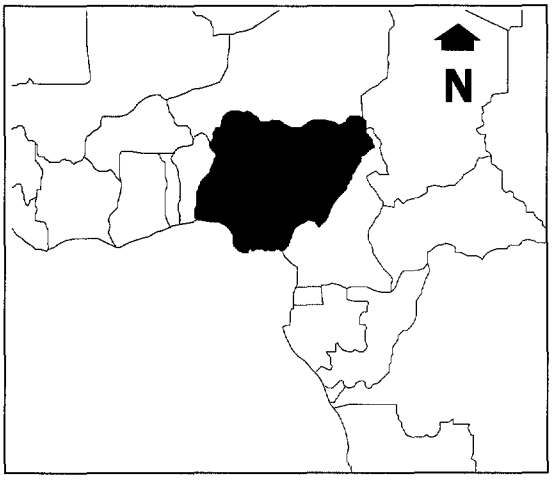


Area (ha × 10^3) harvested, temporary crops, 1990. (In determining harvested area, a land unit is counted each time it is cropped in a year.)



Harvested rice area (ha × 10^3) by ecosystem, 1991. (In determining harvested area, a land unit is counted each time it is cropped in a year.

Nigeria



Nigeria lies on the southern coast of West Africa between 2° and 15° E longitude and 5° and 15° N latitude. It is bordered by Benin in the west, Niger in the north, and Chad and Cameroon in the east. The southern coast fronts on the Gulf of Guinea. The country is divided into four regions by topography—coastal mangrove swamps in the south east, tropical rain forest, a plateau of savanna and open woodland, and semidesert in the north.

The population of 88.5 million is mostly rural, with about 35% living in urban areas. Cocoa, tobacco, palm products, peanut, cotton, and soybean are the major agricultural crops. Cocoa is the main export crop.

Importance of rice

Although rice does not figure importantly in the diet of Nigerians—making up only about 5% of total calorie supply—if the potential riceland in the country could be brought under production, rice could become the largest rice-producing country in Africa before the end of the century.

Of nearly 4.6 million ha of potential riceland, only 2.0 million ha are currently under rice cultivation. Annual rough rice production stands at about 3.5 million t, making Nigeria the largest producer in West Africa and the second largest in Africa behind Egypt.

The overall growth rate of rice production, particularly in 1985 when rice imports were banned, is estimated at 11.5%, far in excess of the World Bank estimate of 3.5% in the late 1970s. Still, with even the most optimistic projections of technology advances, agricultural investment, input use efficiency, and slower population growth, Nigeria can expect a rice deficit of about 0.2 million t in 1994.

Rice environment

Based on physical environment, especially sustained water depth and control, five rice ecosystems are recognized: upland, irrigated, rainfed lowland, floating, and mangrove. The relative contributions of these ecosystems to overall production is a function of

- actual production potential and chances for profitable enhancement;
- amount of public and private investment in research, production, and infrastructure;
- loss of land by degradation and changes in land use;
- extent to which additional land is brought under cultivation and productivity increases are achieved;
- price of rice compared with that of alternative crops; and
- population grow, irrigation, and urban encroachment.

Whatever the combined effects of these and other factors, three ecoystems will continue to dominate national rice production—irrigated, rainfed lowland, and upland.

Production constraints

Nigerian rice production has been on the increase as a result of careful introduction of exotic varieties and the breeding of improved varieties, which have won acceptance among rice farmers. Despite recent gains, average yields have remained low at less than 2 t/ha.

The main constraints to high farm productivity are

- reliance on traditional crop management and ignorance of improved technology;
- lack of modern inputs (improved seed, fertilizers, and other agrochemicals), extension services, and credit;
- lack of appropriate implements;
- pests and diseases;
- nutritional disorders, iron toxicity, acidity;
- poor soil and water management;
- lack of irrigation;
- limited appropriate technology; and
- inadequate marketing systems.

Production opportunities

The Nigerian strategy for increasing rice production is increasing yields rather than bringing more land into production. Increasing yields is thought to contribute more to sustained self-sufficiency and cost effectiveness over the long term.

Rice research is conducted through the National Cereals Research Institute (NCRI), with programs in plant breeding, agronomy, soil and fertilizer management, crop protection, and agricultural engineering.

The plant breeding program includes collection and evaluation of local and exotic germplasm; breeding for high yields and field stability, stress tolerance, disease resistance (particularly to blast and African rice gall midge), and adaptability; and seed multiplication of breeder's seed.

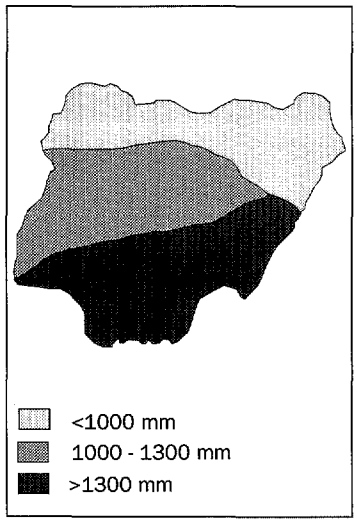
Agronomy research is aimed primarily at increasing the productivity of the lowlands through improved cultural practices. The agricultural engineering program works to develop simple and relatively inexpensive farm machines for resource-poor farmers.

Nigeria cooperates with the International Network for Genetic Evaluation of Rice (INGER) as well as international centers such as the International Institute of Tropical Agriculture, the Institute for Research in Tropical Agriculture, and the West Africa Rice Development Association.

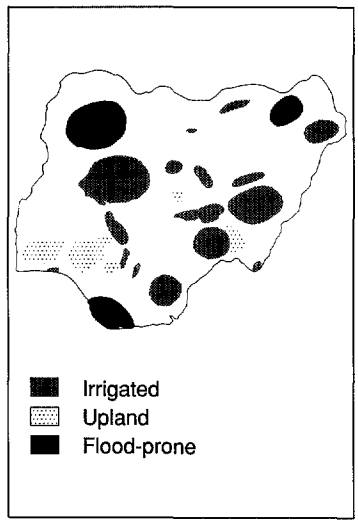
INGER nursery entries that show promise for Nigerian ecosystems are further evaluated by NCRI in multilocation tests through state agricultural development projects before they are recommended for release as commercial varieties.

Research goals for the 1990s are, first, to sustain the production gains achieved so far and, second, to continue to introduce or develop varieties with high-yielding ability, fertilizer responsiveness, resistance to or tolerance for major pests and diseases, and good grain quality.

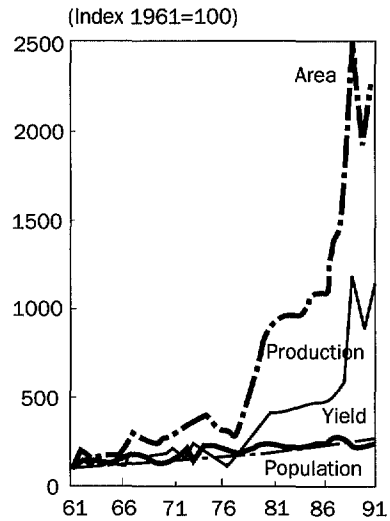
Nigeria



Mean annual rainfall.



Rice ecosystems.

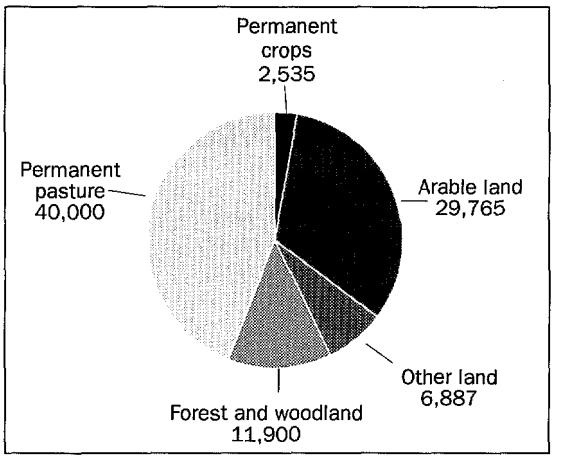


Trends in population, rice production, area, and yield.

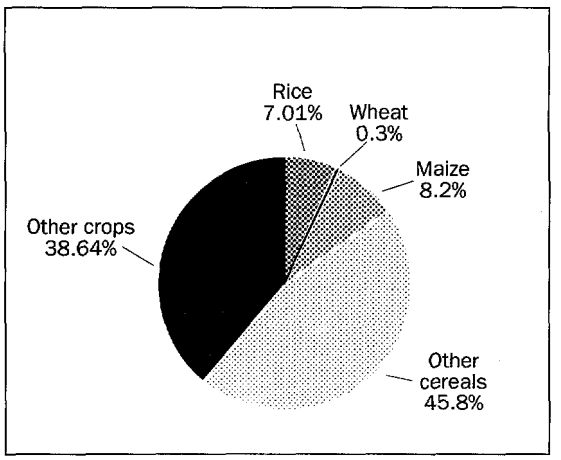
Nigeria

Land (km²)[a]	
Total area	923770
Population[a]	
Total population (no. × 10³)	116738
Urban population	40858
Rural population	75880
Agricultural population	75633
Agricultural labor force	28584
Population density (no./km²)	128.2
Annual growth rate (%)[b]	3.16
Gross domestic product (US$ × 10⁶)[a]	34760
Agricultural share in GDP (%)[a]	36
Land use (ha × 10³)	
Total irrigated agricultural area[a]	870
Harvested area, modern rice varieties[a]	1289
Harvested area, traditional varieties[a]	0
Rice production (t × 10³)	
Irrigated area	1286
Rainfed lowland area	0
Upland area	1079
Flood-prone area	820
Total rough rice	3185
Yield (t/ha)	
Irrigated area	4.9
Rainfed lowland area	0
Upland area	1.3
Flood-prone area	1.5
Average yield[c]	1.9
Per capita rice consumption (kg)[a]	
Milled	12
Rough rice equivalent	19
Per capita calorie supply (no.)	
Total calorie supply	2147
Calories supplied by rice	130
Rice trade (t × 10²)	
Total imports	2500
Total exports	0
Fertilizer use, chemical sources (t × 10³)[a]	
Total consumption (N, P, K)	330
N	210
P	42
K	78

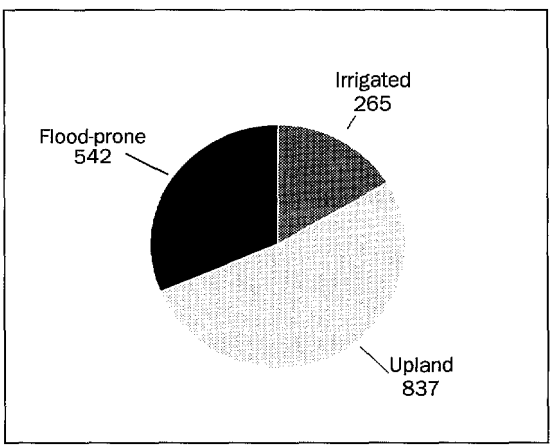
Data are for 1991 unless otherwise indicated. [a]1990. [b]1985-90. [c]Weighted average is for all ecosystems.



Land use by physical area (ha × 10³), 1990.

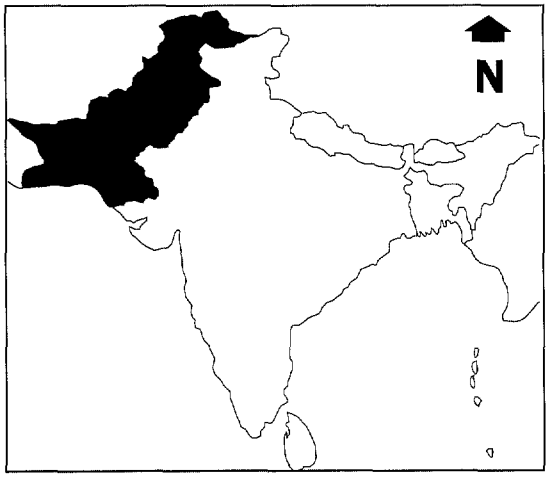


Area harvested, temporary crops, 1990.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)



Harvested rice area (ha × 10³) by ecosystem, 1991.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)

Pakistan



Pakistan is located in between 24° and 36° N latitude and 62° and 76° E longitude. The wedge-shaped country is bounded on the south by the Arabian Sea, on the southwest by Iran, on the northwest by Afghanistan, on the northeast by the People's Republic of China, and on the east by India.

Elevation ranges from sea level on the Arabian sea to over 7,600 m in the north. The country may be roughly divided into three geographical regions: the highlands, where the western extension of the Himalayan mountains meets that of the Hindu Kush; the vast, lightly populated southwestern plateau and the mountains on the north and northwestern flank of the country; and the upper and lower plains of the Indus River.

Pakistan lies in AEZ 5, characterized as warm arid and semiarid subtropics with summer rainfall. Climate varies from north to south over different periods of the year, but the country is generally arid. There are four seasons: a relatively dry-cool winter from December through March, the dry-hot summer from April through June, the summer rainy season or southwest monsoon from July through September, and the retreating monsoon period of October and November.

Average rainfall is around 250-500 mm in the upper Indus River plains and part of the western plateau, only 125-250 mm in the lower Indus River plains and most of the southwestern plateau, and around 500-1,000 mm in the northern high altitudes. About 80% of total annual rainfall comes during July and August.

The population in 1990 was 114.3 million. About 68% of the people live in rural areas, although the proportion is slowly decreasing. About 52% of the population is engaged in agriculture.

Importance of rice

The economy of Pakistan is still largely based on agriculture. In 1988-89, 26% of GDP was generated in the farming sector, down from 34% in 1975-76.

Wheat is the staple crop, providing about half of the daily calorie intake. Rice provides only 8% of the daily calorie intake. Annual per capita consumption of wheat is 124 kg/yr compared with only 19 kg/yr for rice.

Unlike in other South and Southeast Asian countries, rice is not considered a subsistence crop in Pakistan. It is a cash crop grown for export. Rice is the third major crop, after wheat and cotton, in its contribution to GDP originating from agriculture. It contributes 13% while wheat and cotton each contributes around 30%.

Rice is the second major crop in its contribution to export earnings from raw material, contributing about 9%/yr to foreign exchange earnings from raw items. Pakistan exports about 1 million t of rice annually, which is about 10% of the world rice trade. The annual export of about 250,000 t of long-grained, aromatic, fine-quality rice (called basmati), goes mainly to the Middle East market. About 500,000 t of long-grained, modern varieties (MVs) are exported each year to South and Southeast Asia. The international market price for basmati rice has been three times or more than that of the MVs.

Rice environment

Rice occupies about 25% of the cultivated area in the summer monsoon season and 10% of the total cropped area. Wheat, being the staple food, occupies 75% of the cultivated area in the winter season and about 38% of the total cropped area.

Of the nearly 20 million ha of cultivable land, 16.5 million ha are irrigated. Crop production on the remaining area depends mainly upon rainfall.

As in many other sites in South Asia, rice cultivation in Pakistan generally follows a wheat crop on the same parcel.

Production constraints

Despite a fairly stable irrigation water supply, rice yields are low for both traditional basmati and MVs. There is a potential for about 25% higher yields at the present level of inputs. This potential can be achieved by advancing farm-management practices through improved institutional functioning, access to infrastructure, and developing technologies consistent with farm conditions.

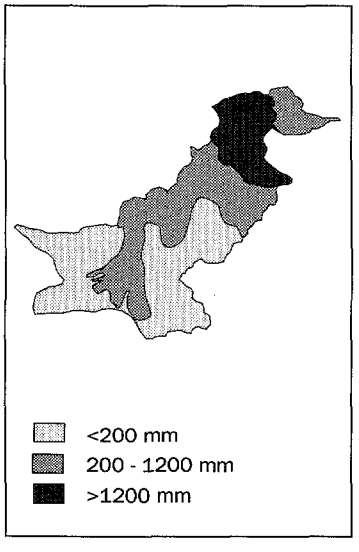
Of more immediate concern is sustaining yields, even at the current level. Rice yields of MVs are stagnating and those of basmati rice are declining. The reasons for stagnating or declining yields are thought to be the increasing incidence of salinity caused by injudicious use of irrigation water, mismanagement in the use of inputs such as fertilizer, unfit underground water, soil nutrient depletion, the development of insect-pest and weed complexes peculiar to the rice - wheat system, and inadequate economic incentives for long-term investments in land and soil improvements.

Production opportunities

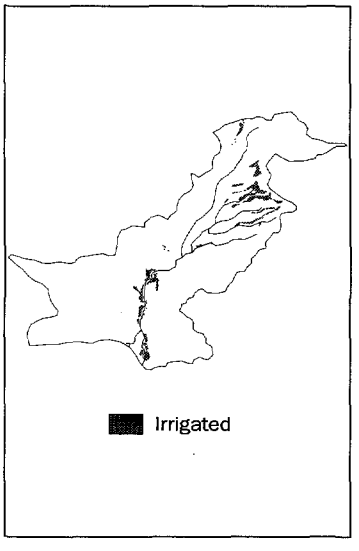
Pakistan has strong rice research programs at the national and provincial levels. At the national level, the Rice Coordination Program in the Pakistan Agricultural Research Council coordinates provincial research activities and links these activities to the international agricultural research centers such as IRRI and the International Irrigation Management Institute (IIMI). Recently, the Kala Shah Kakuo Research Institute offered farmers in Punjab a fertilizer-responsive, short-duration, high-yielding, basmati rice variety, which increases the time available for land preparation for wheat after rice. The Dokri Rice Research Institute works to improve postharvest processing, soil fertility, rice - wheat system, and insect management. IIMI is working on water management issues to address waterlogging and salinity problems.

Pakistan has strong collaborative programs with IRRI through the rice - wheat project funded by the Asian Development Bank. Sustainability issues and new technologies are being tested for the site-specific environments. The rice - wheat collaborating countries (Bangladesh, India, Nepal, and Pakistan) share each other's experience.

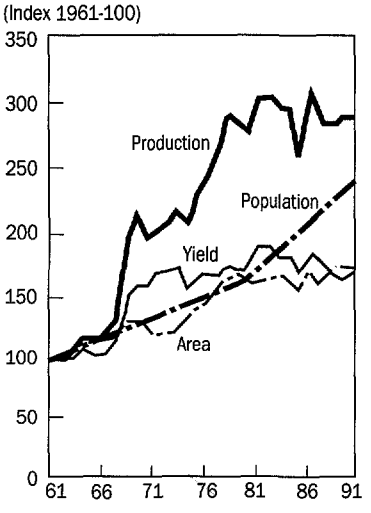
Pakistan



Mean annual rainfall.



Rice ecosystems.

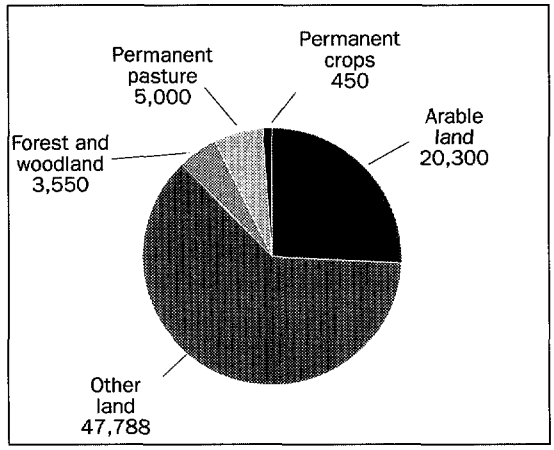


Trends in population, rice production, area, and yield.

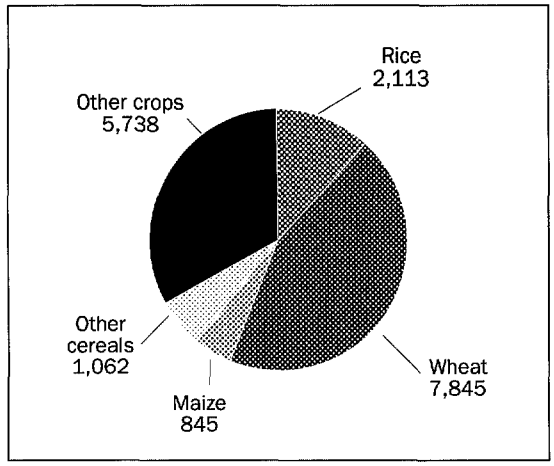
Pakistan

Land (km^2)[a]	
Total area	796100
Population[a]	
Total population (no. × 10^3)	114290
Urban population	36573
Rural population	77712
Agricultural population	59431
Agricultural labor force	16389
Population density (no./km^2)	148.26
Annual growth rate (%)[b]	3.45
Gross domestic product (US$ × 10^6)[a]	35500
Agricultural share in GDP (%)[a]	26
Land use (ha × 10^3)[a]	
Irrigated agricultural area	16500
Harvested area, modern rice varieties	887
Harvested area, traditional varieties	1226
Rice production (t × 10^3)	
Irrigated rice	4903
Rainfed lowland rice	0
Upland rice	0
Flood-prone rice	0
Total rough rice	4903
Yield (t/ha)	
Irrigated rice	2.4
Rainfed lowland rice	0
Upland rice	0
Flood-prone rice	0
Average yield[c]	2.4
Per capita rice consumption (kg)[a]	
Milled	19
Rough rice equivalent	29
Per capita calorie supply (no.)	
Daily total supply	2377
Calories supplied by rice	189
Rice trade (t × 10^2)	
Total imports	0
Total exports	12046
Fertilizer use, chemical sources (t × 10^3)[a]	
Total consumption (N,P,K)	1671
N	1472
P	171
K	27

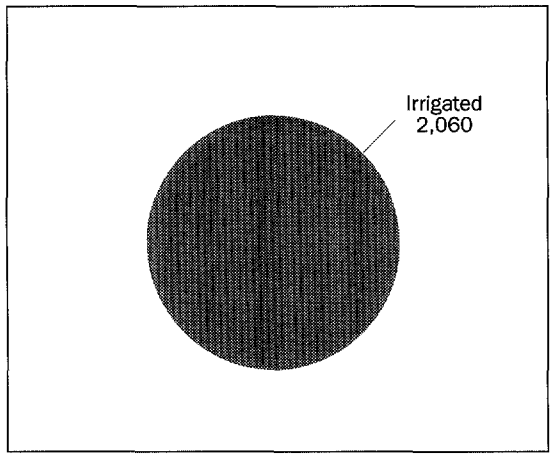
Data are for 1991 unless otherwise indicated. [a]1990. [b]1985-90. [c]Weighted average for all ecosystems.



Land use by physical area (ha × 10 ³), 1990.

