

Frontiers of Rice Research

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FEEDING A HUNGRY WORLD

One of the biggest challenges mankind will have to face is how to keep on adequately feeding all the people in the world. Population experts estimate that the world population had been about 250 million 2,000 years ago (Figure 1). The first doubling of the population appeared to have occurred by about the year 1650. Thus, it took 1,650 years to double the population from 250 million to 500 million. However, it took only another 200 years (1650 to 1850) for the world population to double again to 1 billion. From there, it took only 80 years (1850 to 1930) for the world population to double again from 1 billion to 2 billion. After another 45 years (1930 to 1975), the population became 4 billion, i.e., double the figure for 1930. Experts project that by the year 2015 the world population will have doubled again to 8 billion people.

Within 25 years from today, there will be one and a half times as many people to feed as there are now. Not only will the number of people increase, the demand for diets that are more nutritious and varied will also be much greater as a result of the higher standard of living at that time. The implications are formidable.

Farmers, livestock keepers, food processors and distributors will not only have to produce, process and distribute twice as much food as they do now but they will also have to change the mix among cereals, meats and vegetables. They will also have to increase production and distribution by perhaps as much as another 100 percent to satisfy the greatly expanded demand in developing countries for foods other than the simplest of diets based primarily on major cereals like rice, wheat and maize.

Figure 2 illustrates that our problem is even more complicated than that. If the increased demand for food is to be evenly spread all over the world, there would be a good chance that agronomists could meet the challenge. Yet again, unfortunately, world population growth rates are the highest in areas where production growth rates are the lowest. Developing countries, which already find it difficult to produce enough food, will have greater difficulties in becoming self-sufficient in food (Figure 3).

However, the situation is not desperate. Scientists from different agricultural disciplines are working very hard to ensure that food production growth rates keep pace with the population increase. To illustrate this, I would like to introduce you to some of the frontier research which is currently conducted to increase the world rice production.

