Development and Spread of High-Yielding Rice Varieties in Developing Countries

Agency for International Development

Development and Spread of High-Yielding Rice Varieties in Developing Countries

Dana G. Dalrymple

Bureau for Science and Technology
Agency for International Development
Washington, D.C.
1986

PUBLICATION HISTORY

The first edition of this report was issued in November 1969 under the title *Imports and Plantings of High-Yielding Varieties of Wheat and Rice in the Less Developed Nations.* Further editions with this title were issued in January 1971 (second edition) and February 1972 (third edition). The first three words of the title were changed to *Development and Spread* in the fourth edition issued in July 1974. The fifth edition was issued in August 1976 and the sixth in September 1978. All were prepared by Dana G. Dalrymple and published by the U.S. Department of Agriculture in cooperation with the U.S. Agency for International Development.

ABOUT THE AUTHOR

Dana G. Dalrymple is an agricultural economist specializing in international agricultural research and technology. He is with the Technical Assistance Division of the Office of International Cooperation and Development, U.S. Department of Agriculture, on detail to the Office of Agriculture, Bureau for Science and Technology, US. Agency for International Development. There he serves as research adviser on the CGIAR staff. Dr. Dalrymple received B.S. and M.S. degrees from Cornell University and a Ph.D. from Michigan State University.

DISCLAIMER

Library of Congress Catalog Card Number: 86-71411

Publication development services provided by
METROTEC, Inc.
Washington, D.C.

Contents

Foreword

The most significant technological accomplishment of this century in international agriculture is the development of high-yielding cereal crop varieties. These fertilizer-responsive food crops, with a high degree of resistance to insect pests and diseases, have provided on-farm yields far in excess of those obtainable from traditional varieties. They have given rise to the green revolution, which has helped many nations increase their food production in the face of substantial increases in human population. Increased production means higher returns to many farmers and lower food costs to consumers.

The U.S. Agency for International Development (AID) has long been involved in crop improvement activities in developing countries. Since the early 1950s, AID has supported the development and strengthening of national research programs in which considerable research has been done on varietal improvement. Since 1969 the Agency has also provided about 25% of the funding for international agricultural research centers sponsored by the Consultative Group on International Agricultural Research. Much of the research leading to the development of new crop varieties has been carried out at these centers. The national and international centers cooperate in the varietal development process, and the result is usually a joint product.

This publication documents the development and adoption of new rice varieties. A comparable report on wheat is being published simultaneously.

The research reported in this document represents, we think, a highly efficient and effective way of assisting the needy in developing countries and of stimulating their economic development. AID is proud to have played a role in the process.

Nyle C. Brady
Senior Assistant Administrator for Science
and Technology
US. Agency for International Development

Preface

This report is, to borrow a biological term, somewhat of an induced mutant. It is the offspring of a series of earlier reports, the last edition of which was published in September 1978, but it differs from them in several ways. The most obvious change is that whereas wheat and rice were formerly covered in the same report, they are now the subject of separate, although nearly concurrent, publications. A less obvious change is that the reports are now published wholly by the Agency for International Development (AID) rather than in cooperation with the U.S. Department of Agriculture.

In addition to including a vast amount of new information, other changes have been made—

- The report has been almost entirely rewritten, with the principal exception of the first part of chapter 1, which was revised. Chapter 2 is virtually new. In chapter 3 additional countries are included, particularly in Africa. A new appendix has been added.
- There has been a change in style in the country chapter (chapter 3). Formerly many of the country entries consisted only of tables; these have now been cast in narrative form and contain a broader array of information. Tables are included where statistical information was available; they now indicate the proportion of total area covered by high-yielding varieties.
- The footnotes have been moved to the ends of chapters and have been thinned out for the pre-1977 period. Also, some long-standing but now dated appendices have been dropped.
- The high-yielding rice varieties are no longer listed, along with their genealogies, in a summary table. There are now simply too many to list. Considerable information of this type is, however, provided in chapter 2 and in the country sections in chapter 3.

While the varietal developments and releases can fairly readily be captured and reported, statistics on their use at the farm level generally remain somewhat elusive. Those that exist are, except for a few Asian countries, outside the main statistical stream; they are in the byways and must be tracked down. This detective process takes time and is not always successful. Coverage is sometimes uneven.

Despite careful preparation and extensive review, this report undoubtedly contains some errors and inconsistencies. These are particularly likely to be found in the spelling, specification, or spacing of variety names and lines in individual nations. In some cases, what might seem like inconsistencies may be due to variation in transliteration and usage between countries. In other cases, particularly those involving genetics, scientific opinion occasionally varies. Nevertheless, I am responsible for any inconsistencies or errors and would be grateful to learn of them.

The updating of this report has been in part an AID contribution to a broader study on the impact of the international agricultural research centers sponsored by the Consultative Group on International Agricultural Research. The area data from this report have been used as a basis for further statistical calculations presented in the reports of that study. In turn, some information provided in country studies prepared for the impact study has proved useful for this report.

Acknowledgments

This report would not have been possible without the support of numerous individuals and organizations over many years. Those who provided help on specific points are generally mentioned in the references and notes of the chapters that follow. Those who were of more general assistance are noted here.

First, this report would not have been prepared had it not been for Dr. Nyle C. Brady, senior assistant administrator for science and technology, US. Agency for International Development (AID). Dr. Brady provided the stimulus to update the report, directed the allocation of resources to do so, and followed the project with keen interest.

Five other individuals also made vital contributions:

- Robert Bertram, my associate at AID, contributed both directly through his knowledge of plant breeding and indirectly by carrying an increased workload while I was involved with this project.
- Daniel Timms of the International Economics Division, Economic Research Service, US. Department of Agriculture (USDA), diligently searched through USDA records for statistical information.
- Walter Rockwood and Alexanderina Shuler of AID served as editors. Mollie Sayers of METROTEC, INC., carefully guided the manuscript through the publication process.

Among the many scientists who provided valuable technical assistance and advice, I particularly acknowledge the contributions of

- Dr. T.T. Chang, principal scientist and head, International Rice Germplasm Center, International Rice Research Institute (IRRI);
- Dr. G.S. Khush, plant breeder and head, Plant Breeding Department, IRRI;
- Dr. Peter Jennings, plant breeder, International Center for Tropical Agriculture;
- Dr. W.R. Coffman, professor of plant breeding and international agriculture, Cornell University (formerly plant breeder at IRRI); and
- Dr. J. Neil Rutger, rice geneticist, Agricultural Research Service, USDA, Davis, California.

Several groups of individuals were of considerable help in obtaining data on specific nations:

- Country desk officers of the International Economics Division, Economic Research Service, USDA, Washington, D.C.; and
- AID food and agricultural officers and USDA agricultural attaches in developing countries.

Other individuals of help were: Dr. Thomas Hargrove, editor and student of rice genealogy at IRRI: Dr. Trinh Ton That, agriculture officer (rice agronomy), Plant Production and Protection Division, Food and Agriculture Organization of the United Nations, Rome; Dr. Robert Herdt, scientific advisor, Consultative Group on International Agricultural Research; and Drs. Jock Anderson and Carl Pray of the Consultative Group on International Agricultural Research Impact Study.

Support also came from other quarters. The International Agricultural Development Service (IADS) kindly provided a much-needed quiet haven for writing of the first draft; individual IADS staff members were also helpful. Kim Harmon and Dolores SeGuine of AID typed much of the final draft.

I should not close without mentioning several other vital groups who will not be mentioned by name in the report. These are the many scientists and technicians who carried out the varietal improvement work reported here and who gathered the basic statistical data summarized here. The accomplishments reported in this bulletin are but the tip of a pyramid of activity by others. My role has been that of observer and reporter.

Acronyms

U.S. ORGANIZATIONS

AID, USAID	U.S. Agency for International Development
ARS	Agricultural Research Service, U.S. Department of Agriculture
ERS	Economic Research Service, US. Department of Agriculture
FAS	Foreign Agricultural Service, U.S. Department of Agriculture
USDA	U.S. Department of Agriculture

INTERNATIONAL ORGANIZATIONS AND CENTERS

CGIAR	Consultative Group on International Agricultural Research (Washington, D.C.)
CIAT	International Center for Tropical Agriculture (Colombia)
CIMMYT	International Maize and Wheat Improvement Center (Mexico)
FAO	Food and Agriculture Organization of the United Nations
IITA	International Institute for Tropical Agriculture (Nigeria)
IRRI	International Rice Research Institute (Philippines)
IRTP	International Rice Testing Program, International Rice Research Institute
UNDP	United Nations Development Program
WARDA	West African Rice Development Association (Liberia)

1. RICE AND RICE BREEDING

I trust that the day will come when humanity will take as great an interest in the creation of superior forms of life as it has taken in past years in the perfection of superior forms of machinery. In the long run, superior life forms may prove to have a greater profit for mankind than machinery.