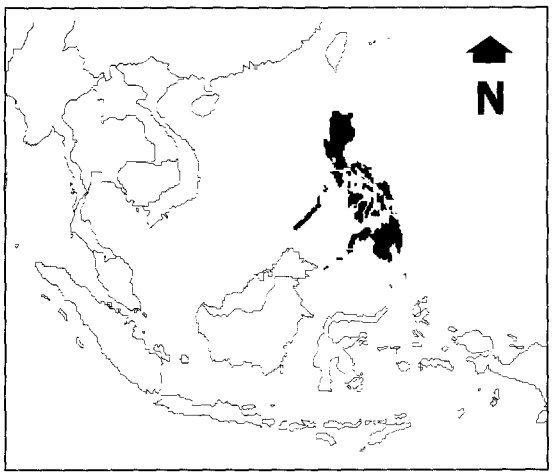


Area (ha × 10 ³) harvested, temporary crops, 1990.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)



Harvested rice area (ha × 10 ³) by ecosystem, 1991.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)

Philippines



The Philippines is an archipelago of some 7,100 islands located between 4° and 21° N latitude and 116° and 127° E longitude. The country is bounded by the South China Sea to the west, the Pacific Ocean to the east, the Sulu and Celebes Seas to the south, and the Bashi Channel to the north.

It is in AEZ 3, characterized as warm humid tropics. The climate is tropical marine, i.e., mainly moderated by the surrounding seas, with a November to April northeast monsoon and a May to October southwest monsoon. Climate also varies within the country because of a mountainous topography. There are four general climatic types: 1) two pronounced seasons, dry from November to April and wet the rest of the year (central Luzon, western Visayas), 2) absence of a dry period, but with maximum rains from November to January (eastern Luzon, eastern Visayas, and northeast Mindanao), 3) dry from November to February and wet the rest of the year (central Visayas, western Bicol, northern Mindanao), and 4) more or less even rainfall distribution throughout the year (central Mindanao).

The population was 62 million in 1990, with a growth rate of 2.2% per year. Infant mortality rate in 1992 was 53 deaths/1000 live births, and life expectancy was 62 yr (male) and 68 yr (female). The population is predominantly rural (57%), with 43% living in urban areas. Employment in the agricultural sector accounted for 44% of the 24-million-person labor force.

Importance of rice

Agriculture, including forestry and fisheries, contributed approximately 22% to total GDP of the Philippines in 1990. Rice constituted about 16% of total crop production and 66% of total cereal production. Total harvested rice area was 3.5 million ha in 1980 and 3.4 million ha in 1991, about 13% lower than the area under maize. The rice area of the country planted to traditional varieties (TVs) decreased from 23% in 1980 to 13% in 1988; while production from modern varieties (MVs) stood at 87% in 1991, about 13% lower than the area under maize. Mean yields were 2.2 t/ha in 1980 (1.5 t/ha for TVs and 2.4 t/ha for MVs) and 2.6 t/ha in 1988 (1.9 t/ha for TVs and 2.8 t/ha for MVs). Rice production increased from 7.7 million t in 1980 to about 9.7 million t in 1991. Although the Philippines was self-sufficient in rice from 1980 to 1983 and in 1987, it imported 190,000 t of rice in 1984 and 920,000 t in 1991.

Rice environments

Of the approximately 3.4 million ha of ricelands, some 2.1 million ha (61%) are irrigated, 1.2 million ha (35%) are rainfed lowland, and 0.07 million ha (2%) are upland. Much of the country's irrigated rice is grown on the central plain of Luzon, the country's ricebowl. The rest comes mainly from various coastal lowland areas and gently rolling erosional plains, e.g., in Mindanao and Iloilo. Rainfed rice is found in the Cagayan Valley in northern Luzon, in Iloilo Province, and on the coastal plains of the Visayas region and Ilocos in northern Luzon. Upland rice is grown in both permanent and shifting cultivation systems scattered throughout the archipelago on rolling to steep lands.

Production constraints

Irrigated rice cultivation has increased in intensity to up to three crops per year in Central Luzon. Problems associated with such intensified systems include yield stagnation (and a possible yield decline) due to factors that are not yet fully understood, deterioration of irrigation systems (given low and decreasing investments in systems maintenance), and increased pests (insects, weeds) and diseases in some areas. Rainfed lowland rice suffers from uncertain timing of arrival of rains,

and drought and submergence—often on the same fields over the course of a single season or on different fields within a farm over the same season. Weeds, drought, diseases (blast), acidic soils, and soil erosion are major problems of upland rice in the Philippines.

Production opportunities

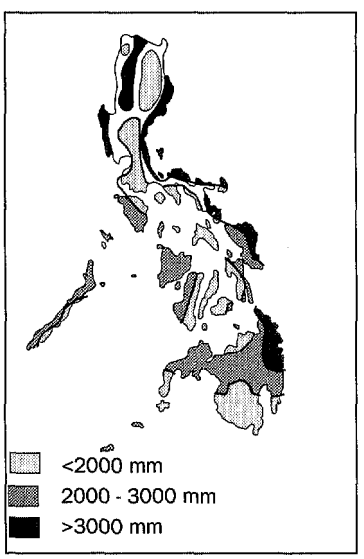
In terms of agricultural research and development, the Philippines has the advantages of a relatively strong Department of Agriculture, a network of state colleges—e.g., the Visayas State College of Agriculture—and universities—e.g., University of the Philippines at Los Baños, Central Luzon State University, Central Mindanao University—offering agricultural curricula. There is also a national rice research institute (PhilRice) created in 1985.

PhilRice is located in Central Luzon. It seeks to improve the economic conditions of small farmers and, more specifically, to develop and implement a national rice research and development program, sustain gains made in rice production, solve site-specific problems of the rice industry, and direct and coordinate activities of all agencies in the country working on rice. PhilRice has eight program areas: rice varietal improvement, planting and fertilizer management, integrated pest management, rice-based farming systems, rice engineering and mechanization, rice chemistry and food science, social science and policy research, and technology transfer.

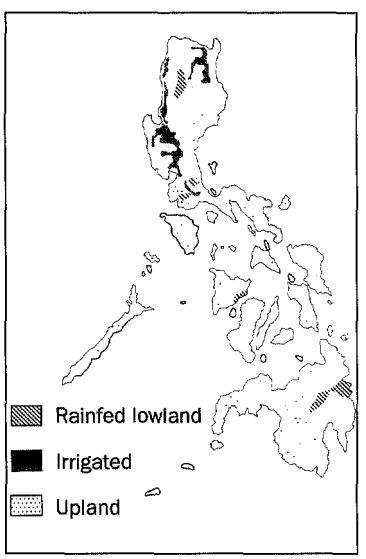
In the near term, few gains are expected in irrigated rice in the Philippines. MVs and corresponding management practices have been adopted in most of the irrigated and favorable rainfed lowland areas. Deterioration of irrigation schemes and conversion of ricelands to urban uses pose longer-term problems.

Some economic gains at the farm level may be expected through further adoption of direct wet seeded rice and mechanization (new harvesters). Rainfed lowland rice gains may result from some crop intensification in more favorable areas, further adoption of direct dry seeded rice, and development of new rice varieties adapted to rainfed lowland stresses. Upland rice systems in the Philippines are the least sustainable, and future system maintenance will require policies and technologies encouraging a slowing of deforestation rates, the control of soil erosion, and conversion of cereal production systems to mixed systems with perennial crops on sloping lands.

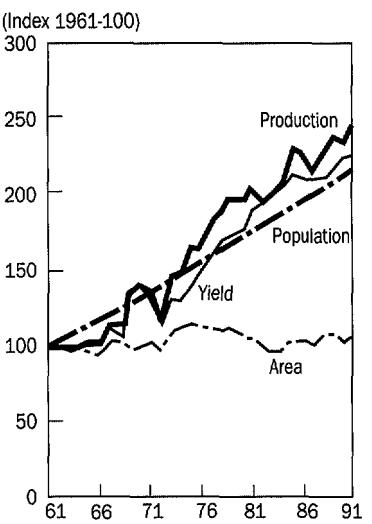
Philippines



Mean annual rainfall.



Rice ecosystems.

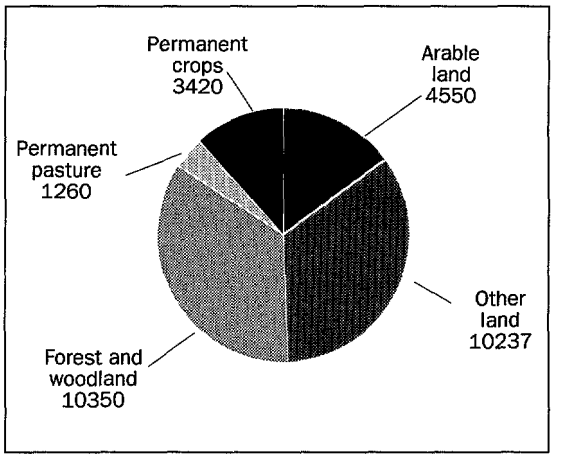


Trends in population, rice production, area, and yield.

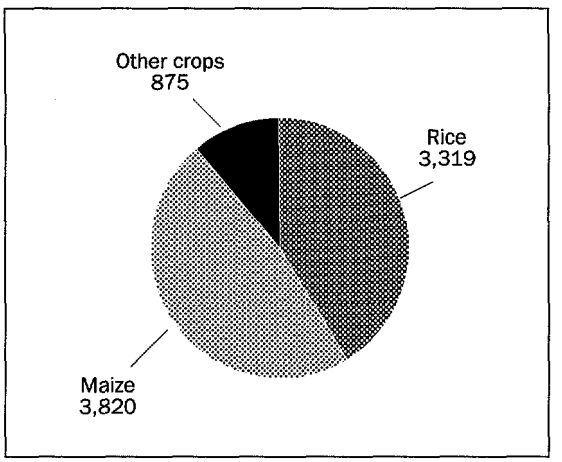
Philippines

Land (km^2)[a]	
Total area	300000
Population[a]	
Total population (no. × 10^3)[a]	62154
Urban population	26726
Rural population	35428
Agricultural population	28902
Agricultural labor force	10461
Population density (no./km^2)	208.45
Annual growth rate (%)[b]	2.15
Gross domestic product (US$ × 10^6)[a]	43860
Agricultural share in GDP (%)[a]	22
Land use (ha × 10^3)[a]	
Irrigated agricultural area	1560
Harvested area, modern rice varieties	2954
Harvested area, traditional varieties	365
Rice production (t × 10^3)	
Irrigated rice	7117
Rainfed lowland rice	2396
Upland rice	68
Flood-prone rice	89
Total rough rice	9670
Yield (t/ha)	
Irrigated rice	3.4
Rainfed lowland rice	2.0
Upland rice	1.0
Flood-prone rice	1.3
Average yield[c]	2.8
Per capita rice consumption (kg)[a]	
Milled	99
Rough rice equivalent	152
Per capita calorie supply (no.)	
Daily total supply	2452
Calories supplied by rice	995
Rice trade (t × 10^2)	
Total imports	920
Total exports	100
Fertilizer use, chemical sources (t × 10^3)[a]	
Total consumption (N,P,K)	516
N	401
P	46
K	69

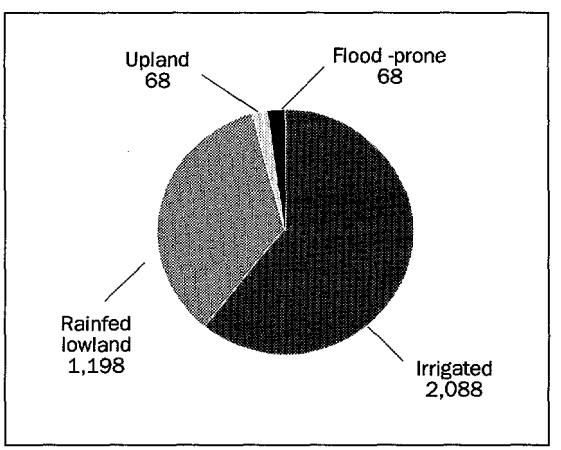
Data are for 1991 unless otherwise indicated. [a]1990. [b]1985-90. [c]Weighted average for all ecosystems.



Land use physical area (ha × 10^3), 1990.

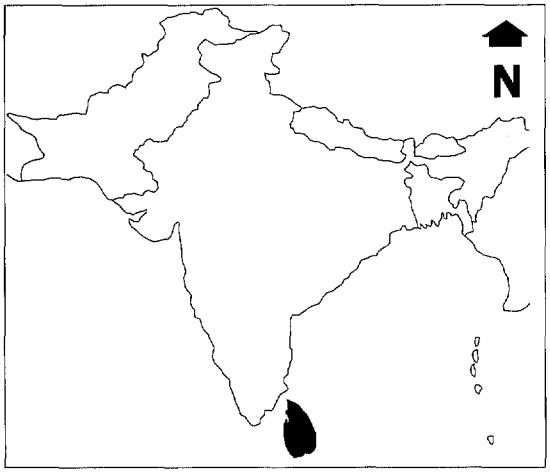


Area (ha × 10^3) harvested, temporary crops, 1990.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)



Harvested rice area (ha × 10^3) by ecosystem, 1991.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)

Sri Lanka



Sri Lanka is a pear-shaped island lying at the southern extremity of India, between 6° and 10° N latitude and 79° and 81° E longitude. The island extends 432 km north and is 224 km wide. Its highest peak reaches 2,526 m above sea level.

Sri Lanka lies in two AEZs: AEZ 2, characterized as warm subhumid tropics; and AEZ 3, characterized as warm humid tropics. It has a tropical monsoon climate. In the course of a year the monsoon occurs twice: the southwest monsoon from mid-May to September, and the northeast monsoon from December to February. Together with transitional periods (intermonsoon), there are two distinct seasons, locally called maha (October to February) influenced by the northeast monsoon, and yala (March to September) influenced by the southwest monsoon.

Rainfall varies to a remarkable extent, ranging from about 1,000 mm in the driest parts to about 5,500 mm in the wettest parts. The northeast monsoon is strong and brings rain to the whole island. The southwest monsoon is weak and only the windward slope receives heavy rains.

Therefore, the island is broadly divided into two major climatic zones: the wet zone (southwestern part of the island), which receives rain from both the northeast and southwest monsoons, and the dry zone. The average temperature ranges from 26 to 28 °C in the plains and from 14 to 24 °C in the hilly areas.

The total population of Sri Lanka in 1990 was 17 million, with an annual growth rate of 1.4%. Nearly 80% of the population is rural. The main economic activities of rural areas are agriculture, fishing, and cottage industries.

Importance of rice

The agriculture sector accounts for 26% of GDP; rice makes up about 5%.

Rice is the staple food of Sri Lankans. At present, about 10% of the domestic rice requirement is imported. The annual per capita consumption of rice is approaching 100 kg, which represents 75% of total grain consumption. Some 40% of the total calories is derived from rice. Wheat is the next most important food. All wheat is imported and average per capita consumption is about 30 kg.

Rice farmers derive about 50% of their total income from rice cultivation.

Dramatic changes took place in Sri Lanka's rice production during the past 15 yr. Annual production doubled while the area under rice increased by about 30% and average yield increased by 44%. Yet Sri Lanka remains a net rice importer.

Improved varieties are cultivated on about 95% of the total ricelands. Increasing costs, decreasing real profits, and some water problems have led farmers to cultivate other crops wherever possible. They are substituting high-value cash crops for rice, for local as well as export markets.

Rice environment

Of the 860,000 ha of total riceland, 321,000 (42%) are irrigated. The remainder are rainfed lowlands, with about 25,000 ha of tidal rice along the southwestern coast. Approximately 17% of the rainfed lowlands are of favorable type, 74% are drought prone, and 6% are submergence-prone or submergence- and drought-prone.

The majority of irrigated and drought-prone rainfed lowlands are in the dry and intermediate zones. Ricelands in these zones are located mainly on floodplains and valley bottoms where soils are clayey and the water table is high. In the wet zone, ricelands are situated mainly on terraced slopes and narrow inland valleys of the highly dissected middle peneplain.

Production constraints

Sustainability problems have begun to surface in recent years, especially in the highly productive areas of the dry zone. Increasing costs, reducing profits, flat or declining yields, and micronutrient deficiencies are observed.

Drought in rainfed areas and water shortages in irrigated areas are more frequent than before in the dry zone. As a result, the area grown to short-duration varieties has increased considerably. Seasonal flooding is a regular occurrence in the coastal plains of the wet zone.

In the wet zone where ricelands are situated in the valley bottoms, low solar radiation is the major limiting factor for high yields.

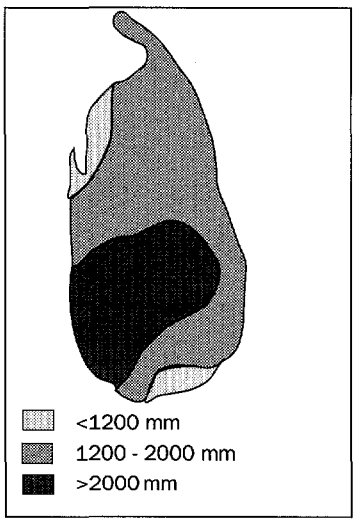
The geographical location of the dry zone ensures favorable air and soil temperatures as well as adequate solar radiation for rice cultivation throughout the year. Although salinity and alkalinity are reported, only minor soil chemical problems are encountered on soils of the dry zone. In poorly drained Ultisols of the wet zone, P and K deficiencies, and Fe toxicity are common. Peaty and acid sulfate soils are found in the coastal plain. Some of them are also affected by salinity due to saltwater intrusion from the sea.

Production opportunities

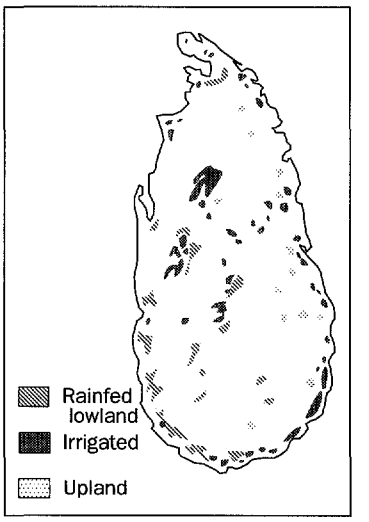
During the period 1975-85, massive investments were made to increase the extent of irrigable lands. Rice self-sufficiency is still an objective, but the resources allocated to increase the production of other crops have increased considerably during the recent past.

Total rice production is now reaching a plateau as a result of stagnating yields and limited possibilities for area expansion. Only about 60% of the potential yields are attainable. The Department of Agriculture spends about 40% of its resources on research, technology transfer, and rice seed production. A collaborative project with IRRI, supported by the Swedish Agency for Research Cooperation with Developing Countries, is designed to implement a strategy for achieving and sustaining rice self-sufficiency in Sri Lanka.

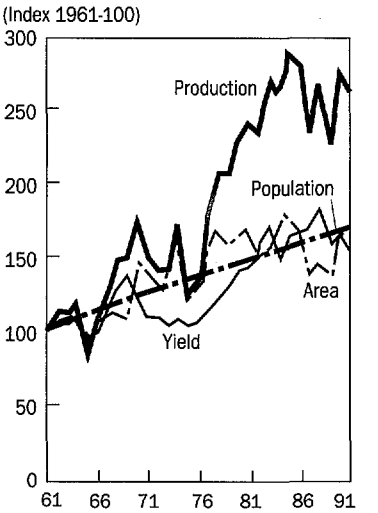
Sri Lanka



Mean annual rainfall.



Rice ecosystems.

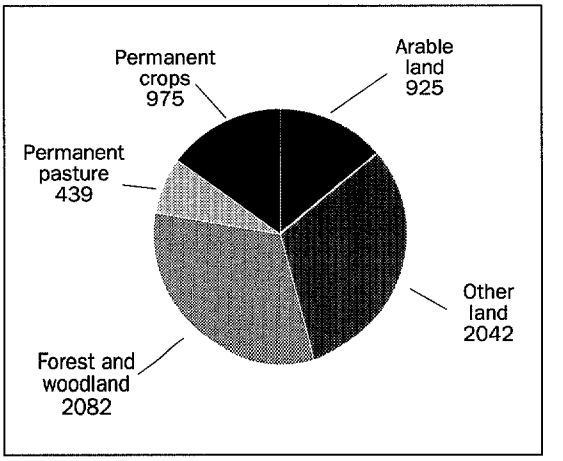


Trends in population, rice production, area, and yield.

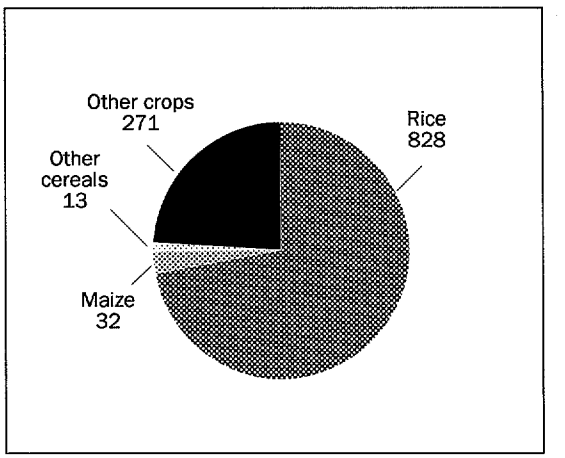
Sri Lanka

Land (km²)[a]	
Total area	65610
Population[a]	
Total population (no. × 10³)	17247
Urban population	3621
Rural population	13626
Agricultural population	8790
Agricultural labor force	3247
Population density (no./km²)	263
Annual growth rate (%)[b]	1.42
Gross domestic product (US$ × 10⁶)[a]	7250
Agricultural share in GDP (%)[a]	26
Land use (ha × 10³)[a]	
Irrigated agricultural area	520
Harvested area, modern rice varieties	753
Harvested area, traditional varieties	75
Rice production (t × 10³)	
Irrigated rice	1118
Rainfed lowland rice	1123
Upland rice	60
Flood-prone rice	26
Total rough rice	2397
Yield (t/ha)	
Irrigated rice	3.5
Rainfed lowland rice	2.5
Upland rice	1.0
Flood-prone rice	1.0
Average yield[c]	2.8
Per capita rice consumption (kg)[a]	
Milled	100
Rough rice equivalent	145
Per capita calorie supply (no.)	
Daily total supply	2286
Calories supplied by rice	970
Rice trade (t × 10²)	
Total imports	1330
Total exports	5
Fertilizer use, chemical sources (t × 10³)[a]	
Total consumption (N,P,K)	146
N	92
P	13
K	42

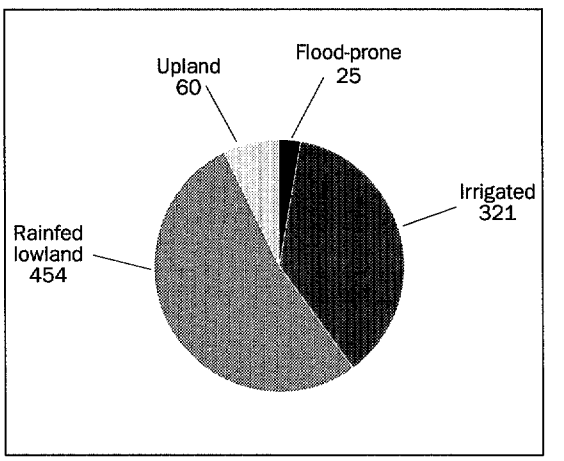
Data are for 1991 unless otherwise indicated. [a]1990. [b]1985-90. [c]Weighted average for all ecosystems.