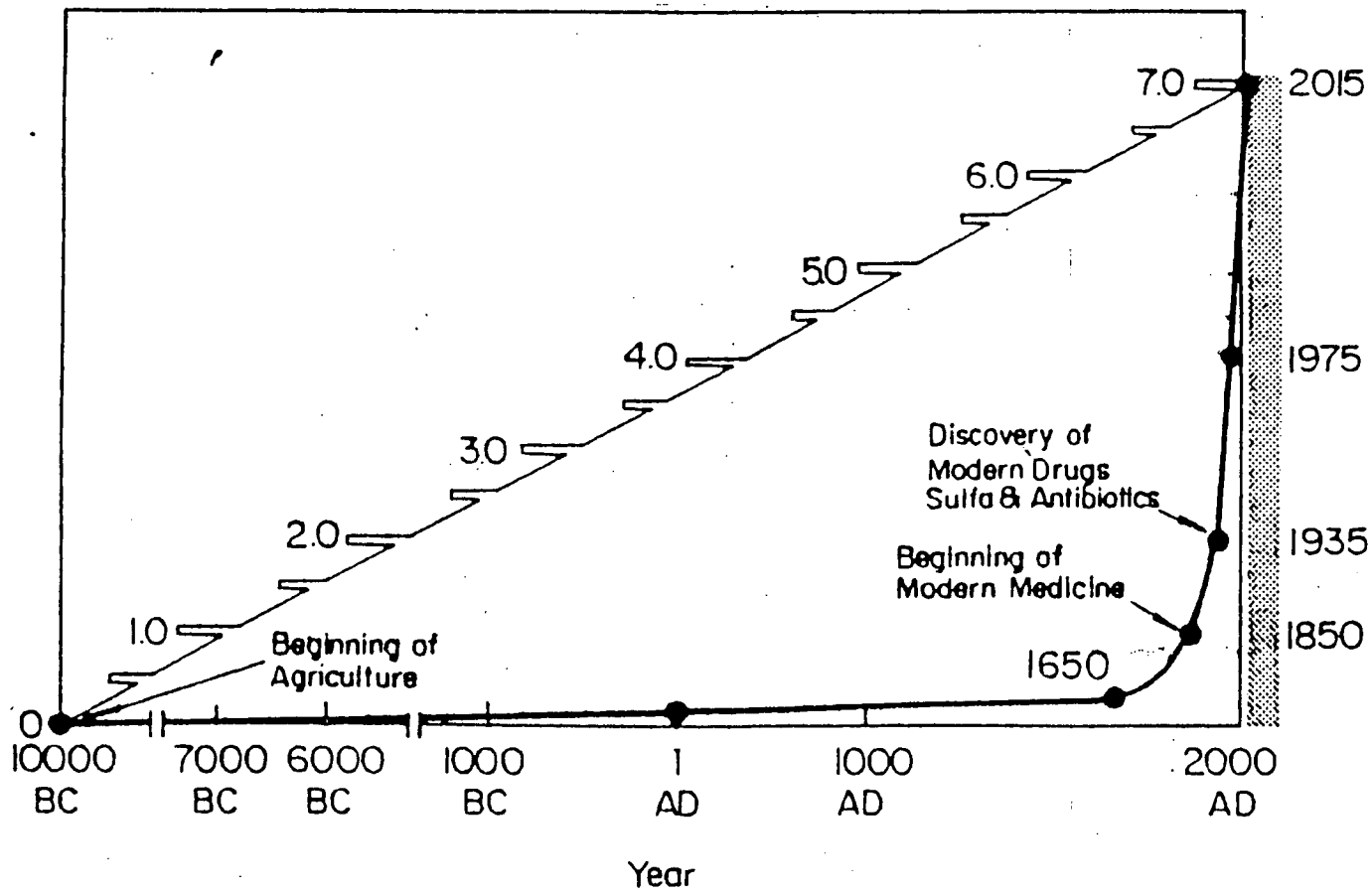


Figure 1. World population growth.

Population in millions

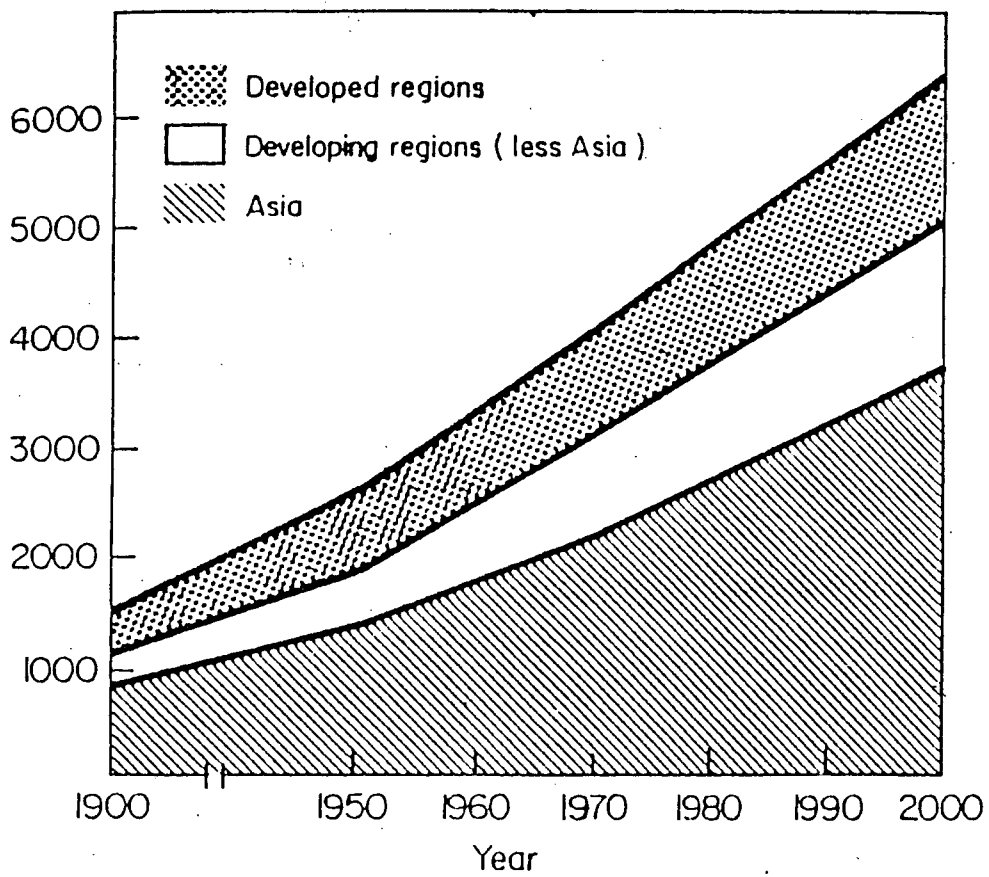


Figure 2. Population growth in developed countries as compared to developing countries.