—Henry A. Wallace, 1936[1]

The use of modern rice and wheat varieties with high-yield potential has increased significantly in the developing countries in recent years. These varieties, along with such critical inputs as fertilizer and irrigation, form the basis for what is popularly referred to as the green revolution.

BACKGROUND

Although the green revolution is a relatively recent phenomenon in developing countries, high-yielding rice varieties (HYRVs) are not. A vast number of rice varieties have probably, over time, been classified as high yielding compared to their predecessors. Improved yields can be developed from any of a number of biological characteristics or cultural practices. The distinguishing characteristic of the modern rice varieties is their relatively short stem. They also are generally early maturing and have a higher tillering capacity.[2]

Dwarf and semidwarf rice varieties have been known for more than a century. The first efforts to develop such rice varieties occurred in Japan in the late 1800s.[3] Initially, the dwarfs were curiosities. The dwarfing characteristic became significant with the advent of chemical fertilizers. Traditional tall varieties lodge (or fall over) at high levels of fertilization; semidwarfs are much more resistant to lodging.

Developing countries began to use significant amounts of chemical fertilizer on food crops in the 1950s. The HYRVs described in this bulletin began appearing in the farmers' fields of developing countries in the 1960s. A food crisis in southern Asia in the mid-1960s further encouraged the use of HYRVs and chemical fertilizers.

Some of the ancestry of most HYRVs can be traced to varieties developed in the +Philippines at the International Rice Research Institute (IRRI) and in Colombia at the International Center for Tropical Agriculture (CIAT). Many HYRVs have been developed in national rice research programs, often utilizing genetic material from the international centers.

Basic information concerning the origin and interrelationships of modern HYRVs is outlined in chapter 2. Chapter 3 provides estimates of the areas of HYRVs planted or harvested in individual countries by crop year between 1965-66 and 1982-83. Some preliminary estimates for 1983-84, as well as scattered data on yields and seed imports, are included. While the main focus is on noncommunist nations, limited data on five communist developing countries are included.

There is much other potentially useful statistical information and analysis about HYRVs that is not included. No attempt has been made to go beyond area data or to estimate increased overall yields and production.[4] Nor is any effort made to

Figure 1.1. Traditional tall and semidwarf rice plants, drawn to same scale. On left is Syntha from Indonesia. On right is IR8. Syntha was crossed with IR5 to produce Pelita 1-1 and Pelita 1-2. Source: International Rice Research Institute.

discuss the economic and social effects of HYRVs within the context of the green revolution. Rather, the purpose of this bulletin is to provide a historical and statistical base for policy analysis and other research.

DEFINITIONS AND SOURCES OF DATA

This report emphasizes the varieties of rice developed by IRRI and CIAT and the offspring of those or similar varieties developed in national research programs. Virtually all these varieties are shorter than traditional varieties.[5] Most are semidwarf, but some might be considered intermediate in height.[6] The short modern varieties are potentially high yielding, but the potential is seldom fully realized on farms because of physical, biological, and management factors.[7] Thus, "high-yielding" refers to yield potential, not necessarily to output.

The definition of HYRVs does not include all improved rice varieties. Improved varieties of conventional height have been under development in many developing countries for decades. In India, for example, systematic research on rice began in 1911.[8] Under certain conditions, some improved and traditional varieties may be as high yielding as some semidwarfs. High yields are not an exclusive property of the semidwarfs. Many improved and traditional varieties are included in the ancestry of modern HYRVs.

In most countries, a progression of varieties in three stages generally is involved (figure 1.2): stage I, traditional varieties; stage II, improved varieties of normal height; and stage III, HYRVs of shorter height, principally semidwarf and intermediate. Although a few of the early varieties introduced or distributed by the international agricultural research centers may have been in stage II, nearly all are now in stage 111. Each

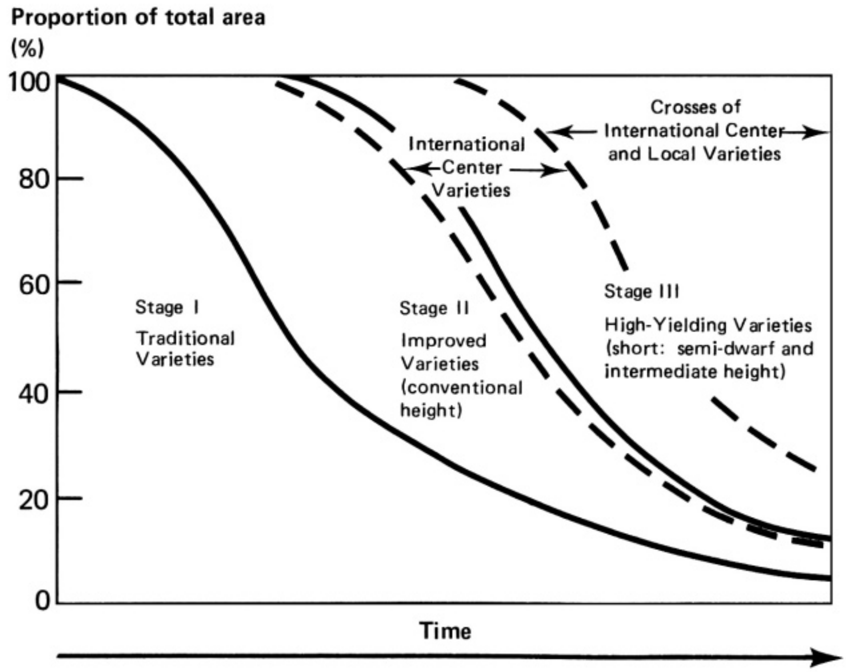


Figure 1.2. Generalized sequence for the adoption of modern varieties in developing nations.

stage may, in turn, be composed of successive waves of new varieties; few individual varieties have a long life. Within stage III, there is a gradual replacement of IRRI varieties by varieties resulting from crosses of genetic materials from IRRI with local varieties.

In most cases, the varietal sequence will follow the order indicated, but without one stage completely replacing the previous stage or stages. At a given point in time, all three stages can be expected to exist in most countries. In some instances, however, farmers may have skipped stage II and moved directly from stage I to III. In other instances, bad experiences with newer varieties will lead farmers to temporarily move back a stage or two. The actual situation in an individual country may vary considerably.

An effort has been made to limit the data in this bulletin to the semidwarf and intermediate HYRVs of stage III, but this has not always been possible. National data are not always broken down by specific variety; it is sometimes necessary to us: whatever definition of HYRVs was used by the national reporting system. This process undoubtedly included some improved varieties. The degree to which improved varieties are included in the reporting may have changed over time. Where the varietal composition is known, it is reported.

Aside from the historical background in chapter 2, this report concentrates on the adoption of varieties introduced by IRRI and CIAT since the mid-1960s. Previously introduced and widely adopted HYRVs are not included in the statistics. Thus, the ponlai rices developed in Taiwan in the early 1920s are excluded. The same is true of the H rice series in Sri Lanka. On the other hand, some of the offspring of these varieties are included in national HYRV figures, and one of the rice varieties developed earlier (Taichung Native 1) was distributed by IRRI. While most HYRVs reported in this bulletin were developed by IRRI or CIAT, or are related in some way to such varieties, this is not always the case.

Some HYRVs have been developed by national programs from local varieties or mutants. These may not be semidwarfs, but they are relatively short and high yielding compared to traditional varieties. Several such rice varieties developed by national researchers in the Philippines and Sri Lanka have, for example, been used in other nations. A leading variety in Burma is a local mutant. China developed semidwarf rice varieties slightly before, and independent of, IRRI.

Reported data cover only commercial plantings; the area planted for research purposes is excluded. Some countries other than those listed may be testing HYRVs and may even have moved into limited commercial production.

Data on area and seed imports generally come from different sources. Most are unpublished. They usually apply to the July-to-June crop year. But this designation is not as clear as it may seem, especially where crop seasons, such as the *aus* (spring-summer) rice crops in Bangladesh, cut across the July-to-June time period. Most of the data are for planted, rather than harvested areas, but this is not always clear in the sources.