Land use by physical area (ha × 10³), 1990.

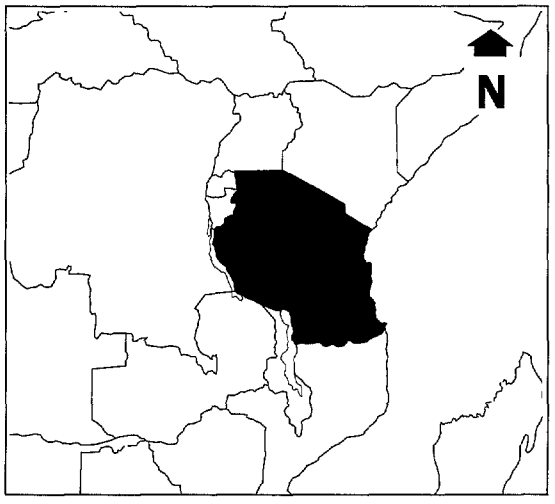


Area (ha × 10³) harvested, temporary crops, 1990.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)



Harvested rice area (ha × 10³) by ecosystem, 1991.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)

Tanzania



Tanzania lies on the east coast of Africa between 1° and 11° S latitude and between 29° and 40° E longitude. The land area is about 1 million km^2, including the off-shore islands of Zanzibar, Pemba, and Mafia. Tanzania is bordered by Kenya in the north and shares Lake Victoria with Kenya and Uganda in the west. Tanzania has frontiers with Rwanda, Burundi, and Zaire in the southwest, and with Zambia, Malawi, and Mozambique in the south.

Tanzania is dominated by the effects of plate tectonic movements, which have formed a dramatic landscape of mountains, lakes, and rolling plains. To the northwest, the huge Lake Victoria Basin separates the western and eastern rift valleys and the separation is continued by the Central Plateau, which is more than 2,000 m in elevation. The northeast border with Kenya is dominated by Mt. Meru and Mt. Kilimanjaro, the highest peak in Africa, and associated spectacular lakes, calderas, and grassland steppes. A second mountain range, the Southern Highlands, separates the Eastern Plateau from the rest of the country. The coastal belt is an important rice-growing area.

The climate is tropical. Rainfall is generally low and unreliable for rice growing. Only a few areas receive more than 1,000 mm annually, but most of the rice-growing areas average 600-800 mm annually. Rainfall in most of the north of the country is bimodal. Rains usually start in October and end in May, with dry months in January and February. The bimodal rains mean that drought resistance is needed for rainfed rice, and special varieties are needed to permit double cropping in the mid-altitude lands.

The south experiences a single wet season from November to April. The normal tropical temperature pattern is affected by altitude over most of the western half of the country, with mean minimum temperature below 15 °C from June to August. Light intensity is good throughout the country.

Importance of rice

Rice is an important crop in Tanzania, with 60% of the population eating some rice. Annual per capita consumption has risen from less than 15 kg in the 1970s to more than 50 kg. Annual rice production is about 800,000 t, up from an estimated 300,000 t annually in 1980. Imports, however, continue to be necessary. About 60,000 t/yr are needed to cover the shortfall.

Rice environment

Only about 16% of the 40 million ha suitable for arable cropping are used for farming. About 17 million ha are thought to be potentially suitable for rainfed or irrigated rice. But at present less than 500,000 ha of rice is grown. Principal areas of rice production are listed below, along with an indication of their potential.

- The Usangu Plains area has an estimated 200,000 ha of irrigable land.
- The Kilombero Valley is one of the most important areas for small farm production. Potential riceland exceeds 300,000 ha, 40,000 ha of which have high potential.
- The Coastal Region experiences no cool season constraints; there is good production potential in the Ruvu and Rufiji Valleys and in the Ruvu Basin.
- The Pangani River Basin, which includes the Rau River system, has 2,300 ha now developed near Moshi and a total potential of more than 150,000 ha.
- The Lindi Mtwara Region has at least eight irrigation projects totaling more than 13,000 ha planned or installed.
- The Ruvuma Region has potential ricelands of some 20,000 ha, some of which are in production.
- The Shinyanga, Mwanza, and Tabora Regions also produce rice. Farmers in these regions have developed effective rice-growing methods without formal irrigation investments.

- Zanzibar and Pemba have about 17,000 ha of ricelands, 5,000 ha of which are suitable for irrigation, much of it by groundwater. About 1,000 ha are under double-cropped irrigated production.

Production constraints

Excellent yields were recorded on state farms (more than 7 t/ha at Mbarali) in the early 1980s. Since then, problems with management, shortage of investment capital for equipment, increasing weed problems, and loss of level fields have become increasingly serious. A major problem is that the farms were planned in the early 1980s when world rice prices were very high; prices have since slipped to less than half of what they were then. The capital-intensive inputs such as machinery and agricultural chemicals are no longer economical at today's rice prices.

The constraints experienced by family farmers are somewhat different from those affecting the state farm sector. Investments are essentially zero and most farmers use traditional varieties. Most farms do not have irrigation water on demand, and fields are not leveled. Such farms often have upland, hydromorphic, and flooded conditions within a 2-ha area, and these conditions may vary from one area to another during the season.

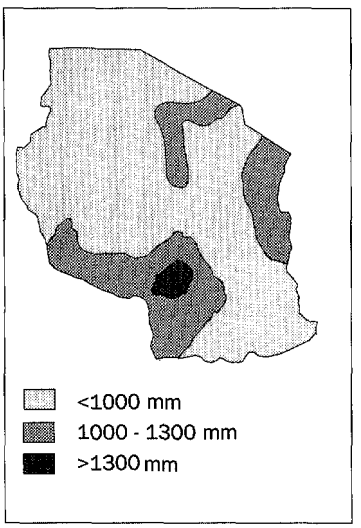
Hand hoes are the most common cultivation tools, with a few farms using ox-drawn plows or rented tractors. Weed competition is consequently very serious, and that, combined with drought risk, means that responses to higher inputs, such as modern varieties and fertilizer, are unreliable.

Losses from damage by wandering stock, game animals, rats, and birds are more serious than losses from diseases and insect pests, which tend to increase with intensification of the rice system. Most of the serious pests and diseases of rice exist only at relatively low levels; tungro virus and brown planthopper do not occur. The low insect pest and disease pressure has enabled the state farms to continue growing IR8 up to now in spite of its susceptibility to several pests and diseases, which have led to its replacement in most of Asia.

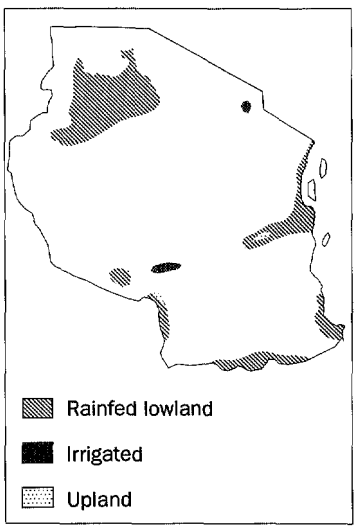
Production opportunities

Developing irrigation systems to bring potential ricelands into production offers the greatest opportunity for increased rice production. With irrigation water available on demand, farmers would more likely be willing to risk the investment in improved varieties and other inputs necessary to increase yields.

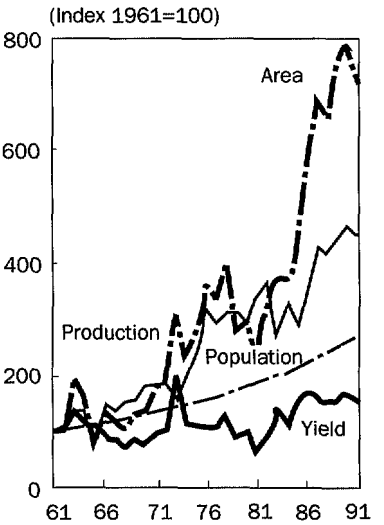
Tanzania



Mean annual rainfall.



Rice ecosystems.

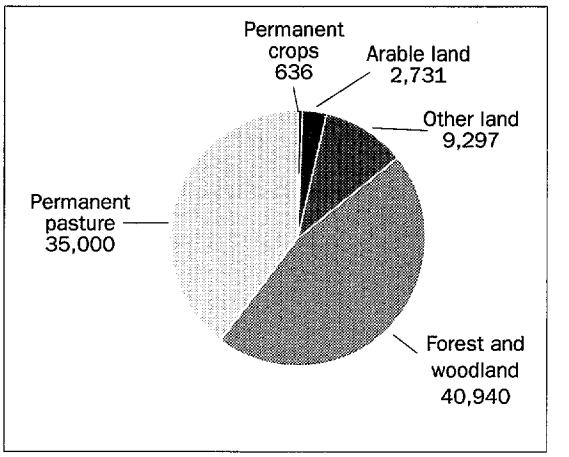


Trends in population, rice production, area, and yield.

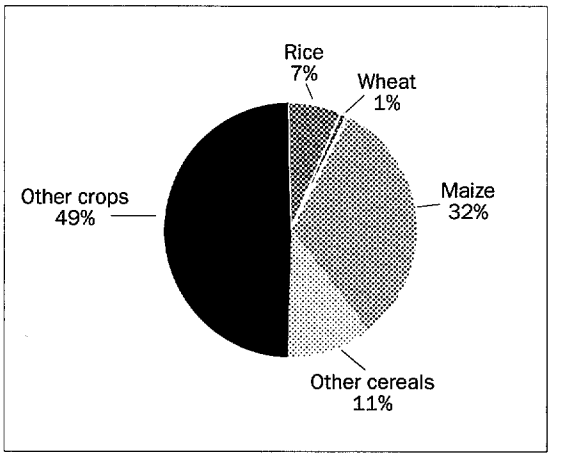
Tanzania

Land (km²)[a]	
Total area	945090
Population[a]	
Total population (no. × 10³)	26673
Urban population	8802
Rural population	17871
Agricultural population	21161
Agricultural labor force	10071
Population density (no./km²)	30.1
Annual growth rate (%)[b]	3.63
Gross domestic product (US$ × 10⁶)[a]	2060
Agricultural share in GDP (%)[a]	59
Land use (ha×10³)	
Irrigated agricultural area[a]	150
Harvested are,modern rice varieties[a]	-
Harvested area, traditional varieties[a]	-
Rice production (t × 10³)	
Irrigated area	28
Rainfed lowland area	564
Upland area	72
Flood-prone area	0
Total rough rice	664
Yield (t/ha)	
Irrigated area	4.0
Rainfed lowland area	2.0
Upland area	0.9
Flood-prone area	0.0
Average yield[c]	1.8
Per capita rice consumption (kg)[a]	
Milled	16
Rough rice equivalent	25
Per capita calorie supply (no.)	
Total calorie supply	2181
Calories supplied by rice	165
Rice trade (t × 10²)[a]	
Total imports	400
Total exports	0
Fertilizer use, chemical sources (t × 10³)[a]	
Total consumption (N, P, K)	41
N	31
P	6
K	4

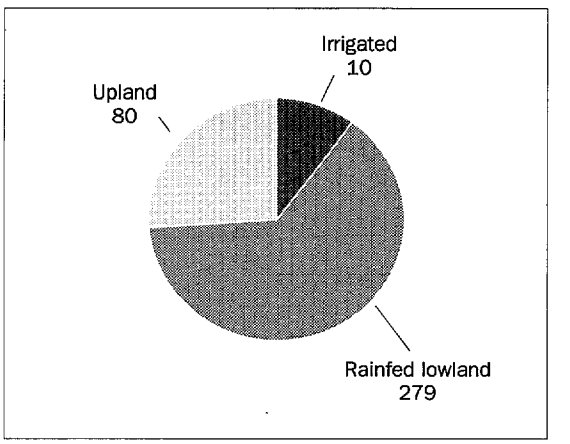
Data are for 1991 unless otherwise indicated. [a]1990. [b]1985-90. – = data not available. [c]Weighted average for all ecosystems.



Land use by physical area (ha × 10³), 1990.

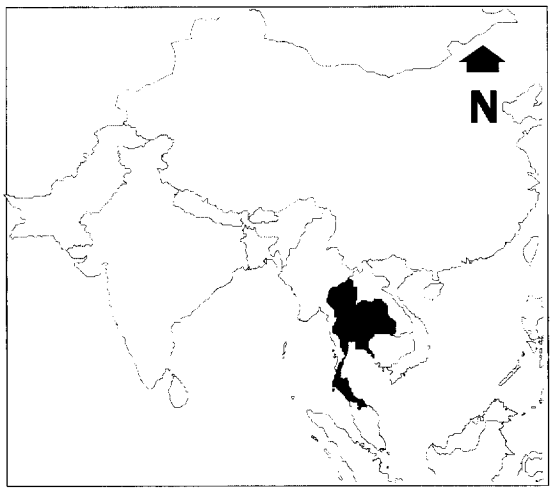


Area harvested, temporary crops, 1990.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)



Harvested rice area (ha × 10³) by ecosystem, 1991.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)

Thailand



Thailand lies between 5° and 21° N latitude and between 97° and 106° E longitude. It is a peninsular country in Southeast Asia sharing boundaries with Myanmar in the west, Laos and Cambodia in the northeast, and Malaysia in the south. The South China Sea touches the east coast, while the Indian Ocean and Andaman Sea border the west coast.

Thailand is in AEZ 2, characterized as warm subhumid tropics. Four seasons are recognized: southwest monsoon from May through September; a transition period from the southwest to the northeast monsoon during October; the northeast monsoon from November through February; and a premonsoon hot season during March and April.

Temperatures in the Central Plain during the rainy season (May to November) average 27 °C, with only 8-10 °C between the daily minimum and maximum. There is a brief cool period (December and January) with temperatures as low as 2-3 °C in the northern highlands.

Although in recent years the economic growth in nonagricultural sectors has greatly reduced the relative importance of agricultural exports, which dropped from about 75% in the 1970s to around 45% in 1989, agriculture still characterizes Thailand. Despite its rapid transformation to an industrialized economy, 77% of the population is still rural.

Importance of rice

Rice is the most important crop of the country. Even though declining in relative importance, it still occupies over half of the total cultivated land. Rice farmers are generally subsistence farmers, selling only their excess production. The main surplus production is from the central region. Rice is the staple food of the entire population regardless of income. The average annual per capita consumption is about 128 kg of milled rice.

Thailand is the major rice exporter in the world market, currently exporting about 4 million t/yr. It has a reputation for high quality, long-grain, white rice, which usually commands a substantial price advantage over lower grades. The emphasis on grain quality is the main reason for the low adoption rate of modern, high-yielding rice varieties in Thailand.

In response to the export opportunities as well as the increasing domestic requirement, riceland has increased steadily over time. Only recently has it begun to stabilize at around 10 million ha. About one-fourth is irrigated; the rest is still rainfed.

Rice environment

Administratively as well as geographically, Thailand is divided into four regions: central, north, northeast, and south. Each region has different rice growing environments.

Northeast region. Almost one-third of the area of Thailand is located in the northeast region. Nearly one-half of the riceland is located in this region and the average size of the rice farm is larger compared with other regions. Soil erosion and drought during the dry season are acute. The water holding capacity of the soil is extremely poor.

Less than 20% of the total irrigated land of the country is located in this region, with less than 10% planted to rice in the dry season.

Central region. The central region is an intensively cultivated alluvial area. During the rainy season, rice covers the major part of the region. The central region accounts for about one-fifth of the total cultivated riceland of the country in the wet season.

Northern region. The northern region has almost 17 million ha. Upland rice is grown in the lower altitudes of high hills and in upland areas. Lowland rice is grown mainly in lower valleys and on some terraced fields where water is available. The northern region has about 20% of the total riceland in the country.

Southern region. The southern region, touching the west and east coasts of the peninsula, constitutes about 14% of the total area of the country. The region has around 6% of total riceland. With limited ricefields under cultivation, there is always a shortage of rice for local consumption.

Production constraints

In addition to the physical and weather problems associated with the different rice ecosystems, the main problems farmers face are stagnant yields and labor shortages.

The average rice yield in the wet season is stagnant at about 2 t/ha. But the high quality, aromatic Thai rices, which command high prices on the world market, are low-yielding, traditional varieties. So the low yields do not necessarily reflect low input supply, poor water control, or any of the other constraints normally associated with low yields. Still, maintaining productivity of the system, even at a 2 t/ha plateau, is of some concern.

The greater constraint is a shortage of labor during peak periods, especially in the central region where industrial employment is higher than in the other rice-producing regions.

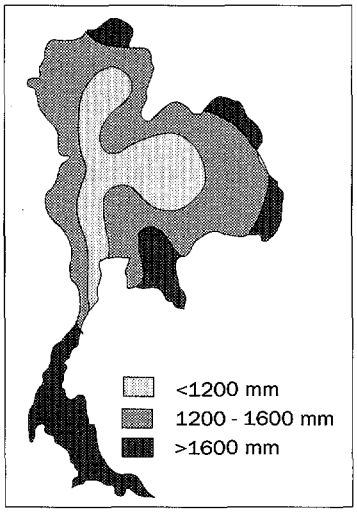
Production opportunities

The Rice Research Institute is the branch of the Department of Agriculture that is directly involved in rice research, primarily in increasing productivity through varietal improvement and crop management. Crop protection and machinery development are undertaken by related divisions.

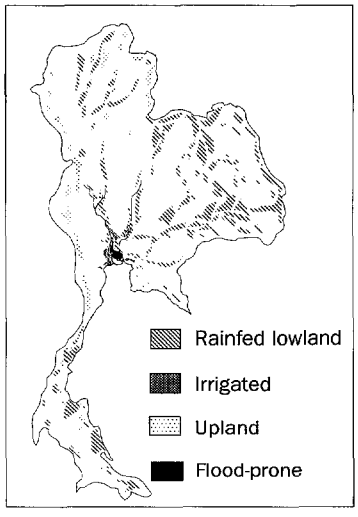
The major research efforts are on varietal improvement, better crop establishment methods for rainfed and irrigated areas, optimum fertilization rates for organic and inorganic fertilizers, efficient chemical and biological pest control, improved rice farming machinery, and basic research on seed improvement and processing.

Crop substitution will be introduced in areas not well suited to growing rice. In addition, more emphasis will be given to crop rotation, green manuring, and other measures aimed at sustainability of rice production.

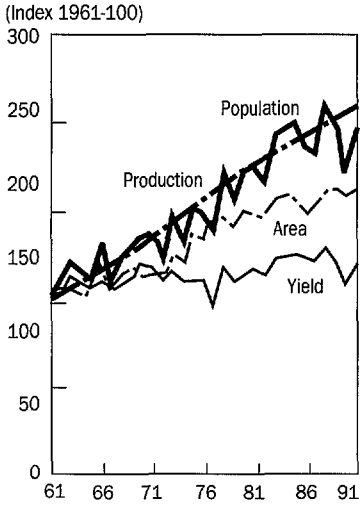
Thailand



Mean annual rainfall.



Rice ecosystems.

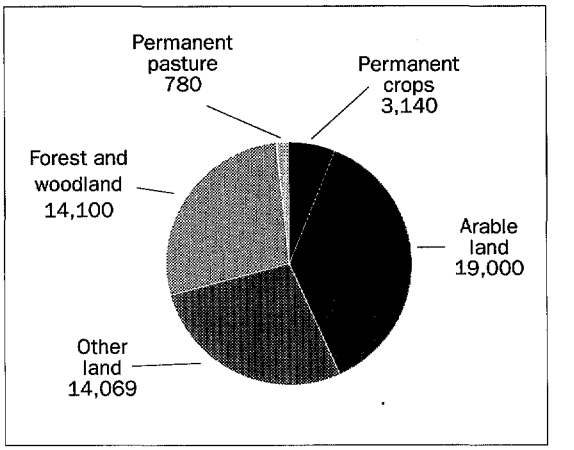


Trends in population, rice production, area, and yield.

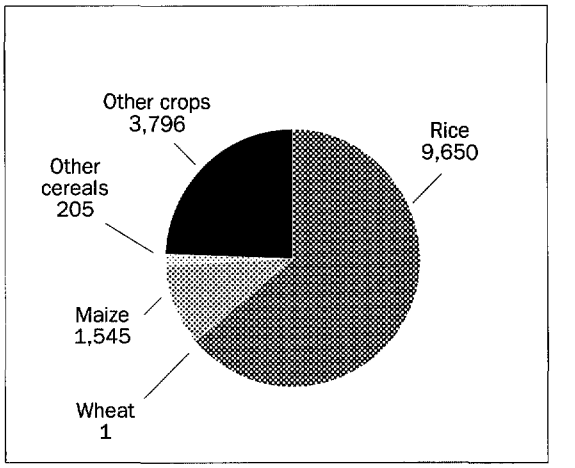
Thailand

Land (km^2)[a]	
Total area	513120
Population[a]	
Total population (no. × 10^3)	56280
Urban population	12944
Rural population	43336
Agricultural population	34049
Agricultural labor force	19186
Population density (no./km^2)	110.16
Annual growth rate (%)[b]	1.70
Gross domestic product (US$ × 10^6)[a]	80170
Agricultural share in GDP (%)[a]	12
Land use (ha × 10^3)[a]	
Irrigated agricultural area	4300
Harvested area, modern rice varieties	6562
Harvested area, traditional varieties	3088
Rice production (t × 10^3)	
Total rough rice	20040
Irrigated area	2880
Rainfed lowland area	15760
Upland area	80
Flood-prone area	1320
Yield (t/ha)	
Irrigated area	4.0
Rainfed lowland area	1.8
Upland area	1.5
Flood-prone area	2.0
Average yield[c]	2.0
Per capita rice consumption (kg)[a]	
Milled	128
Rough rice equivalent	197
Per capita calorie supply (no.)	
Daily total supply	2271
Calories supplied by rice	1258
Rice trade (t × 10^2)	
Total imports	0
Total exports	43331
Fertilizer use, chemical sources (t × 10^3)[a]	
Total consumption (N,P,K)	841
N	577
P	140
K	124

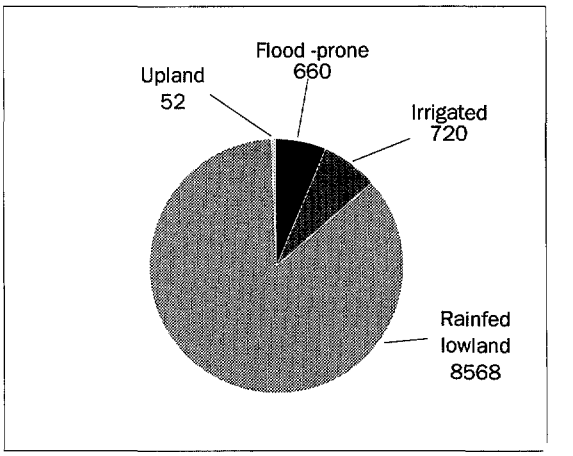
Data are for 1991 unless otherwise indicated. [a]1990. [b]1985-90. [c]Weighted average for all ecosystems.