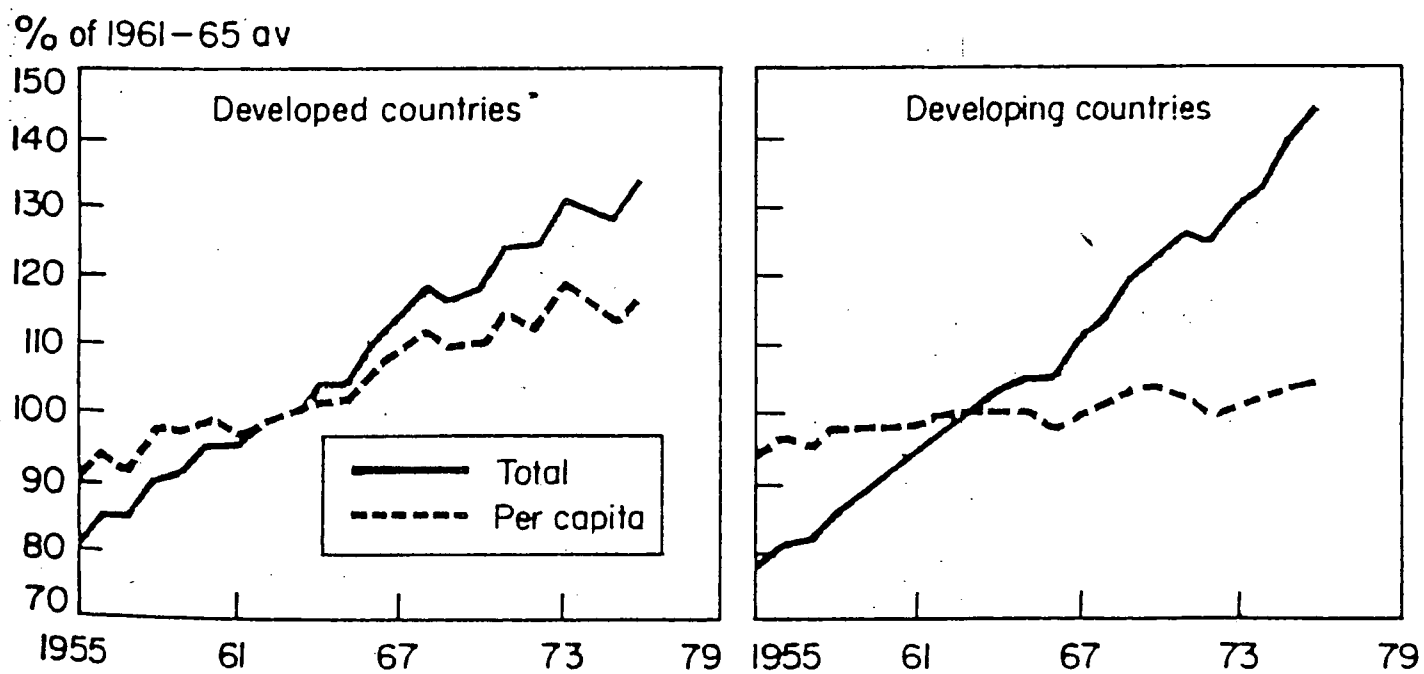


Figure 3. Index of world agricultural production (Source: Palacpac, 1980).

RICE IN PERSPECTIVE

In a Balinese legend, Lord Vishnu, the God of Fertility and Water, came to earth to provide better food for the people who had only sugarcane juice as food. Lord Vishnu made Mother Earth give birth to rice. Thereafter, he had to fight Lord Indra, the Lord of the Heavens, to force him to teach man to grow rice. Thus rice, as a source of life and wealth and as a gift from the gods, was born from a union of the divine creative forces that are represented in earth and water. Rice, therefore, was treated with reverence and respect and its cultivation developed into an elaborate ritual. Most of these beliefs and practices have changed over the years but rice has remained truly 'life itself' for most of the world's densely populated regions.

The ancient home of rice is monsoonal Asia and it remains the area of the world where rice is practically the whole of the people's diet. Rice represents nearly all of their agriculture and, much of their hopes for the future depends on this crop. Rice is the most important food crop of the world when one considers the total area under rice cultivation and the number of people depending on this crop.