The area information is based largely on reports provided by AID country missions or U.S. Department of Agriculture (USDA) agricultural attaches and international center staff members. The data usually were obtained from official country reports or estimates. The national systems for collecting this information may not, in many cases, be very sophisticated. In some instances, the area planted with HYRVs may be overestimated; in others it may be understated[9] or simply not available.

The seed figures are believed to be relatively accurate but incomplete except for unusually large shipments from the Philippines and India. Virtually all of the statistics on Philippine rice exports were provided by IRRI.

BIOLOGICAL CHARACTERISTICS

The basic biological characteristic of high-yielding rice varieties is their semidwarf growth habit, but other biological features are also important. These features are, in part, related to their botanical classifications. There are several different major rice species and types.

Classification of Rice

In terms of botanical classification, rice belongs to the genus *Oryza.* Commercial rice production is principally composed of one species, *Oryza sativa* L., known as Asian or common rice. Indica and japonica are the two major ecogeographic races within tlus species. Japonica is sometimes known as sinica or keng.[10]

Indica is the major group grown throughout south and Southeast Asia and in most areas of the People's Republic of China. The majority of traditional indica varieties raised in the humid tropics evolved from combined natural and human selection processes. They were well adapted to conditions of low soil fertility, uncertain weather, and poor water control. Most traditional indicas have resistance to endemic diseases and insects, and compete well with weeds. They also have the dry cooking characteristic preferred by consumers in tropical and subtropical areas. But the features that enable the traditional types of indicas to survive—talland high-tillering plants, late maturity, long drooping leaves, etc.—also provide the basis for their weakness under modern agricultural practices. Improved fertilization, for instance, leads mainly to vegetative growth and lodging rather than significantly increased yield.

Japonica varieties are widely grown in the temperate zone: the lower Yangtze valley of China, Taiwan, Korea, Japan, parts of Australia, California, Europe, and Egypt. In China, japonica varieties evolved later than the indicas and are the result of an intensive human selection process. In comparison with the indicas, japonicas have darker, upright leaves; a shorter, stiffer stalk; more thrifty vegetative growth; and earlier maturation. Japonicas respond well to improved cultural practices, especially fertilizer, and are more resistant to lodging. As a result, yields are considerably higher than for the indicas.

Japonicas are not, however, well adapted to traditional cultural practices in tropical Asia. Among other things, the japonicas require precise water, weed, and insect control; most are susceptible to the viral diseases of the tropics; some react to high temperature during early growth stage by flowering too early; they lack the grain dormancy needed in the monsoon season; and the grains have a sticky cooking quality not well accepted by consumers.

Breeding efforts, outlined in chapter 2, have centered on improving each of these types as well as developing japonica and indica crosses. The principal emphasis of this bulletin, however, is on the indica rices.

Classification of Environmental Conditions

Rice is grown under a wide range of environmental conditions divided into five main categories: irrigated (lowland), rainfed lowland,

Figure 1.3. Preparing a wet rice field in West Sumatra. Photo by Ulrich Scholz, provided by Winrock International.

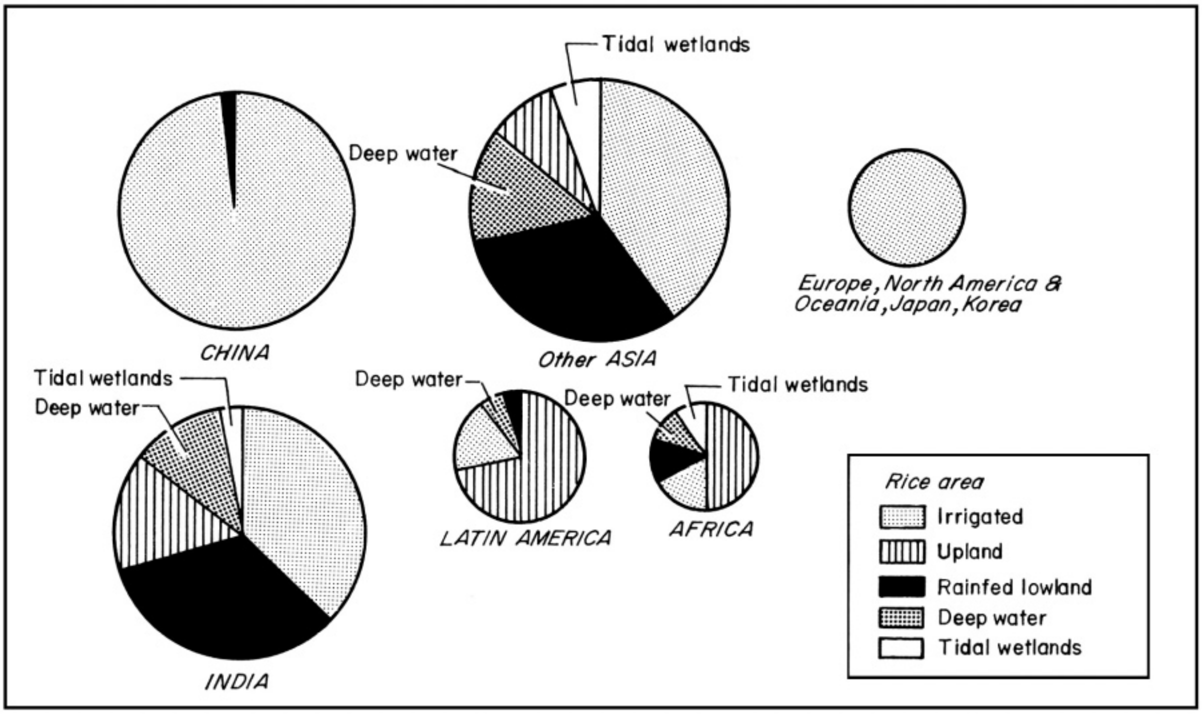


Figure 1.4. Distribution of rice areas by major cultural systems, principal nations, and regions. Source: International Rice Research Institute.

upland (rainfed), deepwater, and tidal wetlands. Each is further divided into subcategories reflecting water regimen, drainage, temperature, soils, and topography.

Principal characteristics of the major categories are:[11]

• *Irrigated* (nearly 52.8% of world rice area). The soil has an adequate water supply through the growing season. In much of the area, rainfall supplements irrigation water. This land is well adapted to improved cultural practices and HYRVs.

• *Rainfed lowland* (about 22.6% of world rice area). A great diversity of growing conditions requires a similar diversity of management practices. Varieties are needed with tolerance for varying levels of moisture, growth duration, and plant height.

• *Upland* (about 13.0% of world rice area). The rice grows on naturally well-drained soils without surface water accumulation. Varieties are required with drought tolerance (through deep root systems) and recovery ability, intermediate stature with moderate tillers and large panicles, blast resistance, and iron deficiency and aluminum toxicity tolerance.

• *Deepwater* (about 8.2% of world rice area). Flooding occurs only during the latter part of the growing season. Rice seed is broadcast and grown under drought conditions for 50 to 60 days before water accumulation during the rainy season.

• *Tidal wetlands* (about 3.4% of world rice area). These areas are located near seacoasts and inland estuaries and are directly or indirectly influenced by tides. These are heterogeneous environments.

The relative importance of these categories in terms of area varies by geographic region (figure 1.4). In Asia, relative importance follows the above-noted order, but with some rather wide variations by country. In Africa and Latin America, upland culture predominates (though to a differing degree), followed by irrigated, and with rainfed lowland and deepwater of roughly equal importance. Tidal wetlands are found in Africa but not in Latin America.

Of the various categories, only irrigated and one of the five subcategories of rainfed lowland (shallow/favorable) are regarded as favored environments. HYRV production has been found mainly in the favored environments, particularly in the irrigated zone. Large HYRV areas, however, are found in the rainfed lowland areas of some countries. The Philippines are a notable example.

HYRVs and Water Control

HYRVs do not require more water than local varieties. In fact, because of higher yields and shorter growing periods, they may actually use less water per unit of product. But because the high-yield potential of the varieties is achieved by applying inputs such as fertilizer and pesticides, there is additional cost. When water supply and drainage are inadequate or unreliable, the added risk discourages the use of inputs, thus reducing the advantage of the varieties. The attainment of the full potential of HYRVs without undue risk requires an assured water supply.

In some instances, where water control is favorable, HYRVs or HYRVs and other crops may follow each other in multiple-cropping (the production of more than one annual crop) rotations.