Land use by physical area (ha × 10^3), 1990.



Area (ha × 10^3) harvested, temporary crops, 1990.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)



Harvested rice area (ha × 10^3) by ecosystem, 1991.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)

United States

The United States lies mostly on the North American continent, from 65° W on the North Atlantic Ocean to the International Date Line of the Aleutian Islands of Alaska, and from below the Tropic of Cancer in the Hawaiian Islands at 20° N to above the Arctic Circle in Alaska at 65° N . Climate ranges from the warm humid tropics of Hawaii to the cold arctic of Alaska, with temperate to subtropical climates in the contiguous 48 states.

The US population is approximately 250 million. The country is highly industrialized. The populace is employed principally in manufacturing and service industries, with only 1.8% directly involved in farming. In 1992, the total number of farms (defined by sales exceeding $1,000/yr) was 2.1 million with an average size of 189 ha.

Importance of rice

US rice consumption was 9.6 kg per capita in 1992, including direct food use (58%), processed food use (21%), and beer (20%). Although small by comparison to many Asian countries, consumption has more than doubled since 1972, largely due to a general interest in rice for improving diet and health as well as marked increases in Asian and Hispanic populations with a preference for rice. The highest direct food consumption is in Hawaii with a per capita consumption of 48 kg annually.

United States rice production in 1992 was 8.1 million t, accounting for only 1.4% of total world production, but between 1987 and 1993 averaging 18% of world trade, second to Thailand in rice exports. Rice represents only 0.7% of the area cropped and less than 1% of the value of agricultural production.

Rice environment

Rice in the US is produced in three principal areas: the Grand Prairie and Mississippi River Delta of Arkansas, Louisiana, Mississippi, and Missouri from 32° to 36° N latitude; the Gulf Coast of Florida, Louisiana, and Texas from 27° to 31° N latitude; and the Sacramento Valley of California from 38° to 40° N latitude. The climate varies from semiarid California, with less than 50 mm rainfall during the growing season, to the humid subtropical Gulf Coast of Louisiana, Texas, and Florida where rainfall may total 700-1,000 mm.

In all these environments, rice is grown as a single crop per year, but can be ratooned in the warmest, southernmost regions of the Gulf Coast states. Approximately 40% of Texas and southwest Louisiana hectarage is ratooned annually. All rice in the US is irrigated and direct seeded. In California, pregerminated seed is seeded into standing water by aircraft. Southwest Louisiana is also wet seeded. Dry seeding with a mechanized grain drill is the most common method of planting in the southern US.

Rice is grown on natural flatlands. In California, nearly 100%, and in the southern US approximately 40% of these flatlands have been further leveled by laser-directed machinery. In rice monocrop systems, the land may be leveled to a slope of 0.02 to 0.05 m/100 m. In rice - row crop systems, grades of 0.1 to 0.2 m/100 m are required for drainage or irrigation of the rotation crop. Precision leveling has greatly facilitated water management and is considered second only to the introduction of semidwarf varieties as contributing to increased rice yields.

In California, where the rain-free environment and high latitude provide maximum solar radiation and low disease pressure, farm yields average 9.4 t/ha. In the humid southern rice environments, disease (primarily blast and sheath blight), warm nights, cloudy days, and frequent thunderstorms at heading limit average yields to about 6.5 t/ha.

Production constraints

Although US yields are high, production is constrained by several factors.

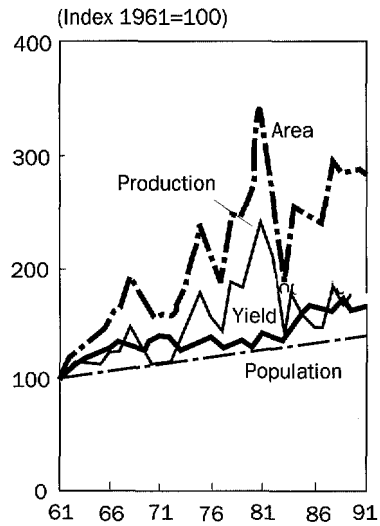
- In the humid subtropical climates of the Gulf Coast and Mississippi River Delta areas, diseases (particularly blast and sheath blight) limit yields.

- Because all areas are direct seeded, weeds and poor stand establishment are significant problems.
- In the southern US, many share crop arrangements are short term and tenant farmers are reluctant to spend capital for long-term improvements to productivity.
- An indirect production constraint is embodied in concern over agriculture's role in environmental degradation. All of US agriculture now operates within a stringent and costly regulatory environment. One critical concern is maintaining high quality water (surface and ground) with respect to potable water, the health of aquatic organisms, and recreational uses.
- In some areas, especially California, degradation of air quality from burning rice straw is highly regulated and rice straw disposal is a production issue.

Production opportunities

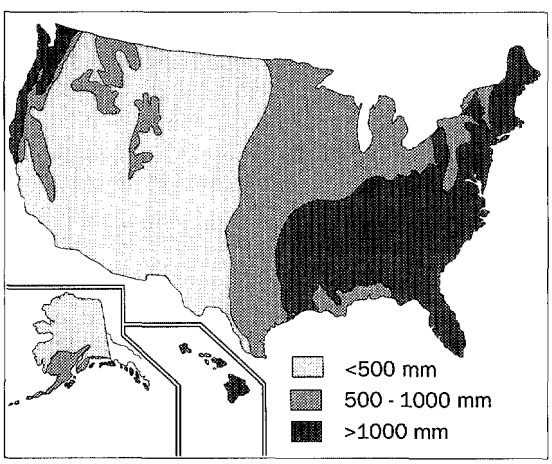
Rice research and extension are an integral part of the US Department of Agriculture and University Land Grant system, supplemented by private research and development, primarily by commercial seed and agricultural chemical producers. All of the principal rice-growing states have well-staffed and equipped public sector rice research stations. Scientific exchange between these institutions is linked by the US Rice Technical Working Group. Linkages to IRRI and other international programs on rice are scientist-to-scientist, mostly on an ad hoc basis.

The challenges for US rice production are to maintain high yields and quality as well as the sustainability of the rice-based cropping system, in the context of maintaining and improving soil, air, and water quality in an increasingly regulatory environment. Improved technology and equipment for land and irrigation management and for harvesting and handling high-quality rice; varietal improvement through the integration of genetic engineering and conventional breeding programs; integrated pest and crop management; and the development of sophisticated pest control technology will be key elements in future production opportunities.

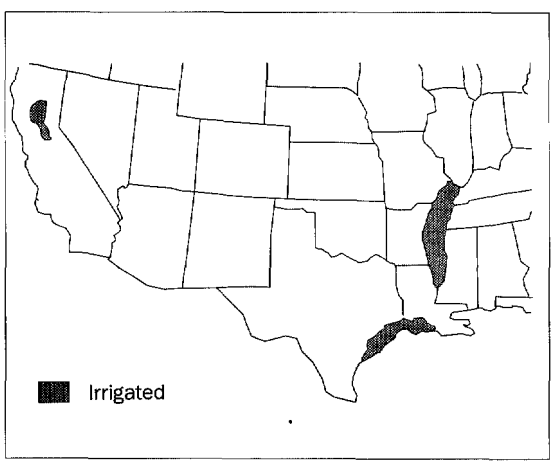


Trends in population, rice production, area, and yield.

United States



Mean annual rainfall.

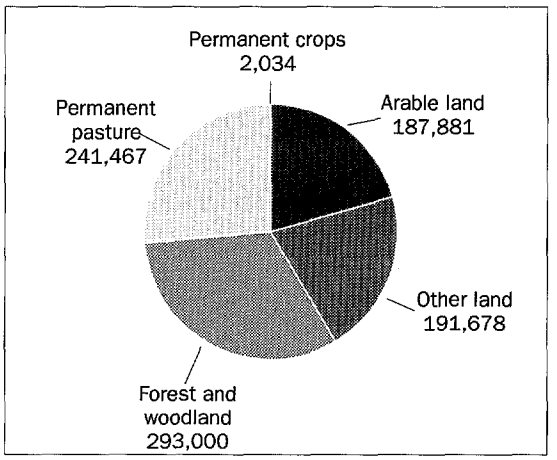


Rice ecosystems.

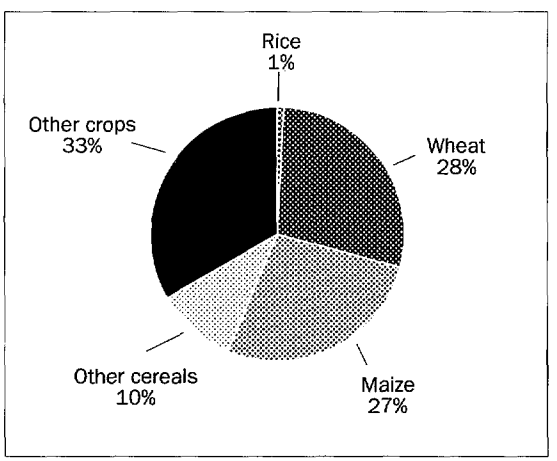
United States

Land (km^2)	
Total area	9170635
Population	
Total population (no. × 10^3)	250256
Urban population	246056
Agricultural population	4504
Agricultural labor force	2446
Population density (no./km)	27.3
Annual growth rate (%)	0.7
Growth domestic product (US$ × 10^6)	4418000
Agricultural share in GDP (%)	4.4
Land use (ha × 10^3)	
Irrigated agricultural area (all crops)	18780
Harvested area, modern rice varieties	1267
Harvested area, traditional rice varieties	0
Rice production (t × 10^3)	
Irrigated rice	8140
Rainfed lowland rice	0
Upland rice	0
Flood-prone rice	0
Total rough rice	8140
Yield (t/ha)	
Irrigated rice	6.4
Arkansas	6.2
California	9.4
Louisiana	5.4
Mississippi	6.4
Missouri	5.4
Texas	6.5
Rainfed lowland rice	0
Upland rice	0
Flood-prone rice	0
Average yield	6.4
Per capita rice consumption (kg)	
Milled	9.6
Rough rice equivalent	13.7
Per capita daily calorie supply (no.)	
Daily total supply	3700
Calories supplied by rice	110
Rice trade (t × 10^2)	
Total imports	1610
Total exports	22430
Fertilizer, chemical sources (t × 10^3)	
Total consumption (N, P, K)	19000
N	12000
P	4000
K	5000

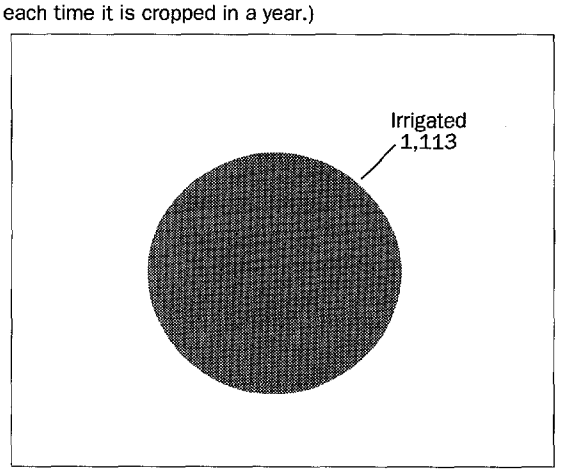
Data are for 1991 unless otherwise indicated.



Land use by physical area (ha × 10^3), 1990.

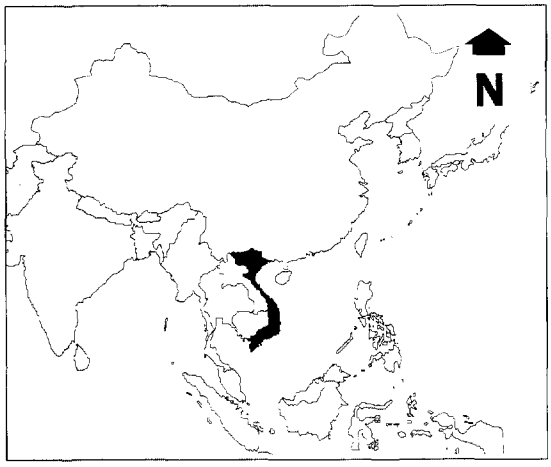


Area harvested, temporary crops, 1990.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)



Harvested rice area (ha × 10^3) by ecosystem, 1991.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)

Vietnam



Vietnam is located along the southeastern margin of the Indochina peninsula in Southeast Asia, extending from 8° to 23° N latitude. It is bounded by Cambodia, China, and Laos.

It is in AEZ 3, characterized as warm humid tropics. Over 30% of the country is forested and about 17% is cultivated. Climate varies from humid tropical in the southern lowlands to temperate in the northern highlands. There are two monsoon seasons: the northeast winter monsoon, and the southwestern summer monsoon. Destructive typhoons sometimes develop over the South China Sea during hot weather. Mean annual sea level temperatures correspondingly decline from 27 °C in the south to 21 °C in the extreme north.

Mean annual rainfall ranges from 1,300 to 2,300 mm. Rainfall is usually evenly distributed in June to October or November. In the Mekong Delta, the summer monsoon brings 5-6 mo of rainfall above 100 mm/mo. October is the wettest month of the year.

The 1990 population of Vietnam was about 70 million with an average density of 215/km^2. Population growth rate is about 2.1%. The population is basically rural and concentrated in the two rice growing deltas: the Red River Delta in the north and the Mekong Delta in the south. Total labor force is 35 million, with about 20 million engaged in agriculture.

Importance of rice

Agriculture continues to play a dominant role in the economy, accounting for about 53% of employment and 50% of GDP.

Rice is the single most important crop. It is planted on 82% of the total farm area (Vietnam's rice area is 6.3 million ha), and it accounts for more than 85% of food grain output.

In 1981, Vietnam departed from the collective agricultural production system by introducing the group oriented contract system of production. That was changed to the individual contract, beginning in 1986. By official estimates, the average small-farm household's share of income from the crops it harvests has risen from 20% before the reforms to around 60% now.

In 1989, Vietnam became a net rice exporter. Foodgrain production amounted to about 21.4 million t in 1990, of which rice accounted for 19.2 million t. There is a trend toward planting modern varieties, which offer high yield and are better adapted to the environment.

Rice ecosystems

The Mekong River Delta has three major cropping seasons: winter-spring, summer-autumn or mid-season, and wet season-long duration. Fifty-two percent of the rice in the Mekong River Delta is grown in irrigated lowlands, with the remaining 48% grown under rainfed lowland conditions.

The area under modern rice varieties in the winter-spring, summer-autumn, and part of the wet season-long duration crop has increased by 15-20% in recent years. On the average, winter-spring yields are highest (3.8 t/ha) followed by yields of summer-autumn (3.4 t/ha) and wet season-long duration rice (2.7 t/ha). Floating rice yields are low (1.5 t/ha).

The northern provinces of Vietnam have a total rice area of 2.4 million ha or about 74% of the total area of farm holdings. Almost 85% of the total area is irrigated lowland, 12% is shallow rainfed, and 4% is intermediate rainfed. The dominant cropping pattern is spring-summer rice.

Rice environment

Soils in the Mekong Delta are highly variable, but alluvial, acid sulfate, and saline soils predominate. Acid sulfate soils cover some 1.6 million ha, or 40% of soils in the delta, mainly in the Plain of Reeds, Long Xuyen Quadrangle, and Ca Mau Peninsula. The soil is rich in humus and total N, but low in P. In addition Al and Fe toxicities limit yield.

Alluvial soils, prevalent in 30% of the Mekong Delta, are concentrated along the banks of the Tien

and Hau rivers. That is the best soil in the delta with humus content of 2%, total N of 0.1 to 0.25%, and medium P and K. Two to three crops can be grown on these soils each year.

Coastal saline soils occupy about 20% of the total area. The soils are rich in humus, N, and clay (55-60%), but with a high salt content.

Production constraints

The major constraints are flooding at the end of the rainy season, and drought in the dry season.

Small farm size, which is expected to diminish even further because of population pressure, is a major constraint.

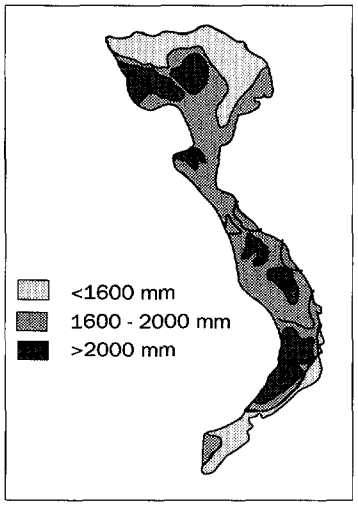
The current level of physical infrastructure is inadequate to support the prospective increases of agricultural production. Two-thirds of the farms have no access to drying areas; most of the crop is sun-dried. Storage space is about 1 million m^3 or 67% of the total needed. Transport for moving the crop to market is inadequate. Energy is also in short supply. Although electricity is available in most provinces, only 50% of the households have access to it.

Production opportunities

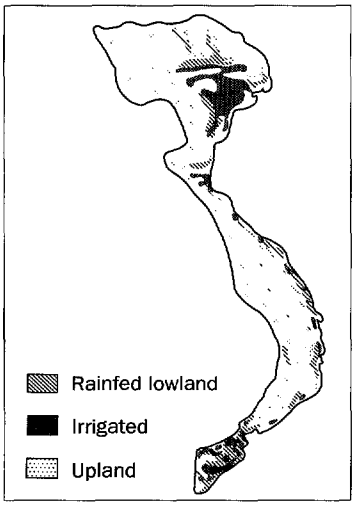
The increased production of rice and productivity of rice-based farming systems remain the primary goals of the national plan. Studies in the Mekong Delta have focused on various rice-based farming systems models: rice - fish integrated with fruit trees, rice - shrimp in saline areas, rice - fish in deepwater areas, and rice - cash crops in the floating rice area.

Cooperation between Vietnam and IRRI started in 1970 with the release of IR8 seeds in Vietnam. Rice research and training is funded by the Australian International Development Assistance Bureau. Three other projects are an integral part of Vietnam-IRRI collaboration: agricultural economics research and training supported by the Canadian International Development Research Centre, strengthening the Cuu Long Delta Rice Research Institute at Omon, Cantho Province, funded by the United Nations Development Programme, and work on integrated pest management funded by the Swiss Development Corporation and the FAO.

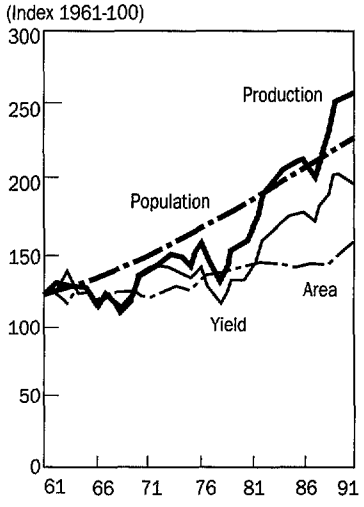
Vietnam



Mean annual rainfal.



Rice ecosystems. Flood-prone areas are coterminous with irrigated areas.

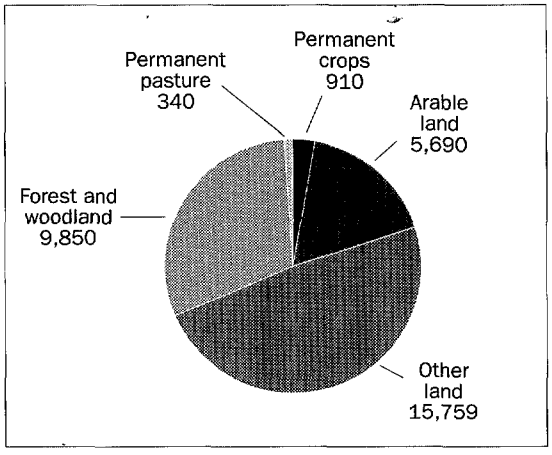


Trends in population, rice production, area and yield.

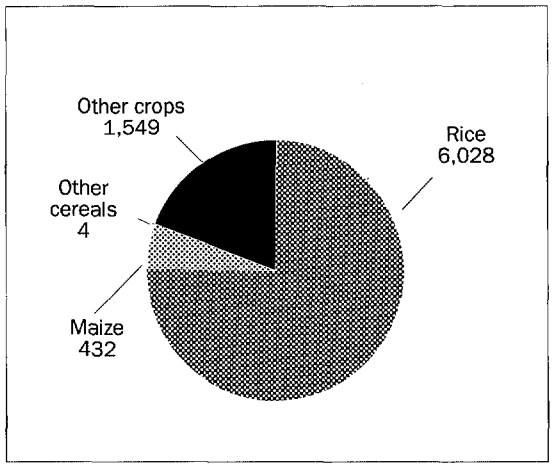
Vietnam

Land (km^2)[a]	
Total area	331690
Population[a]	
Total population (no. × 10^3)	70205
Urban population	15445
Rural population	54760
Agricultural population	42544
Agricultural labor force	20359
Population density (no./km^2)	215.69
Annual growth rate (%)[b]	2.59
Gross domestic product (US$ × 10^6)[a]	14890
Agricultural share in GDP (%)[a]	50
Land use (ha × 10^3)[a]	
Irrigated agricultural area	1840
Harvested area, modern rice varieties	4822
Harvested area, traditional varieties	1206
Rice production (t × 10^3)	
Irrigated rice	14361
Rainfed lowland rice	3525
Upland rice	504
Flood-prone rice	1038
Total rough rice	19428
Yield (t/ha)	
Irrigated rice	4.3
Rainfed lowland rice	2.0
Upland rice	1.0
Flood-prone rice	1.5
Average yield[c]	3.1
Per capita rice consumption (kg)[a]	
Milled	146
Rough rice equivalent	225
Per capita calorie supply (no.)	
Daily total supply	2215
Calories supplied by rice	1513
Rice trade (t × 10^2)	
Total imports	60
Total exports	10000
Fertilizer use, chemical sources (t × 10^3)[a]	
Total consumption (N,P,K)	483
N	419
P	45
K	18

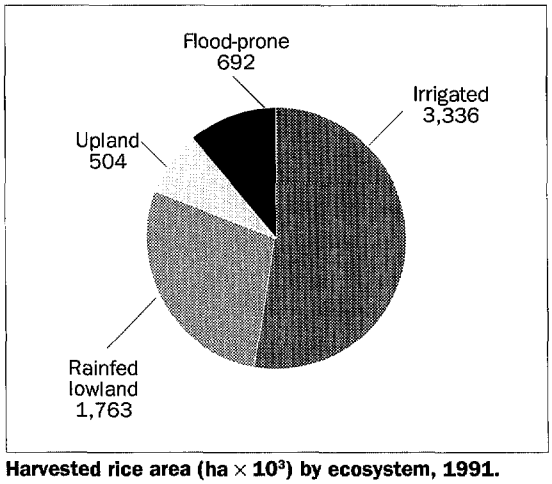
Data are for 1991 unless otherwise indicated.[a]1990. [b]1985-90. [c]Weighted average for all ecosystems.