In 1985, rice occupied about 143.5 million hectares—more than 90 percent of which was in Asia. India has the world's largest rice-growing area, with 39.6 million hectares, followed by the People's Republic of China, with 36.0 million hectares (Figure 4). Globally, rice ranks second to wheat in terms of the area harvested; but in terms of importance as a food crop, rice provides more calories per hectare than any other cereal crop. For example, at average world yields, a hectare of rice could sustain 5.7 persons for a year compared to 5.3 for maize and 4.1 for wheat. The total caloric output of all world food is equal to 3,119 kcal/person/day at the farm gate, with rice accounting for 552 kcal/person/day, or 18 percent of the total.

It is estimated that 40 percent of the world's population use rice as a major source of calories. For 1.3 billion people, rice provides more than half of their food; for another 400 million people rice provides from 25 to 50 percent of their total food. Table 1 shows estimates of persons in some Asian countries whose major food is rice. Note that 90 percent of the population in Bangladesh, Burma, Sri Lanka, Vietnam, and Kampuchea depend on rice as their major food. Besides its importance as a food, rice provides employment to the largest sector of the rural population in most of Asia.

There are 111 rice-growing countries in the world. They include all Asian countries, most countries of West and North Africa, some countries in Central and East Africa, most of the South Central American countries, Australia, and at least four states in the USA. Although the bulk of rice production is centered in wet tropical climates, the crop flourishes in humid regions of the subtropics and in temperate climates such as Japan, Korea, China, Spain, Portugal, Italy, France, Romania, Czechoslovakia, USSR, and USA.