There is a need to broaden the area that can be planted with HYRVs. Researchers at IRRI and elsewhere are attempting to develop varieties that will better withstand drought conditions associated with upland and rainfed lowland rice production, and the deepwater and poor drainage conditions in the low-lying areas of major river deltas.[12]

HYRVs and Growing Seasons

Various types of rices may be grown in regions ranging from the warmer temperature zones to the tropics. The normal range can be extended somewhat by breeding efforts and cultural practices. HYRVs have some flexibility with respect to planting date in developing countries: they may be grown in the dry (winter) or the wet (summer) season.

The wet season is the traditional period for rice culture. Where irrigation or sufficient rainfall is available in tropical areas, rice also may be grown during the dry (winter) months. In fact, in many areas, HYRVs are more responsive to nitrogen fertilizers and produce higher yields during the dry spring months when high solar radiation prevails.[13] Significant quantities of HYRVs are planted during this period in some countries, particularly in Bangladesh, Indonesia, and Thailand. In addition, the photoperiod insensitivity of HYRVs usually shortens their growing period.[14]

Photoperiod insensitivity and short growing seasons are not, however, always desirable characteristics. Under certain environmental conditions, and during the wet season in low-lying areas of Asia, photoperiod sensitivity may be desirable. Development of HYRVs for these areas is at an early stage.

The shortened growing period of HYRVs facilitates multiple cropping where weather and water supply permit. This characteristic is of major importance in some areas.

THE NATURE OF HIGH YIELD

The first step in discussing the underlying nature of high yields is to define "yield."[15] Traditionally, yields have been defined as quantity of plant output per unit of land per crop. This approach is quite satisfactory when only one crop is grown per year, which is normally the case in most of the temperate developed nations. In the tropical developing countries, however, multiple cropping is possible and often practiced. In such a setting, a temporal dimension must be included—"yield" refers to yield per unit of land per unit of time.[16]

As traditionally defined, yield increases can be achieved in three main steps:

Step 1—improvements in the genetic yield potential;

Step 2—better varietal adaptation to environmental factors; and

Step 3—improved agronomy.

The first two steps primarily involve plant breeders and are complementary. The third can be of equal or greater importance but includes a somewhat different group of scientists.

Step 1 involves increasing the pure yield potential of the plant. This is the yield level reached when the normal factors of production—nutrients, water, insects, diseases, weeds, lodging, and other stresses—are controlled. Yield increases of this nature have been obtained, generally by reducing the height of the plants, which means that relatively less of the plant's biomass is

Figure 1.5. Fertilizing rice in the Philippines. World Bank photo by Edwin G. Huffman.

represented by stems and more by grain. The harvest index has been increased. Other physiological characteristics, such as rate of photosynthetic activities, may or may not be significantly different.

Step 2, better varietal adaptation to environmental factors, reduces some of the normal constraints on productivity. Four particularly important factors are resistance to lodging, suitable growth duration, greater resistance to insects and diseases, and greater tolerance for environmental stress. Fortunately, the shorter stem of the HYRV, which contributes to a higher harvest index, also generally contributes greater resistance to lodging. Growth duration suitable for the intended geographical area is essential for high yield and double cropping. Most breeding programs also have given considerable attention to incorporating natural resistance to insects and diseases. Increasing attention is being given to similarly incorporating greater tolerance for adverse environmental conditions—soil salinity, for example—but this work is less advanced in terms of its effects on yields.

Improved agromony, step 3, includes a wide range of cultural practices such as increased and more effective use of water, fertilizer, pesticides and herbicides; closer spacing; and more effective management. Again, shorter plant height is a key element. Shorter plants are less likely to lodge at higher levels of nitrogen fertilization. On the other hand, they are less tolerant of weeds. Generally a combination of improved cultural practices is recommended with HYRVs.

Once the definition of yield is broadened to take time into account, another factor becomes important. Typically, HYRVs are photoperiod insensitive and tend to mature more rapidly than traditional varieties. The vegetative stage of plant growth is shortened. This characteristic can be of value in several ways. It may enable the crop to avoid drought at the end of a traditional growing season. But it may have even more pronounced effects on cropping patterns. Reducing the time required for one crop increases the time available for others, which means that multiple cropping may become possible, or that the multiple-cropping index increases. (As many as three or four rice crops a year are possible in some cases.) It also may mean that additional flexibility is introduced in terms of the type or scheduling of other crops. The influence of early maturity on increasing cropping intensity and overall production is generally not given the attention it deserves in analysis of yield effects.

Thus, higher yields are brought about in terms of output per unit of land per crop and per unit of time. The key factor in the former has been the semidwarf characteristic of the plant, which increases the harvest index and which improves the plant's ability to respond to higher rates of fertilizer without lodging. The key factor in terms of per unit of time is the plant's ability to mature in a shorter period of time. Also, semidwarfs usually are higher tillering because they produce additional stems. Other qualities, such as increased resistance to insects and diseases, usually are incorporated.

In some cases, production factors other than simple grain yield may be of significance. Straw yield is important in some developing countries. Thus, farmers may be interested in varieties of intermediate rather than semidwarf height. As noted earlier, shorter varieties may have greater difficulty in competing with weeds. High yield is important but is not everything. Trade-offs may be involved.

METHODS OF VARIETAL IMPROVEMENT

HYRVs sometimes occur naturally but are far more often the result of carefully planned activity by a plant breeder. Natural crosses, or mutations, provided the genetic variation that laid the basis for much of the work that resulted in improving HYRVs.[17]

Varietal Introduction

Varietal introduction is usually the first phase in varietal improvement. Varieties that have proved themselves elsewhere, usually in other countries, are imported and introduced. Sometimes farmers can use them directly; more often, introductions have to be tailored through selection and breeding to adapt them to local environments. Introductions also may be used as parents to develop new varieties.

Selection

Selection is an age-old technique. In its simplest form, it consists of selecting the most promising plants in a field where there is natural variation. The variants may represent natural

Figure 1.6. Selecting varieties developed in rice breeding program. Photo by Ted Spiegel, provided by Winrock International.

mutations, outcrossing, and mixtures. Selection has been practiced by farmers for centuries. Plant breeders also may make selections from pure or single lines, but breeders frequently select from the offspring of crosses.

Hybridization

Hybridization involves planned crosses and the subsequent selection of desired plants from the offspring. With rice, crossing of this type began in the early 1900s. The purpose of hybridization is to combine the most desirable characteristics of two or more varieties. A cross of two different pure line varieties will produce offspring with a great deal of variability in early generations. Breeders grow the progeny of a crossing through at least six generations to stabilize the line and produce true-breeding offspring. This process produces pure-line improved varieties rather than pure hybrids, which can only be the F_1 (first or hybrid) generation.

Hybrids

The first generation of the cross traditionally displays hybrid vigor or heterosis (an increased growth capacity due to crossbreeding). Two major challenges are involved in capturing this characteristic for farm use. The first is to get a reasonably stable F_1 generation. This requires, among other things, genetically pure parents, which is not difficult with a self-pollinated crop such as rice. The second challenge is to develop an economical way of making the crosses in mass, which is quite difficult with a self-pollinated crop. Because each flower floret contains both male and female organs, it is necessary to eliminate the internal source of pollen to prevent self-fertilization. This can be done manually by removing the anthers (male organs), but the process is impractical if commercial quantities of seed are needed.

For a long time, hybrid rice seed seemed impractical. In the 1950s, with the discovery of cytoplasmic male sterility (CMS) and a fertility restorer complex in wheat, a new opportunity appeared. The CMS process, which is applicable to rice, involves a flower that is male-sterile, or female. The CMS plant is crossed with (pollinated by) any line that is desirable as a male parent but that also possesses a gene or genes for restoration of fertility.

For every rice hybrid developed, three separate and distinct lines must be established.

- The male parent must be converted to restore fertility to all F_1 plants grown in farmers' fields.
- The female parent must have the proper cytoplasm and must be devoid of fertility restoring genes.
- There must be a normal fertile counterpart of the female parent (with normal cytoplasm) to use in production of additional seed of the male-sterile female parent; thus its name—maintainer line.

The process is complicated and expensive. Hybrid rice has been developed in China (see chapters 2 and 3) and is being tested in the United States. IRRI conducted research on hybrid rice from 1970 to 1972 and renewed its work in 1979 after learning of the work in China.

An important new development in wheat involves spraying plants with a chemical at the proper growth stage to induce male sterility. Simpler and less costly than the CMS process, the system has not yet been used for rice.

There are a number of unsettled questions concerning the relative economic advantage of hybrids. A key one concerns yields. Plant breeders differ in opinion as to whether heterosis is a particularly significant advantage in self-pollinated crops, where theoretically the same yield characteristics can be obtained through genetic accumulation.