Land use by physical area (ha × 10^3), 1990.



Area (ha × 10^3) harvested, temporary crops, 1990.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)



Harvested rice area (ha × 10^3) by ecosystem, 1991.
(In determining harvested area, a land unit is counted each time it is cropped in a year.)

CHAPTER 6

IRRI's role in rice research

Worldwide collaborative mechanisms

Rice research issues can be resolved more easily and in relatively less time through collaboration. Working with relevant partners also has many synergistic benefits: speeding the transfer of information and advanced research methodologies; shortening the time needed to solve problems; enabling scientific collaboration across political borders and economic barriers; stretching scarce research resources.

Many partnerships have been forged between IRRI and its partners.

Research consortia

Consortia involve a group of selected institutions that mutually agree to accept different responsibilities to contribute to achieving a common objective. Two ecosystem-based consortia are currently active.

Rainfed lowland rice research consortium. The national agricultural research systems of Bangladesh, India, Indonesia, Philippines, and Thailand, and IRRI are conducting targeted research in seven key sites that represent different rice production constraints in subecosystems of the rainfed lowlands: drought-prone, submergence-prone, drought- and submergence-prone, and medium-deep water.

Upland rice research consortium. The national agricultural research systems of India, Indonesia, the Philippines, and Thailand, and IRRI, have targeted five key sites, each of which represent a subecosystem and a major production constraint. Research is underway on the impact of drought, problem soils, weeds, land degradation and blast disease on rice productivity, environmental security, and the well-being of upland farm families. Improving rice productivity is seen as the entry point to alleviating interrelated problems that contribute to upland degradation and damage to the lowland watersheds.

Research networks

Individual scientists from IRRI and other institutions organize to conduct research driven by a particular theme or set of research tools. Current networks coordinated at IRRI include IPM Research Network, International Task Force on Hybrid Rice, Asian Rice Biotechnology Research Network, and Systems Analysis and Simulation for Rice Production (SARP).

Technology evaluation networks

These voluntary, open, informal associations of scientists and research organizations enable members to systematically exchange and evaluate technologies, and share experiences and information. Two are coordinated at IRRI:

International Network for the Genetic Evaluation of Rice (INGER). The objective is to evaluate promising cultivars, elite breeding lines, traditional cultivars, and genetic donors through a network of multilocation trials in different environments and subject to different stresses.

Crop and Resource Management Network. The objective is to evaluate prototype technologies for sustainable production systems in different agroecological and socioeconomic situations.

Other mechanisms

As partners in national systems of rice-growing countries undertake more and more of the needed strategic and applied research, IRRI is shifting its

agenda to conduct more anticipatory research in new partnerships.

These include joint ventures with particular collaborating institutions to carry out specific research projects; shuttle research with IRRI and another institution exchanging scientists to undertake specific phases of a project; bilateral collaboration in which IRRI and collaborating institutions agree on a joint work plan for specific activities of mutual benefit, and direct consultation and training by IRRI to assist a national program to strengthen its own research and its ability to participate in networks and partnerships.

Some critical research issues

Increasing yield potential

Strategic research is needed on breaking the yield frontier and on helping improve the profitability of rice cultivation relative to other economic enterprises, in order to supply rice to urban consumers at affordable prices and release land for other crops.

The target for intensively cropped irrigated systems is to raise the experimental yield ceiling by up to 50%. Raising the yield ceiling is being pursued in two ways:

- Redesigning the rice plant to improve yield potential.
- Developing hybrid rice for the tropics.

A new rice plant type. The prototype of a new rice plant that could yield up to 30% more (yield potential, 13-15 t/ha) than the current modern high-yielding plant type was designed four years ago. Desirable characteristics include 3-4 large panicles (200-250 grains per panicle); no unproductive tillers (harvest index, 0.6); very sturdy stems, dark green, thick leaves and a vigorous root system; 90 cm tall; and 100-130 d growth duration.

Advanced lines with these characteristics are in field evaluation and new donors of desirable characters are being incorporated into the breeding program. We are using molecular marker-aided selection tools and genetic engineering to incorporate genetic resistances needed for environmentally safe pest management. Building in increased photosynthetic efficiency, decreased respiration losses, and increased storage of starch will open the window to even high yield potential.

Hybrid rice. Hybrid vigor or heterosis is a universal phenomenon that occurs in all biological systems. In plant breeding, hybrid vigor denotes the expression of increased vigor of a hybrid over the better parent or the commercial variety.

Commercial exploitation of heterosis to increase rice yields has been successfully demonstrated in China, where nearly 18 million ha of a total 33 million ha of harvested riceland were planted to F_1 hybrids in 1992. Rice hybrids yield about 20% higher than inbred rices.

Research in countries outside China also indicates that heterosis in rice can increase yields by 15-20% over the best available semidwarf inbreds under irrigated conditions. Commercial hybrids are being developed.

Cytoplasmic male sterility is the most effective genetic tool for developing hybrid rices. Photoperiod-sensitive (PGMS) and thermosensitive male sterility (TGMS) systems have shown promise. In China, the use of chemically induced male sterility is not efficient enough to be applied on a large scale.

Well-developed hybrid seed production practices give average yields of 2 t seed/ha. Outside China, experimental yields of 1-2 t/ha have been obtained.

The high adoption of hybrid rice in China is due primarily to its profitability, as well as to government intervention from 1976 to 1981. Commercial use of hybrid rice technology in countries outside China depends on the development of suitable hybrids, economical seed production practices, and infrastructure to produce, process, certify, and distribute hybrid seed.

N use efficiency

The green revolution that has kept production of food grains ahead of population growth depends on high-yielding modern varieties (MVs), controlled water supply, intensified cropping, and improved crop nutrition and pest management. In Asia, 24% of the increase in rice production from 1965 to 1980 was attributed to better crop nutrition due primarily to the increased use of N fertilizers. Today, more than 20% of all N fertilizers produced worldwide are applied to the ricefields of Asia.

The efficiency with which N is used by the rice crop can be described by the three parameters in the following equation:

$$\frac{\Delta \text{ grain yield}}{\Delta \text{ N uptake}} \times \frac{\Delta \text{ N uptake}}{\Delta \text{ N applied}} = \frac{\Delta \text{ grain yield}}{\Delta \text{ N applied}}$$

where Δ represents the change in a given parameter.

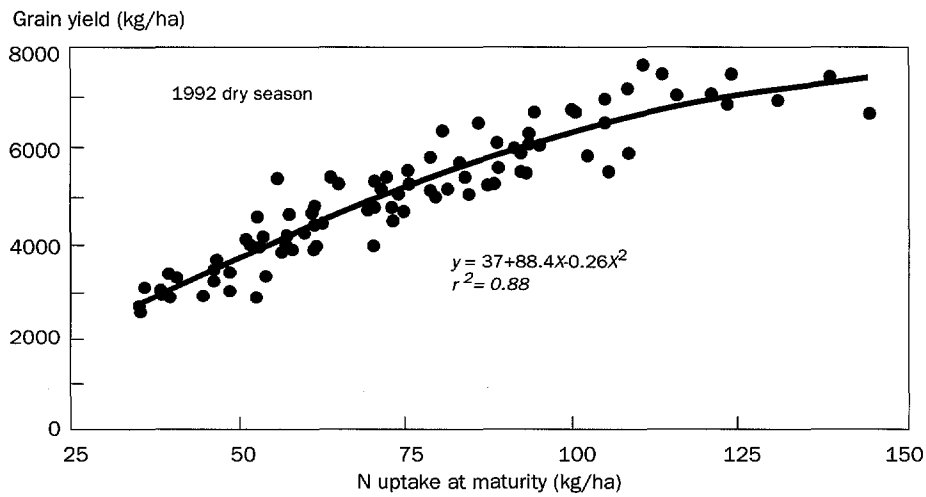
The first term reflects the physiological efficiency with which plant N is used to increase grain yield. The second term represents the uptake efficiency per unit N applied. The third term is the agronomic efficiency, or the increase in grain yield per unit N input. Rice farmers are most concerned with agronomic efficiency because it determines the returns to investment in N inputs. To understand the factor governing improved N use efficiency, however, researchers must measure both the physiological and uptake efficiency.

Most MVs have similar physiological N use efficiencies when grown under similar conditions. This similarity is indicated by a close relationship between grain yield and N uptake when drought, disease, or pest problems are not severe (Fig. 1). Typically, N use efficiency decreases as plant N supply increases.

For example, in a study of N use efficiency in Central Luzon, Philippines, which included 9 rice varieties, grain yield increased by 2,500 kg/ha as N uptake increased from 50 to 100 kg N/ha. That represents a physiological efficiency of 50 kg grain/kg N uptake (Fig. 1). A further increase in N uptake from 100 to 150 kg N/ha resulted in a yield increase of only 1,200 kg/ha so that physiological efficiency decreased by more than 50% (down to 24 kg grain/kg N uptake).

Whereas physiological efficiency is relatively constant between different MVs that have accumulated the same amount of N, the efficiency with which applied N is absorbed by the rice crop varies greatly among MVs and environments. In most cases, inefficient plant recovery of applied N is the largest constraint to high agronomic efficiency. For irrigated rice, uptake efficiency ranges from 20 to 60% of the applied N although average efficiency is between 30 and 40% in most areas. Low efficiency reflects poor agronomic management and the dynamic nature of N in the soil-floodwater system, which leads to gaseous losses through NH_3 volatilization and denitrification. Avoiding N inputs in excess of crop needs at any point during the growing season is the key to optimizing N use efficiency and minimizing gaseous losses . Hence, the timing, rate, and method of application have a large impact on efficiency. Usually at least two split applications of N are needed to achieve an N supply that is synchronous with plant demand.

Vigorous root and shoot growth and healthy plants are also prerequisites for high N uptake efficiency. Agronomic practices that provide adequate nutrients other than N, weed control, and



1. Relation between grain yield (14% moisture) and total N uptake, which includes N in grain and straw, measured at 88 on-farm sites in irrigated ricefields, Central Luzon, Philippines. Nine varieties were represented over the 88 sites.

proper water management contribute to efficient uptake of N inputs. With good management it is common to recover more than 50% of applied N in the plant at maturity, both in field experiments on research stations and in farmers' fields. Unfortunately, the inability to provide good management and neglect of timely N applications result in relatively low N uptake efficiency in most irrigated rice systems.

In the harsher environments, N uptake efficiency is primarily governed by environmental stresses beyond the farmer's control. Examples are drought and flooding in the rainfed lowlands, and P deficiency and Al toxicity on acid soils of the uplands. Because of these constraints, returns to investment in N fertilizer are more variable than in irrigated systems. That risk provides a greater incentive to use legume crops and legume green manures to augment the N supply in less favorable rice ecosystems.

Sources of N and N balance. Industrially manufactured N fertilizers provide the largest fraction of total N inputs to rice systems. Naturally occurring biological N_2 fixation (BNF) by blue-green algae in floodwater and by heterotrophic bacteria in the root zone also make a significant contribution to the total N balance. Inorganic fertilizer N sources used by rice farmers include urea, ammonium sulfate, and various forms of ammonium phosphate. Organic N sources such as farmyard manure, legume green manure, and azolla provide N inputs that may substitute for inorganic fertilizer N. Although research at IRRI and elsewhere has documented the potential for a large reduction in inorganic fertilizer N use by substituting green manures or azolla, adoption has been limited because of the additional labor costs and time needed for production of organic N sources.

On irrigated land in most Asian countries, rice farmers typically apply 100 to 150 kg N/ha to the dry season rice crop and 60 to 90 kg N/ha to the wet season crop. At these input levels the cost of N fertilizer often represents from 10 to 20% of the total variable costs of production.

Nitrogen inputs to the irrigated system from BNF range from 25 to 45 kg N/ha for each rice crop cycle, which is sufficient to sustain rice yields of 2-3 t/ha based on the relationship between rice yield and total N content of the grain and straw (Fig. 1). Rice straw is rarely returned to the soil because it is burned or used as animal fodder. To achieve a yield of 6 t/ha in the dry season requires actual crop uptake of approximately 100 kg N/ha. On a soil that supports a yield of only 3 t/ha without fertilizer N inputs (N uptake of 45 kg/ha) and assuming a relatively high N uptake efficiency of 50%, a farmer must apply 110 kg N/ha to obtain a grain yield of 6 t/ha. If fertilizer N uptake efficiency is only 36%, a more representative value for irrigated rice, the required rate would increase to 150 kg N/ha.

In the less favorable rainfed rice ecosystems, most rice farmers also apply fertilizer N to rice, but input rates are lower than in irrigated systems. Reduced input levels reflect the lower yield potential and greater uncertainty due to climate and abiotic stresses that afflict rice crops in rainfed lowland and upland environments.

Challenges for the future. With little scope for expanding rice area or for the development of new irrigation systems, rice production must increase by more than 60% from 1992 to 2020 on existing riceland. To meet this challenge, finding ways to increase N uptake efficiency from applied N will be needed for two reasons. First, the manufacture of inorganic fertilizer N requires fossil fuels, which are a nonrenewable resource. Second, inefficient use of both inorganic fertilizer N and organic N leads to gaseous emission of N from irrigated systems to the atmosphere which may contribute to global climate change. Also in lowland soils that undergo wetting and drying cycles, nitrate may be leached into groundwater. A large increase in N use efficiency in rice production is essential if we expect to preserve environmental quality, minimize energy costs, and sustain the yield increases that are needed to meet the demands of a growing world population.

Rice-diazotroph associations are well known, but their contribution to N supply is minor. An intimate association between rice and a free-living or loosely associated diazotroph might be achieved by exploiting mechanisms operative in other plant-microbial interactions. Another possibility is examining the capacity of rice to support endosymbiosis or nodulation by rhizobia and other microsymbionts from different plant species. Current advances in understanding symbiotic interactions at the molecular level and the ability to introduce new genes into rice by transformation create an excellent opportunity for investigating possibilities for symbiotic nitrogen fixation.

Pests, diseases, and weeds of rice

Many species of organisms inhabit ricefields. Most of these organisms are not harmful. For example, some 500 species of arthropods (insects and spiders) may appear in a ricefield in a given season, but only a very few are a potential threat. Most are beneficial or innocent, and include a wide range of predatory and parasitic natural enemies that contribute to keeping the insect pest organisms in check. One of the potentially most serious groups of harmful organisms include weeds that compete with rice for nutrients, light, and water.

Other species of potentially harmful organisms include insects, pathogens, molluscs, and rodents (Table 1). Some are herbivores that feed on the rice plant, others are parasitic disease organisms.

Although only a few pest species cause sufficient yield reductions to require intensive control measures, they are frequently cited as major constraints to rice production. Potential losses of up to 55% before harvest have been estimated, but these estimates often represent the worst case or highest levels of loss.

Actual losses are much lower. There have been serious outbreaks of insects such as brown planthopper (BPH) and diseases such as blast, tungro virus, and sheath blight over large areas. But considering the myriad opportunities for pest-crop interactions, such outbreaks can be considered as rare events.

When these outbreaks occur, however, farmers suffer substantial economic losses. For instance, in 1975 the BPH infested nearly 80% of the ricefields in the Republic of Korea. Crop loss in affected fields reached 20-30%. BPH destroyed 200,000 ha of rice between 1975 and 1980. In Indonesia, a virus disease destroyed 100,000 ha between 1972 and 1975 in South Sulawesi alone. In the early 1900s, insect and diseases caused widespread famine in Japan and China. Calamities such as these encouraged crop protection approaches that emphasized eradication and prevention. Those approaches caused the use of agricultural pesticides to increase dramatically.

Table 1. Examples of organisms that may harm or compete with the rice crop.

INSECT PESTS	
Stem borers	
Yellow stem borer	*Scirpophaga incertulas* (Walker)
White stem borer	*Scirpophaga innotata* (Walker)
Striped stem borer	*Chilo suppressalis* (Walker)
Dark-headed rice borer	*Chilo polychrysus* (Meyrick)
Defoliators	
Rice leaffolders	*Cnaphalocrocis medinalis* (Guenée) and others
Rice caseworm	*Nymphula depunctalis* (Guenée)
Leafhoppers	
Green leafhopper	*Nephotettix virescens* (Distant) *N. nigropictus* (Stål.) *N. parvus* Ishihara et Kawase *N. cincticeps* (Uhler)
Planthoppers	
Brown planthopper	*Nilaparvata lugens* (Stål.)
Whitebacked planthopper	*Sogatella furcifera* Horvath
Rice bugs	
Malayan black rice bug	*Scotinophara coarctata* (Fabricius)
Rice grain bug	*Leptocorisa oratorius* (Fabricius)
RODENTS	
Rice field rats	*Rattus rattus argentiventer* (Rob & Kloss) *R. r. mindanensis* Mearns
DISEASES OF RICE	
Viral diseases and their vectors	
Rice tungro	*Nephotettix virescens* (Distant) *N. nigropictus* (Stål.)
Ragged stunt	*Nilaparvata lugens* (Stål.) *L. acuta* (Thunberg)
Bacterial diseases and their causal agents	
Bacterial blight	*Xanthomonas oryzae* pv. *oryzae* (Uyeda ex Ishiyama 1922) Swings et al 1990
Fungal diseases and their causal agents	
Blast	*Pyricularia oryzae* Cav.
Sheath blight	*Rhizoctonia solani (Thanatephorus cucumeris)* [Frank] Donk)
WEEDS	
Echinochloa colona (L.) Link.	
Cyperus iria L.	
Monochoria vaginalis Burm.f. Presl.	
Echinochloa crus-galli (L.) P. Beauv.	
Fimbristylis miliacea (L.) Vahl.	
Cyperus difformis L.	

Although insect pest and disease resistance genes have been introduced into rice cultivars, pesticide use has not declined. Pesticides are often uneconomical and they may disrupt the ecological balance of pest and their natural enemies. BPH outbreaks are often a direct consequence of insecticide use, which wipes out predators that regulate the BPH and sometimes stimulates increased fecundity in surviving BPH females. Besides often causing the pest problems, agricultural chemicals may pose a serious threat to humans and the environment.

Modern approaches to crop protection rely on management rather than control or eradication. In this approach, a pest species is considered a pest only when it reaches numbers that can cause yield reduction. Natural factors—such as natural enemies—that prevent a pest species from increasing are emphasized. Pesticides are used only as a last resort to bring abnormal pest densities down when crop loss is expected to exceed the cost of treatment. In addition, the use of rice cultivars that are resistant to major pest species is encouraged. These cultivars do not need prophylactic treatment to control the insects or diseases to which they are resistant. Using a combination of control tactics instead of relying on just one tactic such as host plant resistance or pesticides — and basing the decisions for control on sound economic grounds is called integrated pest management or IPM.

Global climate change and rice

Climate change is not a new phenomenon. Change has been a consistent feature of the earth's climate. Periods of relatively cool temperatures caused the ice ages. For the past 10,000 yr, however, the earth has experienced the longest period of consistently warm temperatures since the beginning of life. That warm period almost exactly matches the period over which modern agriculture has evolved.

For the first time in history, climate appears to be changing as a direct result of human activity. People have released chlorofluorocarbons into the atmosphere, thereby degrading stratospheric ozone and increasing biologically harmful ultraviolet (UV) radiation that reaches the earth's surface. Through mining and combustion of fossil fuels, deforestation, maintenance of livestock herds, and even through rice cultivation, people have released enormous quantities of carbon dioxide (CO_2), methane (CH_4), and other greenhouse gases into the atmosphere.

Concentrations of greenhouse gases in the atmosphere are increasing at an accelerating rate. We have the best records for CO_2. At the beginning of the 20th century, the concentration of CO_2 in the atmosphere was less than 300 parts per million (ppm). By 1974, when the first records of atmospheric CO_2 monitoring were widely reported, it had risen to 330 ppm. Today, it stands at over 360 ppm. It took the first 70 yr of this century to increase atmospheric CO_2 by 30 ppm from 300 to 330 ppm, but less than 20 yr for the same incremental increase to 360 ppm.

Samples from ice cores show that past fluctuations in global temperatures were strongly correlated with concentrations of atmospheric CO_2. Simulation models of global atmospheric circulation predict that greenhouse gases will cause a 2-8 °C global temperature rise before the end of the 21st century. There are still many unknowns and the models are far from perfect. For example, the ash cloud produced by the volcanic eruption of Mount Pinatubo in Luzon, Philippines, in 1991 has cooled the earth by 1 to 2 °C. The cooling effect of that eruption is expected to be dispelled by the end of 1993. Any similar eruption, however, could counteract the global warming effects of greenhouse gases.

IRRI and the United States Environmental Protection Agency are cooperating to determine the effects of a likely global climate change on rice production. Under study are 1) direct and indirect effects of ultraviolet-B (UV-B) radiation on rice, and 2) the direct and indirect effects of increased CO_2 and temperature on rice.

Once having established the mechanisms by which climate change affects rice and rice production, and the range of responses of different rice varieties to climate change, varieties and management practices to mitigate those effects can be addressed.

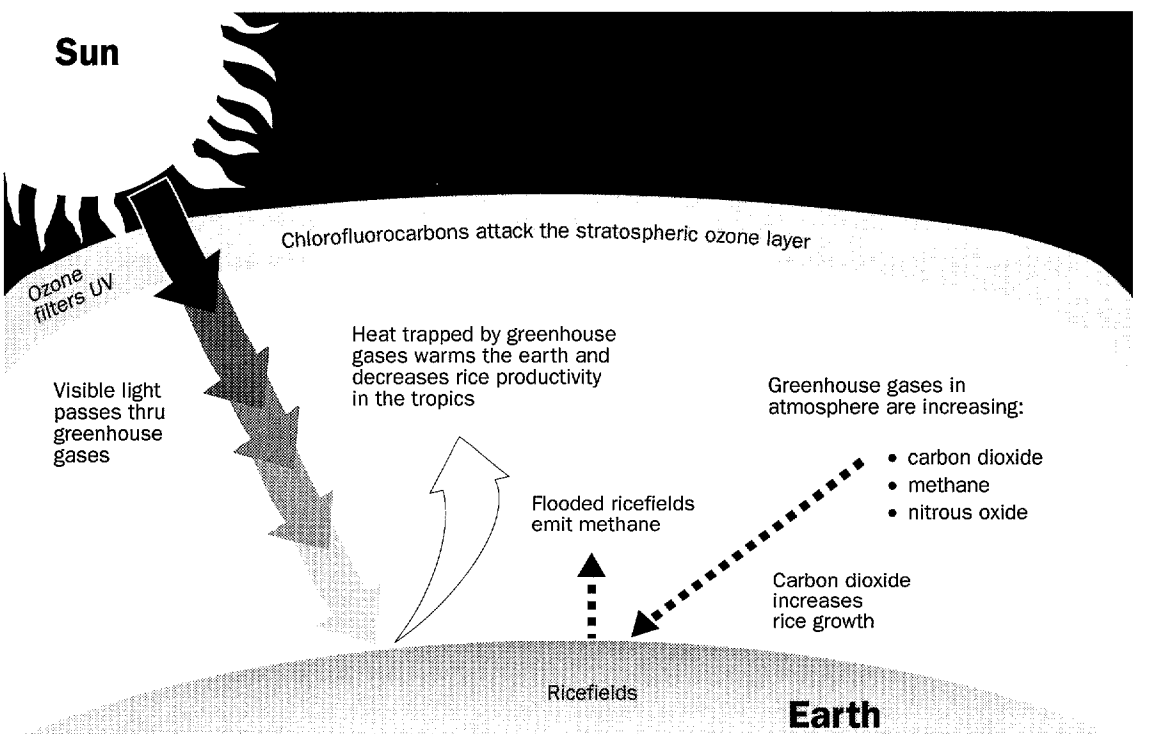
UV radiation effects. UV-B radiation damages leaf tissues in rice seedlings. Leaves become stunted, stomata collapse, and photosynthesis decreases. Some rice varieties appear to be better able than others to withstand the adverse effects of UV radiation. Leaves of tolerant varieties contain phenolic compounds, which are natural chemicals that filter out harmful UV-B radiation before it can damage sensitive tissues. Research is now in progress to predict possible regional losses in rice productivity if UV-B radiation continues to increase, and whether plant breeders can prevent

those yield losses by developing new varieties that tolerate UV radiation.