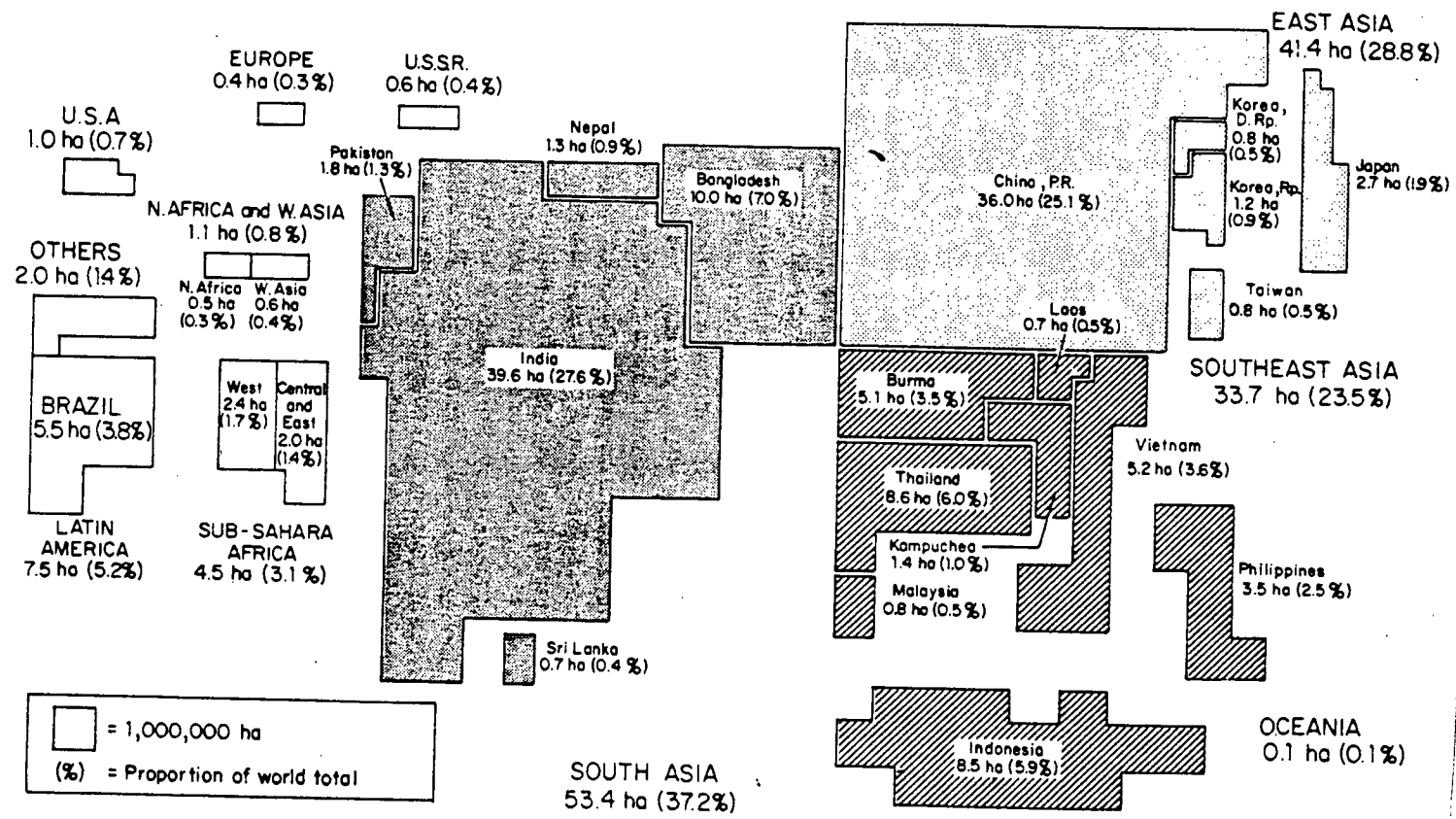


Figure 4. The world's riceland, 1976 to 1978 (adapted from Palacpac, 1980).

Table 1. Estimate of persons in selected Asian nations whose major food is rice.

	Population (x 1000000)	Percentage of rice eaters	Number of rice eaters (x 1000000)
People's Republic of China	956	63	602
India	660	654	29
Indonesia	147	80	118
Japan	116	70	81
Bangladesh	90	90	81
Pakistan	80	30	24
Vietnam	50	90	45
Philippines	49	75	37
Thailand	48	80	38
Republic of Korea	38	75	29
Burma	35	90	32
Taiwan	17	70	12
Sri Lanka	15	90	14
Nepal	15	60	9
Kampuchea	9	90	8
Total			1559

Japan and Spain have historically produced the highest average rice yield per hectare (6.0 t/ha). In 1977, however, the Republic of Korea took the lead with an average of 6.8 t/ha. South and Southeast Asia, which have the largest rice-growing area and one of the highest concentrations of people, produce only 2 t/ha or less. Although most of the rice in South and Southeast Asia is grown as a lowland crop, the yield per hectare is not much higher than in Latin America where rice is mostly grown as an upland crop. Both regions grow primarily rainfed rice. However, South and Southeast Asia have considerably higher hectareage compared to Latin America. A monsoonal climate causes more variability in water control in South and Southeast Asia than in Latin America, and although drought is a common problem in both regions, flooding is not a problem in Latin America as in South and Southeast Asia.

Rice is the only major food crop that can be grown under various degrees of flooding. It is primarily grown on the vast areas of flat low-lying river basins and delta areas in Asia that are flooded to various depths during the monsoonal season. If it were not for rice, the unprecedented population growth in the vast wetlands in Asia would have never taken place.

FRONTIER RICE RESEARCH

Germplasm Evaluation

Evaluation of traditional varieties and wild rice species is a prerequisite to sustained rice improvement across ecosystems. Germplasm evaluation research includes 1). methods for evaluating unimproved germplasm and analysis of useful traits, 2). coordination and analysis of evaluation data, and 3). the supply of these germplasm varieties and associated information to rice scientists all over the world.

Genome Manipulation

Manipulation of the rice genome has long been a major focus of rice research. New techniques are being developed that should allow relatively more rapid and precise manipulation of plant genomes. Adaptation of these techniques to rice will speed up the development of improved rice varieties in all ecosystems.

Saturated Genetic Maps and Cloned Genes

Comprehensive knowledge of the genetic and molecular organization of the rice genome is necessary before effective genome manipulation can be practiced. To take further advantage of emerging techniques for gene transfer, the capability to clone genes of agronomic importance needs to be developed. Two activities have been identified to achieve this output.

The first should develop genetic and molecular maps and establish linkages of isozyme/molecular markers with genes controlling selected agronomic traits, including quantitative trait loci. The markers could be useful for selection in germplasm improvement projects. The second should develop a strategy for cloning genes from wild *Oryza* species and related genera. Species-specific probes generated could be used to monitor alien introgression.