Because hybrid seed costs more than conventional varieties and must be purchased every year, in contrast to conventional varieties, which can be used year after year if kept clean and viable, hybrid yields must be correspondingly higher to justify the purchase price. Yields of the Chinese rice hybrids are generally 10% to 20% higher than the best conventional varieties. If chemically induced sterility makes it possible to reduce hybrid seed costs, their economic potential clearly will be enhanced. Even so, the use of hybrids in many developing countries will be greatly hampered by the lack of well-developed seed production and distribution systems.

Induced Mutations

Throughout history, virtually all of the basic genetic variability in plants has come about through natural mutation. Since the 1950s, scientists have induced mutations in rice varieties through irradiation or chemical means.[18] Several induced mutants of rice were used as parents for commercially important rice varieties in California. (See appendix A.) A number of varieties have been developed in Asia, principally in China, but they do not yet appear to have been very widely planted in developing countries.[19]

Other Techniques

Related breeding techniques being studied and developed include another culture, particularly used for rice in China, and wide crosses involving wild relatives or distantly related species. The Chinese, for example, have crossed rice and sorghum. Anther culture offers a way of speeding up and increasing the efficiency of the breeding process. Wide crosses are a means of broadening the genetic base.

There are a number of ways to develop higher yielding rice varieties. Additional improvements in approach and technique will broaden the horizon.

REFERENCES AND NOTES

[1] U.S. Department of Agriculture, *Yearbook of Agriculture, 1936* (Washington, D.C.: the Department, 1936), p. 120.

[2] For further details, see D.S. Athwal, "Semidwarf Rice and Wheat in Global Food Needs," *Quarterly Review of Biology* 46 (1) (1971):24-26.

[3] In Japan, increasing application of commercial fertilizer (fishmeal, soybean cakes) in the late 1800s and chemical fertilizer in the early 1900s led to an early interest in the development of varieties with shorter stems. One of the first varieties, Shinriki (to be discussed in the next chapter), was selected in 1877. See T. Matsuo, *Rice Culture in Japan* (Tokyo: Yokendo, Ltd. 1955), p. 13; and P. Francks, *Technology and Agricultural Development in Pre-War Japan* (New Haven, Conn.: Yale University Press, 1984), pp. 31, 56, 77-80.

[4] Some of the major factors involved in this process are outlined in D.G. Dalrymple, "Evaluating the Impact of International Research on Wheat and Rice Production in the Developing Nations, " in *Resource Allocation and Productivity in National and International Agricultural Research,* ed. T.M. Arndt, D.G. Dalrymple, and V.W. Ruttan (Minneapolis: University of Minnesota Press, 1977), pp. 171-208; and "The Adoption of High-Yielding Grain Varieties in Developing Nations," *Agricultural History* 53 (4) (October 1979): 704-726.

Two recent studies attempt to assess the effect of the HYRVs and associated technology on production. R.W. Herdt and C. Capule, *Adoption, Spread, and Production Impact of Modern Rice Varieties in Asia* (Los Baños, Philippines: International Rice Research Institute, 1983), 54 pp; and E.M. de Rubinstein, "The Diffusion and Economic Impact of High Yielding Semi-dwarf Rice Varieties in Latin America," CIAT Working Paper, Cali, Colombia, July 1984, 56 pp.

[5] There are, however, significant exceptions. Several varieties of relatively tall stature are counted as HYRVs. Some of the newer IRRI varieties under development for upland and deepwater conditions will not be so short as their predecessors.

[6] For the medium rices, rough height categories are: semidwarf, 80 to 120 cm; intermediate, 121 to 140 cm; tall, more than 140 cm. Dwarf varieties are seldom, if ever, grown commercially.

[7] *See* R. Barker and T. Anden, "Factors Influencing the Use of Modern Rice Technology in the Study Areas," in International Rice Research Institute, *Changes in Rice Farming in Selected Areas of Asia* (Los Baños, Philippines: IRRI, 1975), pp. 17-40; R. W. Herdt and R. Barker, *Multi-Site Tests, Environments, and Breeding Strategies for New Rice Technology,* Research Paper Series No. 7 (Los Baños, Philippines: International Rice Research Institute, 1977), 32 pp.; and International Rice Research Institute, *Constraints to High Yields on Asian Rice Farms; An Interim Report* (Los Baños, Philippines: IRRI, 1977) 235 pp. Brief accounts may also be found in the annual reports of IRRI.

[8] M.S. Swaminathan, "Preface," in All-India Coordinated Rice Improvement Project, *India's Rice Revolution, A Beginning* (Hyderabad, India: the Project, 1974), p. i; and C.E. Pray, "The Impact of Agricultural Research in British India," *Journal of Economic History* 19 (2) (June 1984):434-436.

[9]In the previous edition of this report, examples were given of overreporting the HYRV area in one district in India and in Bangladesh in the mid-1970s (D.G. Dalrymple, *Development and Spread of High-Yielding Varieties of Wheat and Rice in the Less Developed Nations,* Foreign Agricultural Economic Report No. 95 [Washington, D.C.: U.S. Department of Agriculture, 19781, pp. 130-131, appendix C). No similarly well-documented examples have since been found, though as will be noted later in this report, it is thought that the rice estimates in Nepal may be high. The overestimates in Bangladesh were probably due to (1) unintentional overestimation ("HYV rice is conspicuous and usually is found in the foreground when seen from roads and paths"), and (2) deliberate exaggeration (which "probably occurred as a result of pressure from above to achieve high targets and show success"). The previous edition also noted that Pajam (Mahsuri)—whichis carried as an HYRV in this report—wasnot so classified in Bangladesh.

[10]For further details, *see* T.T. Chang, "Rice," in *Evolution of Crop Plants,* ed. N.W. Simmonds (London: Longman, 1976), pp. 98-104; and "The Rice Cultures," *Philosophical Transactions of the Royal Society of London* 275 (series B, 936) (July 27, 1976): 143-147.

[11]G.S. Khush, *Terminology for Rice Growing Environments* (Los Baños, Philippines: International Rice Research Institute, 1984), pp. 5-10; and G.S. Khush, "IRRI Breeding Program and Its Worldwide Impact on Increasing Rice Production," in *Gene Manipulation in Plant Improvement,* ed. J.P. Gustafson (New York: Plenum, 1984), pp. 73-75.

[12]For details, *see* the following publications from the International Rice Research Institute (Los Baños, Philippines). *Major Research in Upland Rice* (1975), 255 pp.; *Drought Resistance in Crops with Emphasis on Rice* (1982), 414 pp.; *Proceedings of the Workshop on Deepwater Rice* (1977), 239 pp.; *Proceedings of the 1981 International Deepwater Rice Workshop* (1982), 501 pp.; and *An Overview of Upland Rice Research* (1984) 566 pp.

[13]T.T. Chang, "The Genetic Basis of Wide Adaplability of Rice Varieties in the Tropics," *Internationa1 Rice Commission Newsletter* 16(4) (1967):4-12. Most developing countries have low potential photosynthesis values in the wet summer months because of cloud cover; this is one reason why summer rice yields are relatively low in many developing countries (J-J. Chang, "Potential Photosynthesis and Crop Productivity," *Annals of the Association of American Geographers* 60[1] [1970]:98).

[14]The extent to which this is true depends on the specific variety, location, and crop season. In the more heavily planted areas of Asia, the improved varieties mature in 105 to 135 days during the wet season, and some mature 5 to 60 days sooner than traditional varieties. (Palman 579 matures in 115 days in the Punjab State of India.) There are a few exceptions associated with low temperatures and long days; during the *aus* (summer) season in Bangladesh, for example, some indigenous varieties may mature faster than IR8 or IR20. (Letter from T.T. Chang, IRRI, October 1973; for details, *see* T.T. Chang and B.S. Vergara, "Ecological and Genetic Aspects of Photoperiod-Sensitivity and Thermo-Sensitivity in Relation to the Regional Adaptability of Rice Varieties," *International Rice Commission Newsletter* (June 1971). *Also see* B.S. Vergara and T.T. Chang, *The Flowering Response of the Rice Plant to Photoperiod; A Review of the Literature,* 3rd ed., Technical Bulletin No. 8 (Los Baños, Philippines: International Rice Research Institute, 1976), 75 pp.