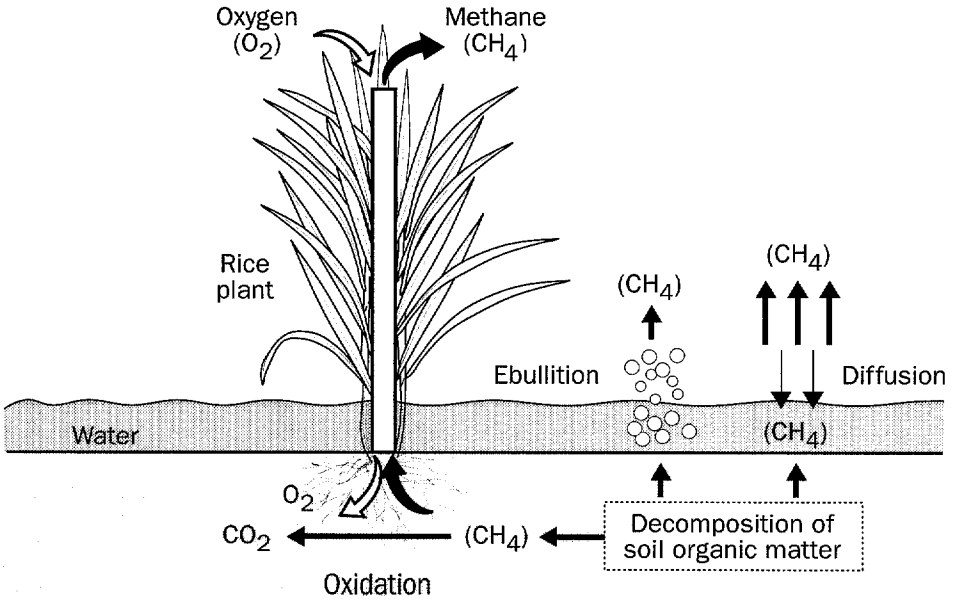
In addition to its adverse direct effects on rice plants, UV-B may change the susceptibility to and/or tolerance for disease. Although there is no evidence as of yet that susceptibility to blast is affected by UV-B, it appears that the tolerance for blast decreases. In other words, disease recently is not increased by UV-B, but the effects of disease on plant growth is enhanced by UV-B radiation.

Global warming. Although increasing atmospheric CO_2 stimulates plant growth, the beneficial effects on rice growth have been observed for levels only up to 500 ppm. Some plant species respond positively to CO_2 levels up to 1,000 ppm. Experts predict that atmospheric CO_2 will surpass 650 ppm before the end of the 21st century. Furthermore, the benefits of increased CO_2 would be lost if temperatures also rise. That is because increased temperature shortens the period over which rice grows. Research is being conducted to identify means by which rice plants may better benefit from increases in atmospheric CO_2 while minimizing the adverse effects of warmer temperatures (Fig.2).

Global warming will clearly have more adverse effects on rice productivity in tropical regions, where temperatures are already warm, than in temperate regions. Yields of tropical rice will decline dramatically with even small increases in global temperatures. But temperate regions such as northern China, Japan, and the Korea Peninsula might benefit from global warming, which would lengthen the season over which rice could be grown without risk of cold damage. Even those potential benefits are not guaranteed. If temperatures become warm enough for rice cultivation earlier in the year than at present, temperatures will also become warm enough for the growth of migrating rice insect pests. Thus, farmers may need to develop new strategies for pest control in a warmer world.



2. How global climate change affects tropical rice. Greenhouse gases trap heat and warm the earth's surface. Higher temperatures reduce the productivity of tropical rice. The two most important greenhouse gases for rice are CO_2, which may enhance rice growth, and CH_4, which is emitted by flooded ricefields. Degradation of the stratospheric ozone layer allows more biologically destructive UV-B radiation to reach the earth's surface. The effects of UV-B on rice are not known.



3. Methane gas escapes into the atmosphere from flooded ricefields in three ways. Up to 80% travel through the plant from the roots. Ebullition, where gas bubbles up to the water surface, and diffusion each contribute smaller amounts.

Methane emission from ricefields

Methane (CH_4) is second in importance to CO_2 as a greenhouse gas. Methane concentration in the atmosphere has more than doubled during the last 200 yr to 1.7 ppm by volume compared with 0.7 ppm in the preindustrial era. Still, it is much lower than the 360 ppm of atmospheric CO_2. But one molecule of CH_4 traps about 30 times more heat than a molecule of CO_2 does. The heating effect of the atmospheric CH_4 increase is about half that of the CO_2 increase. Continued increase in atmospheric CH_4 concentrations at the current rate of about 1% per year is likely to contribute more to future climatic change than any other gas except CO_2.

The current burden of CH_4 in the atmosphere is about 4,700 million t; the global annual emission is estimated to be 500 million t, with an apparent net gain of 40 million t/yr (Table 2). Recent global estimates of CH_4 emission from ricefields range from 20 to 100 million t/yr, corresponding to 6-29% of total annual anthropogenic CH_4 emission. That part of the CH_4 emitted from naturally flooded ricefields is not considered anthropogenic. To reduce the burden and harmful effects of CH_4 in the atmosphere, emissions from all anthropogenic sources have to be mitigated.

The potential for CH_4 release from ricefields has long been noted, but comprehensive measurements of CH_4 fluxes in ricefields have been reported only since the early 1980s. Flooding a ricefield cuts off the oxygen supply from the atmosphere to the soil, which results in anaerobic fermentation of soil organic matter. Methane is a major end product of the process. It is released from flooded ricefields to the atmosphere by diffusion, ebullition, and through roots and stems of rice plants (Fig. 3).

Water regime, temperature, soil properties, and rice plants are the major factors determining the production and flux of CH_4 in ricefields. Up to 90% of the CH_4 produced during a rice-growing season may be oxidized in the aerobic rice rhizosphere and floodwater-soil interface before it reaches the atmosphere.

Irrigated rice ecologies are the major source of increased global CH_4 emissions from ricefields. The assured water supply and control, intensive soil preparation, and resultant improved growth of rice favor CH_4 production and emission. Meth-

ane emissions are lower and highly variable in rainfed rice because of periodic droughts during the growing season. Upland rice is not a source of CH4 emission.

Global estimates of CH_4 emission from ricefields. Because of the limited number and locations of comprehensive seasonal flux measurements, global extrapolations of emission rates are highly uncertain and tentative. Recent global CH_4 budgets from ricefields range from 20 to 100 million t/yr.

The source strength of ricefields in Asia was estimated to range between 46 and 63 million t/yr. Comprising 51% of the global harvested rice area, ricefields in China and India emit 29-40 million t CH_4/yr. Current global estimates of CH_4 fluxes from ricefields do not account for varying flood-water regimes, especially in rainfed rice areas where drought spells may drastically lower emission rates. Neither do they account for organic amendments, ebullition induced by cultural practices, and release of entrapped CH_4 during initial drying phases, which should increase emission rates.

Table 2. Estimated sources and sinks of methane.

Sources and sinks	Volume (t x 10^6)	
Sources		
Natural		
Wetlands	+120	
Lakes, rivers	+20	
Oceans	+10	
Termites	+10	
Total		+160
Anthropogenic		
Mining, processing, and use of coal, oil, and natural gas	+100	
Enteric fermentation (mainly cattle)	+80	
Flooded ricefields	+50	
Biomass burning	+30	
Landfills	+30	
Animal waste	+30	
Domestic sewage	+20	
Total	+340	
Sinks		
Reaction with OH radicals in the atmosphere	-420	
Uptake (oxidation) by soils	-30	
Removal in stratosphere	-10	
Total		-460
Atmospheric increase	+40	

Mitigation options. Water management is a very promising way to mitigate CH_4 emission from ricefields. But sound and feasible management practices that reduce CH_4 emissions, without increasing N losses, increasing weed growth, and reducing yields, have to be developed. The most effective option would be to prevent submergence of ricefields and to cultivate upland rice or other upland crops. But wetland rice is grown mainly because fields are flooded naturally during the rainy season. It is often impossible to drain ricefields during rainy seasons because impounding water in ricefields is an important way to conserve water and to control soil erosion.

Increasing water percolation will add oxygen-rich water to the reduced soil layer and decrease CH_4 production. But that is feasible only with complete control of water supply and drainage. Higher water percolation, however, requires more water and may leach nutrients and CH_4 from the soil. Temporarily aerating the soil by stopping irrigation will enhance CH_4 oxidation and decrease CH_4 formation, resulting in lower emission.

The direct impact of chemical fertilizer applications on CH_4 emission is not clear. Because most CH_4 is emitted through the rice plant, improved rice growth (more tillers and roots) in response to fertilizer application increases emission. But source and mode of application may also have direct effects. Sulfate-containing fertilizer reduces CH_4 emission, although the amount of sulfate normally added as fertilizer seems insufficient to have significant effects. Nitrification inhibitors incorporated into the soil limit CH_4 production.

A few observations at IRRI show that soil disturbances caused by current cultural practices release large amounts of soil-entrapped CH_4. With current cultivation technologies, CH_4 emission from ricefields is expected to increase as rice production increases 50-100% within the next 30 yr.

The use of a combination of mitigation technologies shows great potential to stabilize or even reduce CH_4 emission from ricefields without dra-

matically changing cultural practices or sacrificing yield . The increased adoption of direct seeding (wet and dry seeding) instead of transplanting will likely reduce CH_4 emission. In direct seeded rice, flooding periods are shorter and cultural disturbance of reduced soils is less intense and frequent.

The aerenchyma of the rice plant is the pathway through which atmospheric O_2 is carried to the roots and CH_4 is released to the atmosphere. The number of tillers/m^2, the root mass, the rooting pattern, and metabolic activity all influence the amounts of CH_4 released. These traits and related CH_4 emission rates vary widely among cultivars. That variation opens the possibility for breeding rice cultivars with low CH_4 emission potential. The inheritance of these underlying traits and their relation to yield potential have yet to be elucidated.

Collaboration. With financial support from the US Environmental Protection Agency, IRRI has started baseline research on CH_4 fluxes in ricefields in collaboration with the Fraunhofer Institute for Atmospheric Environmental Research, Germany, and the Wetland Biogeochemistry Institute of Louisiana State University, USA. Other collaborating institutes are the Wageningen Agricultural University, The Netherlands; the Laboratory for Microbiology, French Institute of Scientific Research for Development Cooperation, and the Université de Provence, France; and the University of Georgia, USA. IRRI is also coordinating an interregional research program on CH_4 emission from ricefields funded by the Global Environmental Facility of the UNDP. This program comprises collaborative CH_4 research on irrigated, rainfed, and deepwater rice in China, India, Indonesia, Philippines, and Thailand.

Some new research tools

Exciting opportunities are opening for strategic research on rice. New concepts and new tools help in seeking new knowledge that will provide answers to previously unanswerable questions at different levels of complexity, from the gene to the plant to the ecosystem.

New knowledge in molecular biology enables better understanding of the basis of such genetic traits as pest resistance and tolerance for abiotic stresses. At the same time, biotechnology allows incorporation of specific genes from noncompatible wild rice species or nonrice life forms into improved rice germplasm, to resolve previously intractable problems. New understanding of processes and mechanisms at the plant-soil-environment interface is the basis for increasing the productivity and sustainability of the resource base.

Systems science using process-based models offers new opportunities for identifying causes and quantifying complex phenomena, such as a stagnant yield frontier and signs of declining productivity. Systems analysis and simulation can be tapped to design new plant types capable of achieving higher, more stable yields with greater resource use efficiency in different rice-growing environments, from the favorable lowlands to the harsher uplands. Geographic information systems (GIS) enable analysis of spatial data for characterizing environments.

Rice biotechnology

Some desired features of future improved rice varieties are superior grain quality, higher yield potential, enhanced resistance to pests and diseases, and greater tolerance for stresses such as drought, cold, and nutrient deficiencies. Biotechnology is seen as perhaps the most important new resource for achieving varietal improvement (Table 3).

Rice biotechnology techniques come from plant tissue culture and molecular biology. Two tissue culture techniques, embryo rescue and anther culture, have already made important contributions. Embryo rescue enables breeders to attempt wide crosses between varieties that could not be hybridized before; anther culture allows faster stabilization of breeding lines. Molecular techniques help to accelerate traditional breeding programs through gene tagging, to streamline germplasm management, and to assess population structures in pests and pathogens through DNA fingerprinting. But biotechnology's most novel contribution will probably be in adding alien genes to the rice gene pool through genetic engineering.

Embryo rescue. In addition to the cultivated species *Oryza sativa* and *O. glaberrima*, the genus *Oryza* has 24 wild species, which may be important sources of useful genes for rice improvement. Many wild *Oryza* species, however, fail to hybridize with cultivated rice because of differences in

the number or in the genetic constitution of their chromosomes. Fertilization may occur, but the embryo is later aborted. Until recently, this phenomenon prevented transferring into cultivated rice many useful traits such as disease and pest resistance, and tolerance for abiotic stresses. It is now possible, however, to rescue hybrid embryos that contain extra chromosomes and maintain them through several cycles of backcrossing and tissue culture until their chromosome number declines to that of cultivated rice (2n = 24) and fertility is restored. The 12 chromosomes of the haploid set of these new lines closely resemble the chromosomes of the cultivated parent, but with small regions replaced by segments of the wild genome through random crossover events.

The main disadvantage of wide hybridization is that undesirable wild genes are introduced along with the desired genes. Extensive backcrossing of the selected plant to the cultivated parent may be required to generate the new variety. Hybrids between cultivated rice and 12 wild species have been produced using embryo rescue. Genes for resistance to brown planthopper (BPH), whitebacked planthopper (WBPH), bacterial blight, and blast have already been transferred from wild species into elite breeding lines of rice.

Anther culture. Repeated selfing of a hybrid can also generate new varieties. At least five cycles of selfing are required to produce stable lines. In places where only one generation is possible per year, anther culture is advantageous because homozygous plants can be produced in two generations.

Anthers removed from the hybrid floret are, sterilized and placed on a suitable culture medium. A haploid callus develops from the male gametophyte and spontaneously diploidizes to form a dihaploid that is homozygous at every locus. The dihaploid plant's seeds are usually viable and give rise to plants that can be evaluated immediately. Early generation selection for recessive traits is a major advantage of plants derived from anther culture over plants obtained by conventional inbreeding. Cold tolerance is one of the traits introduced into cultivated indica varieties by anther culture.

Marker-aided selection. Breeders practice marker-aided selection whenever possible. They use this technique when an important trait that is difficult to assess is tightly linked to a trait that is easily measured. For example, a gene for resistance to BPH is close to a gene specifying purple coleoptile color in some traditional rice varieties grown in northeast India. When a resistant plant with a purple coleoptile is crossed with a susceptible plant with a green coleoptile, more than 95% of F_2 plants showing purple coleoptile are also resistant to BPH. In this case, coleoptile color is a morphological marker aiding the selection for BPH resistance.

Unfortunately, few morphological markers are known. They tend to be specific for particular rice varieties, and both the marker and the trait of interest must be dominant or both must be recessive. Moreover, the approach is limited to traits controlled by single major genes and does not apply to many of the most interesting and agronomically important traits that are quantitative in nature and governed by many unlinked genes.

The advent of molecular markers has added enormously to the power of marker-aided selection. Isozyme and DNA markers are more common than morphological markers. They are available for any cross, and are codominant, meaning that both parental markers can be observed in the hybrid. Additionally, the environment does not affect them, and they do not interact with other genes. They are, however, more difficult to measure or score than morphological markers.

The most commonly used DNA markers are restriction fragment length polymorphisms (RFLPs). To score an RFLP marker in an indi-

Table 3. Applications of biotechnology techniques to rice improvement.

Technique	Application
Embryo rescue	Transfer of genes from wild rices to cultivated rice
Anther culture	Rapid stabilization of new lines
Molecular marker-aided selection	Acceleration of breeding programs by use of genetic markers rather than phenotypic selection
DNA fingerprinting	Identification of genetic variation in pests and pathogens
Protoplast transformation	Introduction of novel genes into rice

vidual plant (Fig. 4), DNA must be extracted from the plant, transferred to a test tube, and cut into characteristic fragments using enzymes known as restriction endonucleases. Agarose gel electrophoresis and DNA-DNA hybridization are then used to determine the length of the restriction fragment derived from a particular locus of the rice genome. The locus is specified by the cloned segment of rice DNA used as a hybridization probe. The lengths of restriction fragments often differ between varieties because of mutation. This difference can be used as a marker in much the same way as a difference in coleoptile color. The unlimited number of RFLP markers has allowed for the saturated coverage of the genome with markers and the construction of an RFLP map of the 12 haploid chromosomes of rice.

Gene mapping and tagging. More than 900 RFLP markers have been placed on the genetic map of rice through cosegregation analysis. Scientists are also placing traditional morphological markers and isozyme markers on the map.

The first DNA-based map of rice chromosomes arose from a population of 53 F_2 plants derived from an indica/javanica intraspecific cross. The map has since been refined with additional mapping populations, including a population of 120 vegetatively propagated inbred plants derived from an *O. sativa/O. longistaminata* interspecific cross. Cosegregation analysis placed the RFLP markers into linkage groups, while trisomic analysis on a set of 12 rice lines, each carrying a single additional chromosome, identified these linkage groups with one or the other of the chromosomes. These developments have been possible with rice because it has a small haploid genome (0.6 pg), it is a true diploid, and it contains relatively little repeated DNA that can interfere with map construction. Another contributing factor has been the organization of rice biotechnology into a global network of collaborating laboratories.

The RFLP map can be used to locate genes of agronomic importance relative to DNA markers with known locations on rice chromosomes. Classical *phenotypes* and molecular marker *genotypes* must be evaluated on the same individuals (or related progenies). The data are analyzed to determine if any of the markers co-segregate with the target phenotype. If a marker very tightly linked to a gene is identified, the gene is said to be *tagged*, and the marker can be useful for indirect selection of the gene. A technique called bulked segregant analysis is particularly powerful for gene tagging and can be used with RFLP markers or with random amplified polymorphic DNA markers. With this technique, a linked marker is found, and then located relative to other markers on the RFLP map. This allows the genomic location of the gene to be efficiently determined.

Over 20 single genes for disease and insect resistance have been located relative to RFLP markers. Among them are several genes for resistance to the rice blast fungus, and major genes for resistance to bacterial blight and three insects (BPH, WBPH, and gall midge). A number of other agronomically useful genes such as those determining photoperiod sensitivity, aroma, wide compatibility, and fertility restoration have been mapped as well. Mapping results can be immediately applied to breeding programs.

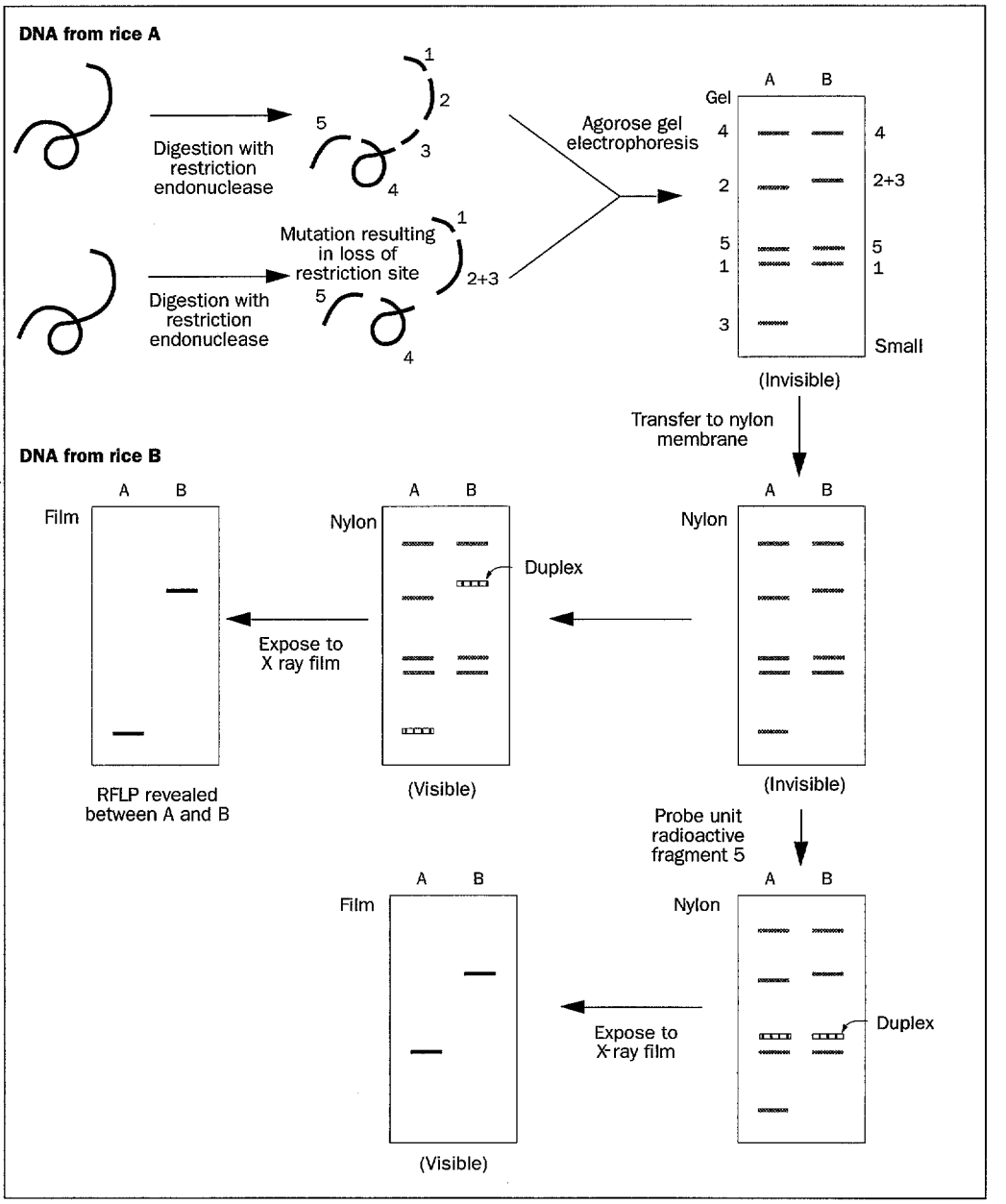
Many important traits are governed by multiple genes with relatively small effects. These traits are difficult to work with in a conventional breeding program. In addition to single genes with strong phenotypic effects, genes governing quantitative traits can be identified and characterized by RFLP mapping. This allows the genetic control of these traits to be better understood, and makes it possible to manipulate these traits by marker-aided selection.