Novel Genetic Variation and Tools to Improve Plant Breeding Efficiency

Several biotechnological tools can be used to supplement the sources of genetic variation used by plant breeders and to enhance the efficiency of conventional breeding techniques. Desirable genes from diverse sources, ranging from wild *Oryza* species and related genera could be introduced into rice through a process known as transformation. As other agronomic genes, such as grain protein genes from other crop species, the tungro virus-coat protein gene, and the *B. thuringiensis* toxin gene, become available, attempts could be undertaken to introduce them into rice. In addition, the cytoplasmic variability available in the wild *Oryza* species could be exploited to overcome genetic vulnerability and ensure long-term stability of hybrid rice production. Anther culture can be used to shorten the time needed to produce a new rice cultivar and to fix complex traits from diverse sources, including crosses involving *indica* and *japonica* rices. This technique could be used to develop homozygous doubled haploid lines.

Improved Pest Management

A variety of unwanted and harmful insects, weeds, microorganisms, rodents, birds, and other organisms threaten the stability of rice production. Estimated losses caused by pests range from 10 percent to as much as 40 percent in different rice ecosystems. Strategies, tactics, and tools that will enhance inherent natural control mechanisms and ensure low pest equilibrium are needed. The emphasis, should be on integrated pest management as an economically efficient and environmentally sound approach to pest control.

Plant-Pest Interactions

Fundamental understanding of various plant-pest interactions will help in developing methods to breed rice for durable resistance and will provide models to quantify the interactions. Three research activities are involved. The first quantifies the effects of pests on yield. The second characterizes the basis of resistance in rice varieties to selected pests and develops methods to breed for durable resistance. The third identifies such factors as allelochemicals that influence insect behavior.

Biology, Etiology, Ecology, and Population Dynamics of Pests and Beneficial Organisms

Understanding pest populations and their interrelationships with the physical and biological environments is basic knowledge needed to develop safe and effective pest-management strategies. The key insect and disease pest species have been well studied but many potential pests, beneficial organisms, and weeds species have not yet been fully examined.

The etiology and impact of new diseases, the biology and ecophysiology of major weeds, and biology and ecology of potential pest and beneficial species should also be studied. Methods to utilize antagonistic bacteria for biological control of diseases will be useful in this respect.

Impact of Seedborne Pathogens and Seed Contaminants on Crop Production

Rice seed provides a venue for the survival and transmission of many pathogens (including nematodes) and insects. Some pathogens and insects infect seeds, causing grain discoloration; others infest seeds. The impact of these seedborne pathogens and seed contaminants on crop production needs to be analyzed.

Seedborne pathogens and contaminants on rice seeds should be characterized to determine their effect on seed quality and viability and on disease epidemiology. Methods and diagnostic techniques should be developed and assessed for safe germplasm exchange and pest management through seed health evaluation.

Plant, Soil, Water, and Nutrient Processes

More knowledge is needed on ways to manipulate the rice crop's external environment to best meet the crop's needs. A rational basis for germplasm selection in different environments is also needed. Much of the work in this area so far has been guided by field experiments and correlations of data from empirical tests of factors that are thought (from limited knowledge) to be influential. Given the heterogeneity of climate, soil, and water resources and the variability of crop and management practices, such approaches will continue to be important. However, a more fundamental, mechanism-based approach has far greater potential for providing insights into the processes involved and for indicating where further research is needed.

Soil Physicochemical Processes and Fertilizer and Organic Matter Reactions

Basic knowledge gaps constrain research concerned with fertilizer and nutrient dynamics, plant nutrition, and the management of problem soils. Quantitative mechanistic models should be developed—based as much as possible on underlying physicochemical and biological processes—that predict how soil, crop, and management conditions affect soil physicochemical conditions and the fate of fertilizer materials and organic matter. The models will guide the development of soil and crop-management practices and simple methods for assessing nutrient availabilities and toxicities in different ecosystems.

The dynamics of soil reduction and oxidation, the fate of inorganic phosphorus fertilizers (both water-soluble and insoluble) in flooded soils, the short- and long-term dynamics of organic matter in flooded soils, and the dynamics of phosphorus, potassium, sulfur, and micronutrients need to be studied.