[15]This section is largely based on recent works by Lloyd Evans, writing both individually and with others. His two most useful general articles are, "The Natural History of Crop Yield," *American Scientist* 68(4) (July-August 1980): 388-397 and "Raising the Yield Potential: By Selection or Design?" in *Genetic Engineering of Plants,* ed. T. Kosuge, C.P. Meredith, and A. Hollaender (New York: Plenum Publishing, 1983), pp. 371-389. For more specific research on rice, *see* L. Evans, R.M. Visperas, and B.S. Vergara, "Morphological and Physiological Changes Among Rice Varieties Used in the Philippines Over the Last Seventy Years," *Field Crops Research* 8 (February 1984): 105-124.

[16]1f two crops are grown in sequence each year, the yield of each individual crop may be less than the yield if only one crop were grown, but the combined yield of the crops is usually higher than the yield of a single crop. However, since the second crop may not be of the same type, weight or volume may be an inadequate measurement of output. Value of production may be a more relevant measure.

[17] This section draws heavily on conversations with L.W. Briggle, Agricultural Research Service, U.S. Department of Agriculture (ARS/USDA), Beltsville, Maryland; J. Neil Rutger, ARS/USDA, University of California, Davis; and W.R. Coffman, Department of Plant Breeding, Cornell University, Ithaca, New York. *Also see* S.S. Virmani and I.B. Edwards, "Hybrid Rice and Wheat," *Advances in Agronomy* 36 (1983):383-413.

[18] Some work of this nature was done much earlier. The earliest known case of radiation being used to produce a short rice variety occurred in India in 1932. *See* N. Parthasarathy, "Rice Breeding in Tropical Asia up to 1960," in International Rice Research Institute, *Rice Breeding* (Los Baños, Philippines: IRRI, 1972), pp. 8, 29.

[19] An extensive listing of rice varieties developed to date is provided in A. Micke, M. Maluszynski, and B. Donini, "Plant Cultivars Derived From Mutation Induction or the Use of Induced Mutants in Cross Breeding," *Mutation Breeding Review* (3) (May 1985):61-62.

2. DEVELOPMENT OF HIGH-YIELDING RICE VARIETIES

. . . plant breeding, using germplasm from any source in the world cuts across national boundaries and develops products useful in the end to all men and nations.

"Gove Hambidge and E.N. Bressman, 1936 [1]

High-yielding rice varieties were first recorded around 1000 A.D., but formal yield-improvement programs did not begin until the late 1800s. Attention was first given to selecting and then breeding relatively short and higher yielding japonica varieties in temperate regions. During the 1950s, breeding programs were begun on semidwarf and high-yielding indica varieties in more tropical regions. Japonica x indica crosses have also been developed.

CHINESE ANTECEDENTS

China has the most extensive history of rice improvement, much of it due to simple farmer selection of improved varieties.[2] Sometime before 1000 A.D., a group of rices called Champa was introduced into Fujian Province from Indochina[3] and spread into the lower Yangtze and lower Huai areas, replacing local varieties. Champa rices had two outstanding features: they were relatively early maturing (60 to 100 days after transplanting), and they were drought resistant.

Following the introduction of Champa varieties, the use of early maturing rices expanded, especially in southeastern China. Other shorter season varieties were developed during the 11th and 12th centuries. By the early 1830s, the area growing early-maturing varieties in China reportedly exceeded the area growing traditional rices. Although most early-maturing rices were used for early season planting, thereby allowing double cropping, some were used to reestablish a crop after severe droughts or floods. [4]

HIGHER YIELDING RICE VARIETIES

The era of higher yielding rice varieties began in East Asia in the late 1800s with the introduction of fertilizers. The plant improvement process began with selection; in the 1900s, it moved into hybridization programs. The varieties developed were shorter than were common at the time, but were not — with the possible exception of one or two varieties — semidwarfs. The exceptional qualities of the varieties led to their cultivation in other countries and their use as parents in breeding programs. Some of their offspring are used today.

Japonica Varieties

From the late 1800s until the mid-1900s, the major improvements made in japonica varieties were in Japan, Taiwan, and Italy.

Japan

From 1890 to 1920, there was a sharp rise in the area planted with *rōnō* varieties. These varieties were originally selected by farmers, subsequently exchanged through farmers' organizations, and finally identified as national standard varieties. A common feature of *rōnō* varieties was that they produced higher yields than other varieties following applications of fertilizer.

The leading *rōnō* variety of the time was Shinriki, which means "power of God." It was reportedly selected from Hodoyoshi by a farmer in Hyogo Prefecture in 1877. Shinriki was relatively short (60-75 cm culm height) and high tillering.[5] Shinriki's principal weakness was a susceptibility to bacterial leaf blight disease. It was crossed with Aikoko in 1912 to provide a variety (Mitsui-Shinriki) more resistant to blight and more tolerant of adverse growing conditions. Through the late 1920s, however, Shinriki was Japan's leading improved variety.[6]

Shinriki also played a leading role in U.S. rice production. It was introduced in the United States in 1902 and was extensively grown in Louisiana and Texas until 1910. Yields were high and of good quality. Average plant height, including panicles, was 94 cm; other varieties averaged from 109 to 137 cm. Shinriki was not widely grown "because its culms are too short to be cut with a binder without the loss of some grain. . . ."[7] Shinriki was also used as a parent in crosses made in Taiwan and elsewhere.[8]

Hybridization programs were initiated in Japan in the early 1900s, and successes were obtained in breeding nitrogen-responsive and disease-resistant types. It was not until 1932, however, that these varieties began to represent any sizable proportion of the rice area. They did not exceed the area planted with *rono* varieties until 1946.[9]

Taiwan

In the early 1920s, Japan established a rice breeding program in Taiwan to develop day-length and temperature-insensitive types of japonica rice. The program resulted in the ponlai series of varieties. (Ponlai is used for all japonica varieties in Taiwan.) They were fertilizer responsive and early maturing, which facilitated multiple cropping. Research verified ponlai's high-yielding ability over a wide area in tropical Asia and Africa, but they did not gain commercial acceptance elsewhere because of disease problems and unpopular grain features.[10]

Taichung 65 was the first ponlai variety, resulting from a cross of Shinriki with Kameji in 1924. Taichung 65, selected in 1927, was of medium plant height and remained Taiwan's principal variety until 1959. Taichung 65 also was used in the breeding of many other ponlai varieties. As of about 1960, 79 of 96 commercially grown varieties were related to Taichung 65. The cross Shinriki × Aikoku (made in 1912 in Japan) was, along with Taichung 65 and indica variety O-luan-chu, one of the parents of Chianan 7 and Chianan 8. Chianan 8 replaced Taichung 65 as the leading variety in 1959.[11] Taichung 65 also was used outside Taiwan and was one of the parents of Mahsuri in India and Malaysia. A mutant of Taichung 65 is known as K84 in India.

Italy

In 1902, a variety or a group of varieties known as Chinese Originario was introduced into Italy from Japan. In 1924, a pure-line selection known first as Ardito, and later as Balilla, was released. Its culm length was reported as 73.9 cm and its overall height (culm plus panicle) was 90 cm. Until about 1960, Balilla was grown on less than 6,000 ha/year, reportedly because its stem was too short for transplanting.

However, when Italian rice growers changed to broadcast seeding in the late 1960s, Balilla—which had good resistance to lodging—suddenly became much more important. The area planted with Balilla jumped to 41,000 ha in 1969. During the 1970s, Balilla was a leading Italian variety. Its use started declining in 1981. Balilla has been grown in other Mediterranean countries. It was also a parent for several other short varieties (Balilla G.G., Castell, Cripto, and Elio) in the region.[12]

While most japonicas do not have a simple gene for dwarfing, Balilla could well be an exception. Efforts are under way to determine whether this is the case. If so, Balilla belongs with the semidwarfs in a subsequent section.

Indica Varieties

Attempts to improve indica varieties in the 1940s and 1950s were moderately successful in Asian national rice breeding programs. Results of this work include H-4 and H-5 in Sri Lanka; and Benegawan, Peta, Remadja, and Sigadis in Indonesia.

Indica breeding in the Philippines was introduced by national researchers; IRRI started its breeding program in the 1960s. The best-known products of the Philippine national program follow.

• BPI-76, derived from a cross between Fortuna and Seraup Besar 15, was developed by the Bureau of Plant Industry in 1957 and released in 1960. Strains having less photoperiod sensitivity, such as BPI-76-1 and BPI-76 (n.s.), were released later.

• C4-63, derived from a cross between Peta and BPI-76, was developed by the College of Agriculture, the University of the Philippines, in 1962 and released in April 1968. A subsequent selection was known as C4-63G. A reselection from this variety has been released as Bhavari in India. C4-63 is widely grown in Burma, Malaysia, and Indonesia, as well as in other Asian nations and in Africa.