For instance, while single major genes for disease and insect resistance often are soon overcome by pest/pathogen populations, it is believed that combining resistance genes may contribute to longer-lasting resistance. Durable resistance is associated with multiple major and minor resistance genes. In the presence of multiple resistance genes, there would be little or no gain in fitness for a pathogen variant that could overcome only a fraction of the genes. Many rice improvement programs aim to incorporate multiple resistance genes, including genes for partial resistance, into rice varieties.

Unfortunately, in a conventional breeding program it is difficult to work with quantitatively inherited resistance and with resistance genes with redundant effects. Because DNA markers are free of these confounding effects, resistance genes could be more easily accumulated based on indirect selection for markers that are linked to them. Several major genes and quantitative trait loci for blast resistance have been mapped using RFLP markers. They will be used to select lines carrying potentially useful gene combinations.

Scientists can simultaneously examine many RFLP markers with the same sample of extracted DNA. If different major genes specifying resistance to several insect pests of rice are tagged with RFLP markers, the inheritance of all of these genes can be followed without recourse to any entomological tests. This is particularly valuable when a breeding program designed to combat several insect pests is conducted in a location where climate variation prevents adequate insect pressure.

Germplasm management. The collection, conservation, characterization, and dissemination of rice germplasm provide plant breeders with new raw material for their programs. Molecular markers are used to address questions about germplasm management, including the genetic diversity,



4. Differentiating genetic material by restriction fragment length polymorphism (RFLP) analysis.

classification, and phylogeny of rice accessions. DNA-based protocols provide a convenient way to distinguish novel accessions from accessions that essentially duplicate existing stocks.

DNA fingerprinting of pests and pathogens. Pest and pathogen populations are heterogeneous. *Population structure* refers to the amount of genetic variation in a population, the ways in which variation is distributed in time and space, and the phylogenetic relationships between individuals within and between subpopulations. An understanding of pest and pathogen population structure allows resistance genes to be effectively evaluated and deployed.

DNA markers can also be used as tools for population genetic studies aimed at understanding the diversity and structure of pest and pathogen populations. For the blast and bacterial blight pathogens of rice, repetitive DNA markers have been used extensively to evaluate pathogen diversity, determine the evolutionary relationships between pathogen strains, and understand how pathogen races evolve.

Because of the substantial effort involved in transfer of a resistance gene to a desired genetic background, and the need for stable resistance, it is important to identify the most useful genes and gene combinations. A resistance gene will face a pest or pathogen population in the field. Thus it is important to characterize each available resistance gene relative to its resistance to pest/pathogen subpopulations. If the local pathogen population structure is understood, potential sources of resistance can be screened with isolates or populations that include the major phylogenetic and pathotypic groupings of the pathogen. For instance, based on DNA typing and virulence data, potential sources of resistance to bacterial blight are screened with a minimum of pathogen isolates that represent the pathogen diversity. Each identified resistance gene has been characterized by its resistance to each of the pathogen subpopulations, and potentially useful gene combinations have been identified. For blast, the diversity of pathogen populations in screening nurseries is being optimized based on DNA typing data. Known resistance genes are being characterized in relation to the pathogen lineages for which they are effective.

Protoplast transformation. Alien genes extracted from organisms that cannot hybridize with rice can be introduced through genetic engineering. This also permits the re-introduction of rice genes that have been extracted and modified to give altered properties. Such gene transfers are impossible with conventional breeding methods. Genetic engineering also allows introducing one or two well-characterized genes at a time. There is no need for the extensive backcrossing done in conventional hybridization to remove undesirable genes.

Several laboratories can produce transgenic rice plants via the uptake of DNA into protoplasts, which are plant cells freed of their cell wall by enzymatic digestion. DNA uptake through the protoplast membrane is achieved either by adding the neutral polymer polyethyleneglycol or by electroporation, in which the membrane is made briefly permeable by application of an electric current.

Rice is the first agronomically important monocot to be transformed from protoplasts to yield viable, fertile plants. Protoplasts prepared from suspension cells appear to give the best regeneration frequencies, with japonica varieties responding better than indica varieties. Chromosomal abnormalities may occur, however, during the 4- to 6-mo of tissue culture required to produce suitable suspension cells before transformation and then to regenerate whole transgenic plants.

Marker genes and promoters. The first foreign genes expressed in rice plants were bacterial genes conferring antibiotic or herbicide resistance. When the appropriate antibiotic or herbicide was present, these selectable marker genes permitted the few transformed cells to grow while nontransformed cells died. Reporter genes, such as the bacterial b-glucuronidase gene, have been used to optimize the transformation protocol and to study the properties of some plant promoters that may eventually be used to control the expression of useful genes in transgenic rice.

A promoter is a segment of DNA that precedes a gene and controls its activity by instructing the enzyme RNA polymerase about where, when, and how often to begin synthesis of messenger RNA. Some promoters allow activation of their gene only in a certain type of cell, at a particular stage of plant development, or in response to a specific external signal. Other promoters allow permanent expression of genes in a wide range of cell types.

The promoters most commonly used for rice transformation belong to the last group because

most current experiments seek to determine whether the gene of interest functions at all in the transgenic situation.

Useful foreign genes. Relatively few useful foreign genes have been introduced into rice because reliable transformation protocols have only recently emerged. Several genes encoding potentially insecticidal or fungicidal proteins are currently being moved into rice, including a gene encoding one of the insecticidal w-endotoxins produced by the bacterium *Bacillus thuringiensis*. Resistance to the rice stripe virus has been engineered into rice by expression of the virus gene encoding its coat protein.

Among the selectable marker genes employed with rice is the *bar* gene for resistance to the herbicide phosphinothricin. In principle, this gene could be used to develop herbicide-resistant rice varieties where direct seeding leads to competition with weeds. Such varieties, however, are unlikely to be released because of the danger that cross-pollination would allow the herbicide resistance gene to escape into local populations of weedy and wild rices and negate the original strategy. It may be necessary to place such genes in the DNA of the chloroplast, which is not transmitted through pollen.

Crop modeling

Crop modeling enables researchers to integrate knowledge from different disciplines in a quantitative way. That, in turn, helps researchers to understand the underlying processes that determine the behavior of complex agricultural systems. It also helps to increase the efficiency and efficacy of problem-solving research because models allow testing of new technologies in other environments before laborious experimental research is begun.

Models at different levels of detail are developed to meet different objectives, ranging from a thorough understanding of an existing system to the prediction of crop production in untested conditions. Four levels of crop production can be distinguished.

1. Potential production, where production is determined by solar radiation, temperature, and crop and varietal characteristics.
2. Water-limited production.
3. Water- and N-limited production.
4. Water-, N- and other nutrient-limited production.

Going from level one to level four, production generally decreases and the variables that determine system behavior increase. At all levels, growth reducing factors such as insects, pathogens, and weeds can be introduced. Models for all production levels have been developed. Models at the first two levels are further developed than models at levels three and four. The approach in systems research is illustrated in Figure 5.

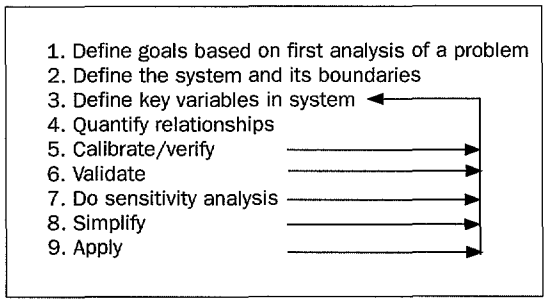
Well-developed models that simulate the growth of a crop in relation to its dynamic environment can be used to prioritize research. Crop modeling combined with geographic information systems (GIS) analysis enables researchers to distinguish agroecological zones and to quantitatively rank the technical constraints to agricultural production within them. These models allow the impact of new technology on agricultural production to be assessed before the technology is introduced. The GIS data base can link the models directly with socioeconomic aspects.

Crop simulation models have three primary uses. First, they guide researchers in prioritizing their research and in integrating quantitative knowledge from different disciplines. Second, the models can be used as a research tool and to support problem solving and decision making. Third, models can be used as a framework for training.

In general, models can be used to extrapolate research findings over broad regions and extended time, since the model accounts for crop-environment interactions. Using long-term weather data, yield probabilities can be simulated. Figure 6 shows the yield probabilities for a modern rice variety under conditions in Los Baños, Philippines, given a high level of leaf N content measured in the dry season.

An aspect that is gaining more interest is the use of models to set breeding goals. The physiological attributes that contribute significantly to crop production in a given environment lend themselves to definition by crop modeling. Through modeling, the optimum timing of seeding or transplanting, irrigation, and fertilization can be determined for a given environment.

Modeling is especially useful in yield gap analysis, a method for identifying constraints to agricultural production in different agroclimatic zones. From yield gap analysis, constraints that can be reduced can be identified. Researchers then concentrate on ameliorating those factors that contribute to the gap between farm yield, poten-



5. Steps to use in systems analysis and the research process.

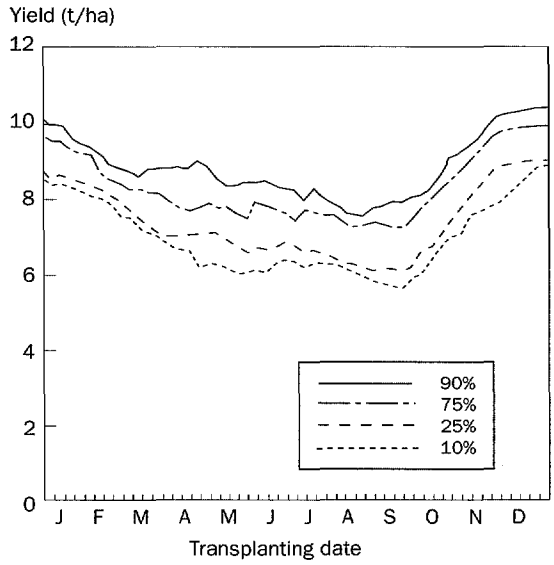
tial farm yield, and potential experiment station yield (Fig. 7).

Geographic information systems

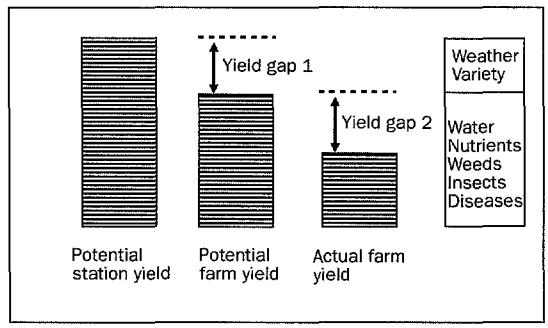
Geographic information systems (GIS) is called an enabling technology because it is a systematic and holistic approach to information integration. At its most basic level, GIS is an information management tool—a method of managing vast arrays of biophysical and socioeconomic information. At the advanced level, GIS is a tool for modeling and testing hypotheses on land use, ecosystem change, or technology suitability. The basic attributes of GIS include the use of computer processing, data base software, geographic analysis, statistics and report generation, and graphic output.

GIS has been used in diverse ways: studies of land use changes, farmland location, forest and soil inventories, watershed management, flood damage assessment, environmental impact assessment, and demographic analysis.

Only recently has it been applied directly to agricultural research. Agricultural research benefits from GIS analysis in at least three ways. First, GIS integrates spatial (maps and satellite images) and tabular (data bases, i.e. census, soils, and climate) information sources within a single system. That enables scientific disciplines to be related within a common system. Second, by bringing large amounts of complex information together in one system, GIS allows researchers and policymakers to view and analyze information from new and different approaches. Third, from a scientific standpoint, the methods and information that are used in the analysis are explicit and can be repeated and used by other researchers.



6. Potential yield of a modern rice variety at a given month of transplanting, predicted from historic weather patterns over a 29-yr period in Los Baños, Philippines. From top to bottom, the curves represent levels of 90, 75, 25, and 10% probability of yields.



7. Modeling applied to yield gap analysis helps to identify constraints that can be reduced and can contribute to higher yields in farmers' fields.

GIS has the capability to encode, store and retrieve, analyze, and display multiple layers of data. For example, three or more layers in hand-drawn maps are difficult to compare. But GIS can integrate multilayered information—each differently weighted if necessary—and express the analysis in tables, graphics displays on computer monitors, or in maps.

Appendix tables

1. IRRI rice facts.
2. Area and production of rice and other cereal grains, by agroecological zones in Asia.
3. Distribution of rice area by ecosystem.
4. Average rice yield by ecosystem.
5. Distribution of rice production by ecosystem

1. IRRI rice facts

GENERAL INFORMATION

Major rice-consuming and -producing countries	Population (000) Estimated 1991	Projected 2000	Projected 2025	Infant mortality 1991 (000 births)	Life expectancy at birth 1991 (years)	GNP[c] per capita 1991 ($)	GNP[c] per capita Average annual growth rate 1980-91 (%)
ASIA	**3,157**	**3,653**	**4,892**	**- b**	**-**	**-**	**-**
Bangladesh	111	128	176	103	51	220	1.9
Cambodia	9	10	14	-	50	200	-
China[a]	1,150	1,316	1,623	38	69	370	7.8
India	866	1,006	1,348	90	60	330	3.2
Indonesia	181	209	275	74	60	610	3.9
Japan	124	128	128	5	79	26,930	3.6
Korea, DPR	22	25	33	71	-	-	
Korea, Republic of	43	47	54	16	70	6,330	8.7
Laos	4	6	10	100	50	220	-
Malaysia	18	22	32	15	71	2,520	2.9
Myanmar	43	51	70	-	59	500	10.3
Nepal	19	24	37	101	53	180	2.1
Pakistan	116	147	240	97	59	400	3.2
Philippines	63	74	101	41	65	730	-1.2
Sri Lanka	17	19	24	18	71	500	2.5
Thailand	57	64	83	27	69	1,570	5.9
Vietnam	68	82	116	-	67	220	-
LATIN AMERICA	**445**	**524**	**709**	**-**	**68**	**-**	**-**
Brazil	151	178	237	58	66	2,940	0.5
Colombia	33	38	50	23	69	1,260	1.2
Cuba	11	12	14	-	76	-	-
Dominican Republic	7	8	11	54	67	940	-0.2
Ecuador	11	13	18	47	66	1,000	-0.6
Guyana	1	1	1	-	65	430	-4.5
Peru	22	27	37	53	64	1,070	2.4
Suriname	0.5	1	1	-	68	3,630	-4.5
Uruguay	3	3	4	21	73	2,840	-0.4
AFRICA	**645**	**831**	**1,467**	**-**	**-**	**-**	**-**
Côte d'Ivoire	12	17	31	95	52	690	-4.6
Egypt	54	62	86	59	61	610	1.9
Guinea	6	8	15	136	44	460	-
Liberia	3	3	6	-	55	-	-
Madagascar	12	15	26	114	51	210	-2.5
Sierra Leone	4	5	10	145	42	210	-1.6
Nigeria	99	127	215	85	52	340	-2.3
AUSTRALIA	**17**	**20**	**23**	**8**	**77**	**17,050**	**1.6**
USA	**253**	**273**	**314**	**9**	**76**	**22,240**	**1.7**
REST OF THE WORLD	**833**	**867**	**940**	**-**	**-**	**-**	**-**
WORLD	**5,350**	**6,168**	**8,345**	**53**	**66**	**4,010**	**1.2**

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1. IRRI rice facts (continued)

INFORMATION ABOUT AGRICULTURE

Major rice-consuming and -producing countries	Arable land[d] 1990 (000 ha)	Agricultural researchers 1981-85 (no.)	Agriculture's share (%)		Average annual growth rate (%)	
			Labor force 1990	GDP[e] 1991	Agriculture sector 1980-91	Rice area 1980-91
ASIA	**422,324**	**76,614**	**60**	**-**	**-**	**0.30**
Bangladesh	8,838	927	68	36	2.7	0.54
Cambodia	2,910	58	70	-	-	2.04
China[a]	93,283	33,831	68	27	5.7	-0.37
India	165,400	8,389	66	31	3.2	0.45
Indonesia	16,000	1,349	48	19	3.1	1.13
Japan	4,121	14,779	6	3	1.2	-1.34
Korea, DPR	1,700	1,253	34	-	-	0.62
Korea, Republic of	1,953	1,356	24	8	2.1	-0.18
Laos	890	29	72	57	-	-1.21
Malaysia	1,040	811	32	17	3.7	-1.10
Myanmar	9,567	267	47	48	-	0.05
Nepal	2,624	446	92	59	4.9	1.05
Pakistan	20,300	2,972	50	26	4.2	0.58
Philippines	4,550	1,965	47	21	1.1	-0.10
Sri Lanka	925	391	52	27	2.3	0.39
Thailand	19,000	1,676	64	12	3.8	0.76
Vietnam	5,690	1,994	61	38	-	1.07
LATIN AMERICA	**131,179**	**9,000**	**26**	**-**	**-**	**-2.43**
Brazil	50,400	3,794	24	10	2.6	-3.66
Colombia	3,900	454	27	17	3.2	0.45
Cuba	2,608	-	19	-	-	-0.25
Dominican Republic	1,000	136	36	18	0.3	-3.58
Ecuador	1,700	211	30	15	4.4	6.43
Guyana	480	50	22	-	-	-2.01
Peru	3,400	262	35	-	2.2	3.97
Suriname	57	22	16	-	-	-1.51
Uruguay	1,260	77	14	10	0.2	5.44
AFRICA	**163,173**	**9,958**	**63**	**-**	**-**	**2.63**
Côte d'Ivoire	2,430	201	56	38	-1.2	4.30
Egypt	2,330	4,246	41	18	2.4	0.54
Guinea	610	177	74	29	-	1.80
Liberia	128	33	70	-	-	-3.06
Madagascar	2,580	82	77	33	2.4	-0.78
Sierra Leone	486	46	62	43	2.7	-1.25
Nigeria	29,765	1,003	65	37	3.5	10.45
AUSTRALIA	**48,813**	**4,579**	**5**	**3**	**2.9**	**-2.38**
USA	**187,881**	**14,366**	**2**	**-**	**-**	**-1.67**
REST OF THE WORLD	**396,460**	**-**	**11**	**-**	**-**	**-0.08**
WORLD	**1,349,830**	**-**	**47**	**-**	**2.6**	**0.23**

1. IRRI rice facts (continued) **RICE CONSUMPTION**

Major rice-consuming and -producing countries	Daily calorie supply per capita 1990 (no.)	Rice in total calorie supply 1990 (%)	Milled rice consumption per capita (kg/yr)		Total rice consumption (rough rice equivalent) 1990 (000 t)	Projected rice food demand (rough rice equivalent, 000 t)	
			Estimated 1990	Projected 2000[f]		2000	2025[g]
ASIA	**2,531**	**35**	**85**	**91**	**405,385**	**511,378**	**684,866**
Bangladesh	2,100	75	155	163	27,185	32,073	44,035
Cambodia	2,114	80	167	172	2,055	2,699	3,625
China[a]	2,706	36	94	106	164,572	214,544	264,658
India	2,243	30	66	70	86,105	108,338	145,126
Indonesia	2,631	58	138	152	38,640	48,850	64,214
Japan	2,926	24	62	51	11,732	10,012	10,020
Korea, DPR	2,860	47	125	149	4,423	5,822	7,496
Korea, Republic of	2,840	36	92	77	6,228	5,520	6,338
Laos	2,475	70	190	186	1,169	1,631	2,976
Malaysia	2,697	29	79	91	2,188	3,122	4,480
Myanmar	2,448	77	190	198	12,277	15,505	21,201
Nepal	2,246	42	102	92	2,982	3,411	5,180
Pakistan	2,377	8	19	24	3,332	5,439	8,854
Philippines	2,452	41	99	90	9,443	10,205	13,971
Sri Lanka	2,286	42	94	111	2,458	3,228	4,047
Thailand	2,271	55	128	117	11,028	11,502	14,886
Vietnam	2,215	68	146	155	15,723	19,554	27,590
LATIN AMERICA	**2,664**	**10**	**26**	**27**	**17,640**	**21,766**	**29,467**
Brazil	2,723	16	43	44	9,923	12,070	16,043
Colombia	2,492	13	32	40	1,526	2,314	3,077
Cuba	3,153	15	48	52	812	928	1,080
Dominican Republic	2,297	21	49	50	528	638	838
Ecuador	2,410	16	38	27	643	523	731
Guyana	2,393	29	67	146	103	180	225
Peru	1,890	21	36	36	1,218	1,468	2,033
Suriname	2,431	35	89	91	55	70	112
Uruguay	2,678	4	9	10	42	51	58
AFRICA	**2,328**	**6**	**14**	**16**	**14,022**	**20,463**	**36,103**
Côte d'Ivoire	2,411	19	24	45	480	1,156	2,174
Egypt	3,318	9	28	30	2,326	2,880	3,951
Guinea	2,229	29	61	71	657	819	1,595
Liberia	2,067	44	98	105	452	549	969
Madagascar	2,162	50	104	121	1,920	2,867	4,784
Sierra Leone	1,940	45	95	118	585	962	1,834
Nigeria	2,147	6	12	14	2,160	2,744	4,635
AUSTRALIA	**3,385**	**8**	**5**	**4**	**131**	**121**	**143**
USA	**3,680**	**2**	**6**	**5**	**2,308**	**2,098**	**2,418**
REST OF THE WORLD	**3,196**	**4**	**6**	**5**	**7,706**	**6,669**	**7,230**
WORLD	**2,712**	**21**	**55**	**59**	**447,192**	**559,856**	**757,506**

1. IRRI rice facts (continued)

Major rice-consuming and -producing countries	RICE PRODUCTION: Rough rice (1991) Production (000 t)	Area (000 ha)	Yield (t/ha)	Area planted to modern varieties 1990 (%)	RICE TRADE: Milled rice (000 t) 1991 Imports	Exports
ASIA	**477,267**	**133,251**	**3.6**	**74**	**4,033**	**8,193**
Bangladesh	28,575	10,940	2.6	51	10	0
Cambodia	2,400	1,800	1.3	11[h]	20	0
China[a]	187,450	33,100	5.7	100 [h,i]	146	818
India	110,945	42,200	2.6	66	18	450
Indonesia	44,321	10,187	4.4	77	171	
Japan	12,005	2,049	5.9	100	18	*[j]
Korea, DPR	5,100	680	7.5	-	160	11
Korea, Republic of	7,478	1,209	6.2	100	4	2
Laos	1,400	640	2.2	2	30	0
Malaysia	1,550	635	2.4	90[k]	400	0
Myanmar	13,201	4,830	2.7	50	0	176
Nepal	3,600	1,432	2.5	36	5	0
Pakistan	4,903	2,060	2.4	42	0	1,205
Philippines	9,670	3,423	2.8	89	92	10
Sri Lanka	2,397	860	2.8	91	133	1
Thailand	20,040	10,000	2.0	68[h]	0	4,333
Vietnam	19,428	6,295	3.1	80	6	1,000
LATIN AMERICA	**17,231**	**6,267**	**2.7**	**37**	**1,800**	**584**
Brazil	9,503	4,143	2.3	23	728	1
Colombia	1,739	435	4.0	87	*	85
Cuba	430	143	3.0	100	260	0
Dominican Republic	303	75	4.0	81	25	0
Ecuador	841	252	3.3	63	0	*
Guyana	250	76	3.3	4	0	54
Peru	814	158	5.2	73	223	0
Suriname	190	55	3.5	92	0	84
Uruguay	540	120	4.5	45	9	270
AFRICA	**13,066**	**6,607**	**2.0**	**-**	**3,617**	**296**
Côte d'Ivoire	690	572	1.2	-	394	0
Egypt	3,152	433	7.3	-	4	159
Guinea	628	650	1.0	-	182	80
Liberia	110	140	0.8	-	165	
Madagascar	2,200	1,100	2.0	-	31	0
Sierra Leone	386	357	1.1	-	135	0
Nigeria	3,185	1,642	1.9	-	250	0
AUSTRALIA	**726**	**89**	**8.2**	**-**	**28**	**210**
USA	**7,006**	**1,113**	**6.3**	**-**	**161**	**2,243**
REST OF THE WORLD	**4,573**	**1,039**	**4.4**	**-**	**2,953**	**1,282**
WORLD	**519,869**	**148,366**	**3.5**	**-**	**12,592**	**12,817[l]**

1. Rice facts, continued

[a]Gross national product; [b]– = data not available; [c]Including Taiwan. [d]Excluding permanent crops. [e]Gross domestic product; [f]FAO projections except Bangladesh. Côte de Ivoire, Japan, India, Indonesia, Korea Rep., Lao PDR, Philippines, Thailand, which are IRRI estimates, and Australia, which is country estimate; [g]Assuming per capita consumption does not change after 2000. [h]Relate to wet season only; [i]Hybrid rice is 40%; [j]Less than 1000 t; [k]West Malaysia only; [l]Difference is changes in domestic stocks.