Plant Nutrition and Processes at the Root-Soil Interface

This work is particularly concerned with phosphorus uptake and the stimulation of biological nitrogen fixation by the rice plant in flooded soils. These processes occur in the narrow zone of soil near the roots which is root-influenced and whose chemical and biological properties differ from those of the surrounding soil. In order to understand these processes, it is necessary to study the physiological and microbiological basis of the oxidizing ability of rice roots and root exudation and microbial activities, including biological nitrogen fixation, in the flooded rice rhizosphere. Because the zone is difficult to study, theoretical models validated on more simple systems should supplement direct experimental observations. For this work, a model of chemical conditions in the rice rhizosphere should be developed, using the findings of work on soil reduction-oxidation processes.

Plant Metabolic Processes

The mechanisms by which the rice plant tolerates adverse conditions (e.g., imbalanced nutrition, high soil salinity, high temperature, drought) are not clear. Without that knowledge, we lack a rational basis for selecting stress-tolerant germplasm.

Tissue tolerance for and avoidance of nutritional disorders should be considered. Emphasis should be on cell and plant leaf expansion, avoidance of toxicity through low transpiration and compartmentation, and tolerance at the biochemical level. Metabolic processes impeded by nutritional and osmotic disorders should be identified and studied. The effects of high temperature on growth and maintenance respiration, quantum yield, and gross photosynthesis in different plant organs and different genotypes are to be investigated.

Rice Quality and Utilization

Improved grain quality in modern varieties should result in higher farm incomes, reduced retail rice prices, and increased demand for such rice. Breeding for grain quality has resulted in lines with translucent endosperm and a narrow range of amylose content. However, current assessment methods cannot differentiate among lines with similar amylose content, although they are differentiated by consumers and are known to behave differently in processing. The increasing cost and dwindling supply of cooking fuel highlight the need to explore the feasibility of screening for low starch gelatinization temperature, which means shorter cooking time.

The ability to easily and consistently identify varieties is becoming important in maintaining germplasm integrity and in reducing varietal mislabeling in the market.

Breeding efforts to improve the protein content of rice have not been successful because of poor heritability of protein content. A major gene for improved protein content and quality is needed to justify a breeding effort to improve the nutritional value of rice. When a genetic source to increase protein becomes accessible, efforts in this area will also increase.

Loss of rice quantity and quality between the field and the consumer continues to be high, particularly in intensively cropped areas. Improvements in grain handling, drying, and storage and the development of household and village level techniques that add value to rice and rice by-products provide opportunities to generate employment and farm income.

Improved Methods for Evaluating Grain Quality

Factors that determine varietal differences in cracking resistance, cooked rice texture among rices in the same amylose class, low gelatinization temperature, and aroma should be described and tools developed to improve screening for these important aspects of rice grain quality.

Sources of Improved Nutritional Value

The protein content and amino acid composition (lysine content) of the grain of new mutants and the effect of mutation on grain quality should be evaluated.

Improved Storage, Handling, and Value-added Technologies

Varietal responses to improved storage and handling systems should be studied and rice processing technologies examined for their ability to add value to the farm product. Low-cost drying and storage systems for household and village levels should be evaluated and systems will be designed to maintain grain quality and rice grade and reduce storage pests.

Improved Biomass and By-product Utilization

Work to improve technologies to utilize rice straw, hulls, and other rice crop by-products is going on. This includes development of equipment for converting straw and hulls into fuel.

Ecosystem Characterization and Impact Analysis

Long-term socioeconomic and environmental impact relative to the cost of developing new technology requires consideration of trade-offs between efficiency and equity, short-term efficiency and long-term sustainability, strategic and applied research, and comparative advantage of national and international institutions. New methods and data are needed to quantify the impact of rice technologies on productivity, income distribution, and the environment and the probability of research success.

A systematic approach to develop and refine methods to document the physical, biological and socioeconomic characteristics of all ecosystems is essential in identifying important constraints, designing suitable technologies, setting research priorities, and determining the transferability of new technology.

Development of analytical frameworks and methods, analysis of the broader implications, assessment of new technologies common to more than one ecosystem, and establishment of research priorities at the institute level need a cross-ecosystems perspective. Analysis of national policies and institutional frameworks governing rice markets are crucial to understanding the impact of technical change on productivity, sustainability, and income distribution. Socio-economic and environmental effects of new technology may motivate policy changes to enhance or sustain benefits or to mitigate the adverse effects of technical change.