A particularly interesting early example of indica improvement is provided by GEB 24 in southern India. This variety was obtained as a spontaneous mutant from the traditional variety Konamani. In 1932, seeds of GEB 24 were exposed to X-rays and a number of mutations resulted. One was a semidwarf (about 100 cm) that was high tillering and adapted to fertile soils. The variety was not popular with farmers, who preferred longer straw for animal feed. GEB 24 also was known as HR 35, Nizersail (in Nigeria), and Chin. 25. GEB 24 was also a parent of CR 36-14 (Supriyal) and Sona and was crossed with CO 18 to produce TKM-6.[13]

TKM-6 has good insect resistance but a weak stem. It was used as a parent for several high-yielding Indian and IRRI varieties in the 1960s and 1970s. Indian progeny include Cauvery, CR 34-16, Kannagi (Pusa 2-221), OR 34-16, Ratna, and Suma. At IRRI, TKM-6 was a parent of IR20, IR26, and the breeding line IR747B2-6. The latter was a parent of IR1561-228-3-3, which was a parent of IR36 and several other IRRI cultivars.

Japonica x Indica Crosses

A program to cross japonica and indica varieties was established in 1950 in Cuttack, India. Participants included the International Rice Commission (sponsored by the Food and Agriculture Organization [FAO]), India's central Rice Research Institute, and several cooperating Asian nations. Results generally were not satisfactory because nearly all of the japonica parents were from Japan and were poorly adapted to a tropical climate. There were, however, several significant exceptions. One cross, ADT-27, showed a substantial improvement over local varieties in India and subsequently was planted widely in the Tanjore District. ADT-27 was also one of the parents of CO-33.[14]

Two of the japonica x indica crosses were selected in Malaysia and were subsequently released as Mahsuri (often spelled Mashuri) and Malinja. Mahsuri (Taichung-65 x Mayang Ebos 80/2) proved particularly popular. It was extensively planted in Malaysia and also was raised in Andhra Pradesh, India. It is widely grown in Bangladesh, Burma, and Nepal under the names Pajam, Manawhari, and Masuli, respectively, and recently was introduced in Vietnam.[15] Malinja (Siam 29 x Pebifun) also was widely grown in Malaysia.

SEMIDWARF VARIETIES

It is not known precisely when or where semidwarf rices first made their appearance, but it was probably in Fujian Province, China, or Taiwan.

Indica Semidwarfs

The semidwarfs, as we know them, first appeared in Taiwan and then in mainland China. IRRI became involved in developing the semidwarfs shortly after China, and utilized semidwarfs from Taiwan.

Taiwan

The earliest known semidwarf rice was an indica, Dee-geo-woo-gen (DGWG), also known as I-geo-woo-gen.[16] (The prefixes Dee-geo, I-geo, and Hsia-geo mean "dwarf.") The 1871 local records of Taiwan (Taiwan Fan-Chih) mention a variety called Woo-gen that was introduced from Fujian Province. In 1906, DGWG and Woo-gen were recorded by the Taiwan Agricultural Experiment Station. The origins of DGWG are unclear; one account suggests that it may have been brought from Fujian several hundred years ago;[17] another suggests that it may have been a spontaneous mutant from Woo-gen.[18]

DGWG and other semidwarfs soon became popular in Taiwan. In 1939, some 5,000 ha of DGWG were planted in the first crop in Hsinchu district. Two other semidwarfs grown at the same time were Ti-chueh-hua-lou (first crop, Taipei district) and Ai-chueh-chin-yu (first crop, Kaohsiung district). DGWG was planted on

10,907 ha in 1953; the area dropped to 4,168 ha by 1965.

After World War II, the Taiwan Agricultural Research Institute introduced 660 rice varieties from mainland China, mainly of the indica type, of which seven had names beginning with Dee-geo or I-geo. In 1951 and 1952, the Institute surveyed Taiwan's native rices. Of the 114 recorded, six semidwarfs were included: DGWG, Dee-geo-liu-chow, Dee-geo-min-tang, Hsia-geo-liu-chow, I-geo-chn-yu, and Tuan-ken-sim-loo (short Siam). Another semidwarf, I-geo-tze, was not mentioned in the survey but was included in 1960 regional trials.

The first cross involving a semidwarf was made on Taiwan. In 1949 DGWG was crossed with Tsai-yuan-chung, a tall disease-resistant local variety. A selection from this cross was named Taichung Native 1 (TN-1) in 1956, and small amounts of TN-1 seed were given to nearby farmers for trial plantings. TN-1 is short-statured (83-85 cm) and high tillering. It responds well to nitrogen fertilizer up to about 100 kg/ha. Its principal deficiency is susceptibility to several insects and diseases. TN-1 was rapidly accepted by farmers. By 1965, 79,000 ha were planted with TN-1, making it the second most popular variety that year. The area planted gradually declined, reaching 50,000 ha in 1970.

Another semidwarf variety, Taichung Sen (Native) 2, was developed at about the same time. Derived from a cross between DGWG and Pai-mi-fen, it has the same plant type and growth characteristics as TN-1, though it matures a little earlier. It shares susceptibility to some of the same diseases, including blast, and for this reason its introduction was delayed until 1966. But farm plantings began before that date and expanded regularly, reaching 41,400 ha in 1968.

The next two semidwarfs to be developed in Taiwan were Kaohsiung Sen 2 and Ai-chueh-chien. The former was developed from a cross between TN-1 and Pai-mi-fen and was released in 1968 for southern Taiwan. The latter was a pure-line selection from a native variety and became popular in northern Taiwan.

The Taiwan varieties were given international exposure during the 1960s. A group of 15 ponlai and 4 semidwarf native varieties were sent to a University of Missouri team in Calcutta during 1960. TN-1 and several ponlai varieties were entered in cooperative variety trials sponsored by FAO and the International Rice Commission from 1961 to 1963 in several countries.[19] TN-1 was widely used in India. It was introduced, or perhaps reintroduced, through IRRI in 1964, and was widely planted (some 810,000 ha during 1968-69) and used as a parent for many varieties (at least 16 including Cauvery, Hamsa, Jaya, Padman, Sona, and Telle Hamsa).[20] TN-1 was also a parent of RD2 in Thailand in 1964.

China

About the time TN-1 was bred in Taiwan, semidwarf rices began to attract attention in mainland China.[21] In 1956 two semidwarf varieties were identified. One was selected by farmers in Guangdong Province and released in 1957 as Ai-jiao-nan-te (figure 2.1). The other was identified in a germ plasm collection from Guanxi province, named Ai-zai-zhan and released as a variety in 1961. Two offspring of Ai-zai-zhan were subsequently released—Guang-chang-ai in 1959 and Zhen-zhu-a in 1962.

The first two Chinese semidwarfs compared as follows with DGWG in a test conducted in the late 1970s:

Variety	Plant height (cm)	Maturity
Ai-jiao-nan-te	75.9	Early (73 days)
Ai-zai-zhan	94.9	Medium (101 days)
Dee-geo-woo-gen	102.0	Medium-late (107 days)

Guang-chang-ai's plant height is about 90 cm. Most other semidwarfs are in the 80-90 cm range.

The Chinese semidwarfs were rapidly adopted during the 1960s, reaching an area of about 4.3 million ha in southern China by 1965. By 1974 semidwarf varieties covered an estimated 90%, or nearly 32 million ha, of the total rice-growing area of the country. (See chapter 3.)