Sources World Bank, World Development Report, 1993; FAP Production Yearbook 1990; IRRI Ricestat Data 1992; FAO AGROSTAT 1992; CIAT, Trends in CIAT Commodities, 1992; Country National Statistical Offices; ISNAR, Agricultural Research Policy: International Perspective, 1989: ADB, Asian Development Outlook, 1992; B. Bos et al. World Population Projections 1992-93 Edition, World Bank 1992.

2. Area and production of rice and other cereal grains, by agroecological zones in Asia .

	Rice		Wheat		Maize		Other coarse grains		Rice area under different ecosystems (000 ha)			
	Area (000 ha)	Prodn (000 t)	Area (000 ha)	Prodn (000 t)	Area (000 ha)	Prodn (000 t)	Area (000 ha)	Prodn (000 t)	Irrigated	Rainfed lowland	Upland	Deep-water
SEMIARID TROPICS	9510	32807	1721	2145	1007	1887	18522	16155	6480	1439	6079	466
Southern India	9510	32807	1721	2145	1007	1887	18522	16155	6480	1439	6079	466
SUBHUMID TROPICS	38927	83933	5774	8681	3780	7718	4430	3242	10427	17167	6079	5254
Eastern India	24212	49949	5653	7851	1947	3131	4036	2865	6880	9527	4266	3539
Thailand	9983	20177	0	0	1710	4393	194	247	2695	5142	1108	1038
Myanmar	4732	13807	121	830	123	194	200	130	852	2498	705	677
HUMID TROPICS	34199	108577	560	1022	7247	11720	130	95	16464	9185	3831	4719
Bangladesh	10554	27691	560	1022	4	3	110	79	2322	4781	908	2543
Indonesia	10531	44726			2944	6193	6	3	7583	821	1453	674
Malaysia	647	1744			19	34	0	0	427	135	80	5
Philippines	3497	9459			3689	4522	0	0	2133	1119	175	70
Lao PDR	596	1404			30	44	0	0	61	240	295	0
Cambodia	1800	2500			25	50	0	0	288	608	443	461
Sri Lanka	690	2063			29	31	11	7	532	104	47	7
Vietnam	5884	18990			507	843	3	6	3118	1377	430	959
SEMIARID SUBTROPICS	4081	13911	18764	50427	12157	45867	9889	9273	4060	0	21	0
Western India	119	227	1650	3400	943	1313	6004	2512	119	0	0	0
Pakistan	2107	4830	7730	14419	863	1179	1110	589	2107	0	0	0
Northeastern China	1855	8854	9384	32608	10351	43375	2775	6172	1834	0	21	0
SUBHUMID SUBTROPICS	24326	123694	27945	79353	9336	32238	4041	5244	18779	3186	1231	1129
Northwestern India	7887	26628	13773	35380	1355	1967	3093	3267	4656	1473	820	938
Nepal	1433	3502	599	830	751	1201	223	252	330	868	44	191
Central & SW China	13079	79872	13521	42933	6500	24499	386	912	12102	711	265	0
Korea, DPR	670	5500	52	210	705	4450	150	285	447	134	89	0
Korea, Rep of	1257	8192	0	0	25	121	189	528	1244	0	13	0
COOL HUMID SUBTROPICS	18352	94726	873	1770	794	1770	25	35	16909	1165	2758	0
Southern & SE China	17876	91928	872	1767	794	1770	25	35	16479	1122	2755	0
Taiwan	476	2798	1	3	0	0	0	0	430	43	3	0
COOL SUBTROPICS	746	3372	6692	17402	3317	11877	937	1148	746	0	0	0
Northern India	353	1011	626	846	606	1111	92	63	353	0	0	0
Rest of China	393	2361	6066	16556	2711	10766	845	1085	393	0	0	0

3. Distribution of rice area by ecosystem.

Major rice-consuming and -producing countries	1991 rice area (000 ha)	Distribution of rice area (000 ha)			
		Irrigated	Rainfed lowland	Flood-prone	Upland
ASIA	133,251	73943	38753	10016	10539
Bangladesh	10,940	2407	5166	2492	875
Bhutan	26	13	1	11	1
Cambodia	1,800	144	864	756	36
China[a]	33,100	30783	1655	0	662
India	42,200	18990	13926	2954	6330
Indonesia	10,187	7335	713	1018	1121
Japan	2,049	2029	0	0	20
Korea, DPR	680	456	136	0	88
Korea, Republic of	1,209	1100	97	0	12
Laos	640	13	393	0	234
Malaysia	635	419	133	7	76
Myanmar	4,830	869	2512	1159	290
Nepal	1,432	329	942	118	43
Pakistan	2,060	2060	0	0	0
Philippines	3,423	2088	1198	69	68
Sri Lanka	860	321	454	25	60
Thailand	10,000	720	8568	660	52
Vietnam	6,295	3336	1763	692	504
LATIN AMERICA	6,267	2042	427	112	3686
Brazil	4,143	787	246	10	3100
Colombia	435	291	44	0	100
Cuba	143	143	0	0	0
Dominican Republic	75	70	5	0	0
Ecuador	252	136	18	98	0
Guyana	76	54	22	0	0
Peru	158	126	32	0	0
Suriname	55	51	4	0	0
Uruguay	120	120	0	0	0
AFRICA	6,607	1107	1373	1327	2800
Côte d'Ivoire	572	34	0	40	498
Egypt	433	433	0	0	0
Guinea	650	32	0	312	306
Liberia	140	0	0	8	132
Madagascar	1,100	110	814	22	154
Sierra Leone	357	0	0	132	225
Nigeria	1,642	263	0	542	837
Tanzania	369	10	279	0	80
AUSTRALIA	89	89	0	0	0
USA	1,113	1113	0	0	0
REST OF THE WORLD	1,039	912	0	0	127
WORLD	148,366	79206	40553	11455	17152

[a]Including Taiwan.

4. Average rice yield by ecosystem.

Major rice-consuming and -producing countries	1991 rice yield (t/ha)	Rice yield by ecosystem(t/ha)			
		Irrigated	Rainfed lowland	Flood-prone	Upland
ASIA	3.6	4.9	2.3	1.5	1.1
Bangladesh	2.6	4.6	2.5	1.6	0.8
Bhutan	1.6	-	-	-	-
Cambodia	1.3	2.5	1.5	0.9	0.9
China[a]	5.7	5.9	3.0	0.0	2.5
India	2.6	3.6	2.4	1.5	0.8
Indonesia	4.4	5.3	3.0	1.7	1.6
Japan	5.9	5.9	0.0	0.0	2.5
Korea, DPR	7.5	9.1	4.6	0.0	3.8
Korea, Republic of	6.2	6.5	3.0	0.0	2.5
Laos	2.2	3.4	2.6	0.0	1.4
Malaysia	2.4	3.0	1.5	1.6	1.0
Myanmar	2.7	4.2	3.0	1.5	1.0
Nepal	2.5	4.2	2.2	0.8	1.0
Pakistan	2.4	2.4	0.0	0.0	0.0
Philippines	2.8	3.4	2.0	1.3	1.0
Sri Lanka	2.8	3.7	2.5	1.0	1.0
Thailand	2.0	4.0	1.8	2.0	1.5
Vietnam	3.1	4.3	2.0	1.5	1.0
LATIN AMERICA	2.8	5.0	2.4	1.8	1.6
Brazil	2.3	5.0	2.7	0.0	1.6
Colombia	4.0	5.0	2.5	0.0	1.6
Cuba	3.0	3.0	0.0	0.0	0.0
Dominican Republic	4.0	4.1	2.8	0.0	0.0
Ecuador	3.3	4.7	1.5	1.8	0.0
Guyana	3.3	4.0	1.5	0.0	0.0
Peru	5.2	6.2	1.0	0.0	0.0
Suriname	3.5	3.6	1.0	0.0	0.0
Uruguay	4.5	4.5	0.0	0.0	0.0
AFRICA	2.0	5.0	2.1	1.3	1.0
Côte d'Ivoire	1.2	4.0	0.0	1.5	1.0
Egypt	7.3	7.3	0.0	0.0	0.0
Guinea	1.0	4.1	0.0	0.9	0.7
Liberia	0.8	0.0	0.0	1.3	0.8
Madagascar	2.0	4.0	2.0	0.7	1.0
Sierra Leone	1.1	0.0	0.0	1.3	0.9
Nigeria	1.9	4.9	0.0	1.5	1.3
Tanzania	1.8	4.0	2.0	0.0	0.9
AUSTRALIA	8.2	8.2	0.0	0.0	0.0
USA	6.3	6.3	0.0	0.0	0.0
REST OF THE WORLD	4.4	4.9	0.0	0.0	1.0
WORLD	3.5	4.9	2.3	1.5	1.2

[a]Including Taiwan.

5. Distribution of rice production by ecosystem.

Major rice-consuming and -producing countries	1991 rough rice production (000 t)	Distribution of rice production (000 t)			
		Irrigated	Rainfed lowland	Flood-prone	Upland
ASIA	477,267	361553	89250	15284	11180
Bangladesh	28,575	10994	12855	4026	700
Bhutan	43				
Cambodia	2,400	360	1328	680	32
China[a]	187,450	180830	4965	0	1655
India	110,945	68028	33422	4431	5064
Indonesia	44,321	38656	2140	1732	1793
Japan	12,005	11956	0	0	49
Korea, DPR	5,100	4146	620	0	334
Korea, Republic of	7,478	7157	291	0	30
Laos	1,400	44	1018	0	338
Malaysia	1,550	1257	206	11	76
Myanmar	13,201	3636	7536	1739	290
Nepal	3,600	1385	2080	92	43
Pakistan	4,903	4903	0	0	0
Philippines	9,670	7117	2396	89	68
Sri Lanka	2,397	1,118	1,1123	26	60
Thailand	20,040	2,882	15,760	1,320	78
Vietnam	19,428	14,361	3,525	1,038	504
LATIN AMERICA	17,231	10,200	1,015	205	5,811
Brazil	9,503	3,935	663	20	4,885
Colombia	1,739	1,469	110	0	160
Cuba	430	430	0	0	0
Dominican Republic	303	289	14	0	0
Ecuador	841	636	27	178	0
Guyana	250	217	33	0	0
Peru	814	782	32	0	0
Suriname	190	186	4	0	0
Uruguay	540	540	0	0	0
AFRICA	13,066	5,549	2,891	1,712	2,914
Côte d'Ivoire	690	136	0	60	494
Egypt	3,152	3,152	0	0	0
Guinea	629	132	0	282	214
Liberia	110	0	0	10	100
Madagascar	2,200	440	1,591	15	154
Sierra Leone	386	0	0	176	210
Nigeria	3,185	1,286	0	820	1,079
Tanzania	664	40	552	0	72
AUSTRALIA	726	726	0	0	0
USA	7,006	7,006	0	0	0
REST OF THE WORLD	4,573	4,446	0	0	127
WORLD	519,869	389,940	93,156	17,201	20,032

[a]Including Taiwan.

Important conversion factors, by country

Country	Conversion factors
Asia	
Bangladesh	
	1 bushel = 0.73 maund = 29.17 seer = 60 lb
	1 maund = 82.29 lb = 37.32 kg
	1 seer = 2.05 lb = 0.93 kg
	1 kg = 2.20462 lb = 1.07 seer
	1 bushel per acre = 67.253 kg per ha
	1 ha = 2.47109 acres
	1 acre = 0.40468 ha
	1 lakh = 100,000
	1 crore = 10,000,000
Cambodia	
	1 picul = 68 kg
	1 mt = 14.7059 picul
China	
	1 mu = 0.067 ha
	15 mu = 1.0 ha
	1 sheng milled rice = 1 liter milled rice = 0.5 kg
	1 dou milled rice = 10 liters milled rice = 5 kg
	1 dan (picul) milled rice = 100 liters milled rice = 50 kg
	20 dan (picul) = 1 mt
	1 dun = 1 mt = 2204.6 lb
	1 dan (picul) = 100 jin
	1 jin (catty) = 0.5 kg = 1.1023 lb
	1 jin/mu = 7.5 kg/ha
Taiwan, China	1 kg rough rice = 0.76366 kg brown rice
	1 kg ponlai brown rice = 0.93 kg milled rice
	1 kg chailai brown rice = 0.94 kg milled rice
	1 ha = 1.03 chia
	1 chia = 0.9699 ha
	1 old catty = 0.5968 kg
	1 shih catty = 0.5 kg
India	
	1 quintal = 100 kg
	1 maund = 37.3 kg = 82.29 lb
	1 Madras measure rice = 54 oz = 3.375 lb
	Bigha is a land measure in rural areas;its definition varies from state to state. In Gujarat, 4/7 bigha = 1 acre; in Rajasthan, 21/2 bighas = 1 acre; in West Bengal, 3 bighas = 1 acre.

Country	Conversion factors
Indonesia	
	1 liter rice = 0.8 kg
	1 gantang rice = 8.58 liters = 0.00686 mt
	1 mt rice = 145.69 gantang
	Dry stalk rough rice (padi) to milled rice (beras) = 52%
	Gabah kering (dry rough rice) to milled rice (beras) = 68%
	Dry stalk rough rice (padi) to rough rice = 76.47%
Japan	
	Brown rice × 1.25 = rough rice
	Milled rice × 1.37 = rough rice
	Brown rice × 0.91 = milled rice
	Rough rice × 0.728 = milled rice
	1 koku rough rice = 187.5 kg
	1 koku brown rice = 150 kg
	1 koku milled rice = 136.5 kg
	1 sho milled rice = 1.425 kg
	1 kan = 3.75 kg
	1 kin = 0.6 kg
	1 picul = 10° kin = 60 kg
	1 cho = 10 tan = 2.45072 acres = 0.99174 ha
	1 ha = 10.0833 tan = 1.00833 cho
	1 tan = 0.1 cho = 0.09917 ha
Korea Rep	
	1 danbo = 0.1 jeongbo = 0.099174 ha
	1 ha = 1.0083 jeongbo
	1 seok milled rice = 144 kg
	1 seok brown rice = 155 kg
	1 seok rough rice = 100 kg
	100 liters milled rice = 79.8264 kg
Malaysia	
	1 picul brown rice = 133.33 lb = 60.48 kg
	1 gantang rough rice = 5.60 lb = 2.54 kg
	1 kati = 0.60478 kg
Myanmar	
	100 measures rough rice = 1 basket
	1 basket rough rice = 46 lb = 20.86 kg
	1 basket milled rice = 75 lb = 34.02 kg
	1 bag milled rice = 225 lb = 102.06 kg
	1 pyi milled rice = 4.69 lb = 2.13 kg
	1 maund = 0.037 mt
	1 mt = 26.792 maunds

continued

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Country	Conversion factors
Nepal	
	1 khet = 1.3 ha
	1 bigha = 0.67 ha (Terai)
	1 matomuri = 0.13 ha = 0.25 ropani
	1 ropani = 0.05 ha (Hills) = 4 muris
	1 muri = 0.013 ha
	1 seer = 0.80 kg (Hills)
	1 seer = 0.93 kg (Terai)
	1 mana = 0.3 kg rough rice
	1 mana = 0.454 kg rice
	1 maund = 37.32 kg rough rice (Terai)
Pakistan	
	1 kg = 2.2046 lb = 1.0716 seer
	1 quintal = 100 kg = 1.96841 cwt = 2.679 maunds
	1 metric ton = 1000 kg = 0.98421 long ton = 26.79 maunds
	100 kg per ha = 1.4869 bushels per acre = 1.09 maunds per acre
	1 bushel = 0.73 maunds = 29.17 seers = 60 lb
	Before 1980, 1 maund = 37.324 kg
	After 1980, 1 maund = 40 kg
Philippines	
	1 cavan rough rice = 50 kg
	1 cavan milled rice = 50 kg
	1 ganta milled rice = 2.24 kg
	Before 1973
	1 ganta = 3 liters
	1 cavan rough rice = 44 kg
	1 cavan milled rice = 56 kg
Sri Lanka	
	1 bushel rough rice = 46 lb = 20.86 kg
	1 bushel rough rice = 30.69 lb milled rice = 14 kg milled rice
	1 bushel milled rice = 64 lb = 32 measures of rice
	1 measure milled rice = 2 lb = 0.907 kg
Thailand	
	1 picul = 60 kg
	1 catty = 600 g = 6 kg
	1 kwein = 2000 liters
	1 ban = 1000 liters
	1 sat = 20 liters
	1 thanan = 1 liter
	1 kwein rough rice = 1 mt rough rice
	1 rai = 0.16 ha = 0.395 acre
Other countries	
Australia	
	1 bushel rough rice = 42 lb = 19.05 kg
Brazil	
	1 bushel rough rice = 45 lb = 20.41 kg
	1 sack (bag) rough rice = 110.23 lb = 50 kg
	1 sack (bag) milled rice = 88.18 lb = 40 kg
Egypt	
	1 sack (bag) milled rice = 220.11 lb = 99.84 kg
Ghana	
	1 sack (bag) milled rice = 240 lb = 108.86 kg
Guyana	
	1 sack (bag) rough rice = 140 lb = 63.50 kg
	1 sack (bag) milled rice = 180 lb = 81.65 kg
Malawi	
	1 sack (bag) rough rice = 150 lb = 68.04 kg
	1 sack (bag) milled rice = 200 lb = 90.72 kg
Mexico	
	1 carga rough rice = 304.24 lb = 138 kg
	1 carga milled rice = 352.74 lb = 160 kg
Panama	
	1 lata milled rice = 24.99 lb = 11.33 kg
	1 lata rough rice = 35.99 lb = 16.32 kg
Sierra Leone	
	1 bushel rough rice = 60 lb = 27.21 kg
	1 bushel milled rice = 84 lb = 38.10 kg
Swaziland	
	1 pocket milled rice = 2 lb = 0.91 kg
United States	
	1 bushel rough rice = 45 lb = 20.41 kg
	1 sack (bag) rough rice = 100 lb = 45.36 kg
	1 sack (bag) milled rice = 100 lb = 45.36 kg
	1 barrel rough rice = 162 lb = 73.48 kg
Uruguay	
	1 bolsa brown rice = 110.23 lb = 50 kg

Sources: For Asia: Rose, B. 1985. Appendix to the Rice Economy of Asia. Resources for the Future, Inc., Washington, D.C.
For other countries: FAO Rice Report. 1974-75. 1975. Rome.

Rice data bases at IRRI

Rice Genetic Resources
The core of all rice-related information is rice germplasm identification. Interrelated tables contain passport information and characterization data will eventually link all rice-related information.

Plant Breeding
Several data files contain information about crosses, pedigrees, and selections, with related information about key selection criteria. This data base is being converted to a set of relational tables using standard keys.

Genetic Evaluation
A number of tables contain evaluation data on material from the germplasm bank and from plant breeding activities. Tables already linked to the germplasm identification standard are Plant Physiology (submergence tolerance, cold tolerance, and internode elongation data) and the Rice Viruses data base (reaction information related to several rice viruses). We are converting data collected through INGER to link network trial results to the standard germplasm identification table.

INSURF trial results
Results of fertilizer trials conducted in the INSURF network.

RICESTAT information
A collection of rice statistics (mainly socioeconomic data) from international and national sources, such as FAO, national statistics agencies, and IRRI research.

Weather data base
IRRI acts as a clearinghouse for meteorological information from many cooperators. Data is stored in CLICOM format, as recommended by the UN World Meteorological Organization, and is accessible for use in crop modeling and GIS applications, or for other analytical activities.

Rice ecosystems information
Spatial information at the mega level on rainfed lowland, upland, flood-prone, and irrigated rice ecosystems. We are converting all the information to enable the data to be used in relation to other research issues, using Geographic Information Systems.

Rice literature data base
The comprehensive bibliography of rice-related literature developed by IRRI's Library and Documentation Service. We are preparing to migrate this data base to a globally accessible research resource using a new library automation system.

Key references

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