International Rice Research Institute

The IRRI breeding program began in October 1961 with the arrival of Peter R. Jennings from the Rockefeller program in Colombia and Te-Tzu Chang from Taiwan. Jennings had been involved in rice research in Colombia; Chang was familiar with the semidwarfs used in Taiwan. In October 1963, H.M. Beachell, a Texas rice breeder with a

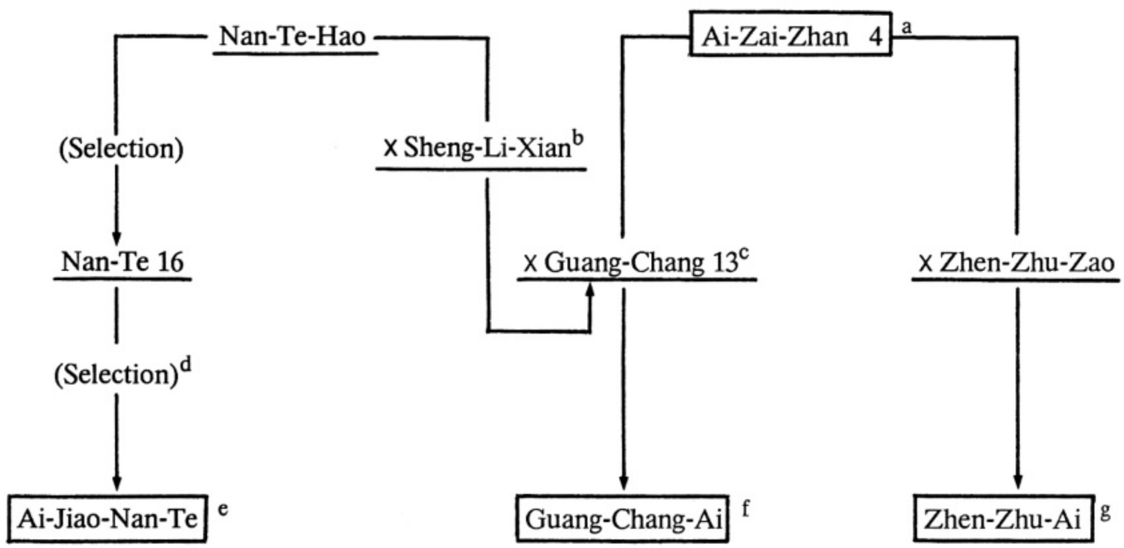


Figure 2.1. Genealogy of the three principal early semidwarf rice varieties, People's Republic of China (semidwarf varieties in boxes).

[a] Identified from germ plasm collection in 1956, Guangxi Province.

[b] Sheng-Li-Xian was selected from a local variety in Central China and crossed with Nan-Te-Hao to produce Guang-Chang 13.

[c] Crossed with Ai-Zai-Zhan 4 in 1956 to produce Guang-Chang-Ai.

[d] Selected by farmer in 1956.

[e] Released in 1957, Guangdong Province.

[f] Selected in 1959; released in 1961. First semidwarf developed in China by cross breeding.

[g] Selected in 1959; released in 1962.

Sources: Derived principally from information provided in J.-H. Shen, "Rice Breeding in China" in International Rice Research Institute, *Rice Improvement in China and Other Asian Countries* (Los Baños, Philippines: IRRI, 1980), pp. 18-24. Additional information provided by W.R. Coffman of Cornell University and S.S. Virmani of IRRI.

long-time interest in developing short-statured varieties, joined the group. They consulted the Varietal Improvement Program and selected lodging resistance as an initial breeding goal.[22]

The first IRRI crosses were made in 1962. Of the 38 crosses made that year, 11 involved 3 semidwarf varieties from Taiwan—DGWG, TN-1, and I-geo-tze. I-geo-tze, although not a prominent variety in Taiwan, was included because of its greater disease resistance than TN-1. The fifth cross was between Peta, a tall Indonesian variety, and Tangkai Rotan, a Malaysian variety of medium height. The eighth cross was between Peta and DGWG. Following further breeding work, a selection from the eighth cross was released as IR8 in November 1966 (figure 2.2); a selection from the fifth cross was released as IR5 in December 1967.

In late 1965 and early 1966, Beachell assembled a group of 303 varieties and breeding lines that showed promise in IRRI trials, and sent them to cooperating rice breeders in Bangladesh, India, Malaysia, Thailand, and Colombia. In addition, 300 breeding lines were sent to rice scientists in Taiwan, Costa Rica, the Dominican Republic, and Mexico. Smaller sets of materials were sent to experiment stations in several other countries. This was the first widespread distribution of IRRI's testing and breeding materials.[23]

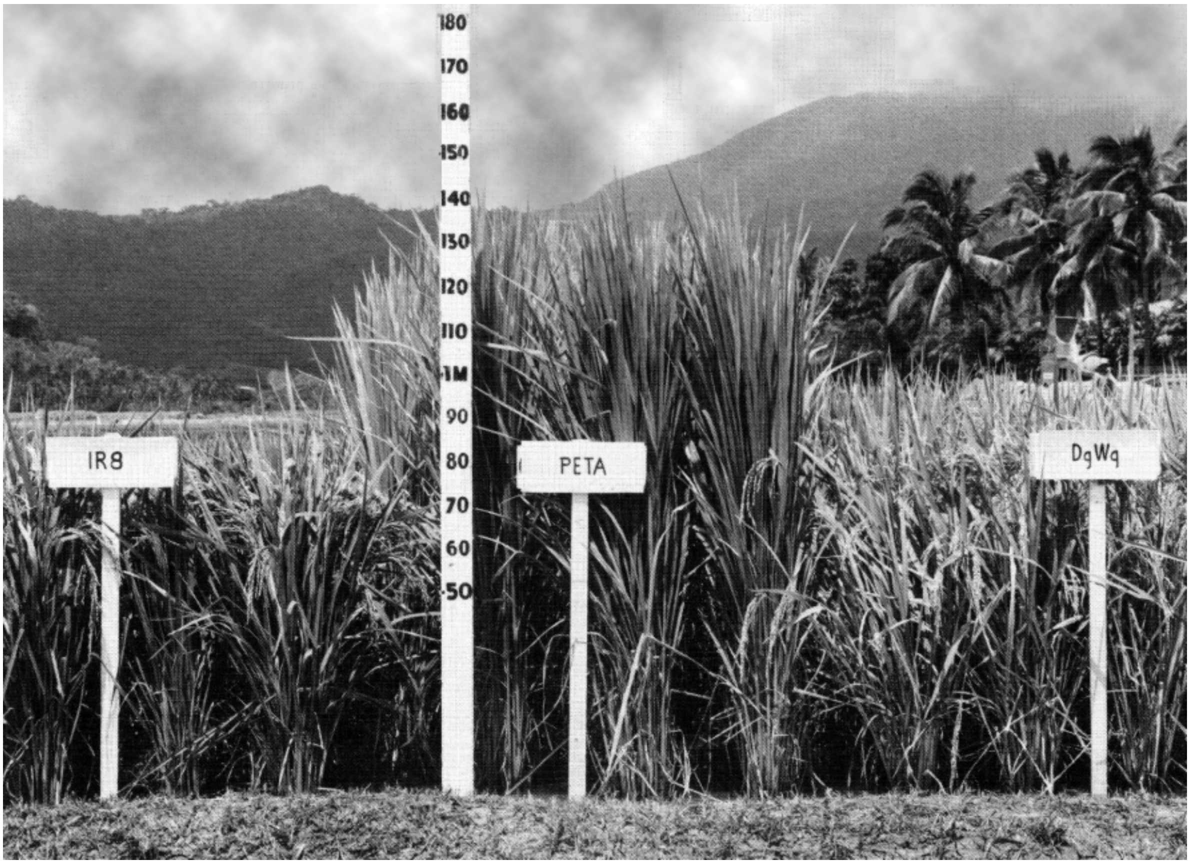


Figure 2.2. IR8 (left) and its parents: Peta (center) and Dee-geo-woo-gen (right). Source: International Rice Research Institute.

Other IRRI varietal releases followed. IR20 and IR22 were released in December 1969, IR24 in May 1971, and IR26 in November 1973. These varieties (as well as IR5 and IR8) had Peta in their ancestry.[24] All but IR5 were semidwarfs and relied on DGWG for this characteristic (figure 2.4).

Additional IR varieties followed (table 2.1). Responsibility for naming varieties was transferred to the Philippine Seed Board in November 1975. By 1985, 29 IR varieties had been released.[25]

IRRI crosses have grown in number and complexity. IRRI makes some 4,000 crosses per year; by 1985, it had carried out over 50,000 crosses. The increasing complexity may be seen by comparing figure 2.4 with the genealogy for IR64 (figure 2.5). Greater attention has been given to incorporating greater insect and disease resistance and tolerance of unfavorable environments, which will result in greater yield and improved grain stability (IR26, IR42). Newer varieties also are faster growing, which means that they use less water, that they are exposed to field hazards for a shorter period of time, and that multiple cropping is facilitated (IR36, IR50, IR58).[26]

In the process, there has been one significant trade-off: the newer varieties are not as short and have less lodging resistance (table 2.2). This is particularly notable in the case of IR36 and is traced to the use of TKM-6 (which has good insect resistance but weak straw) as a parent. TKM-6 is involved in the ancestry of a number of IR varieties, starting with IR20. IR8 is still the highest yielding and most lodging-resistant variety. Renewed attention may have to be given to lodging resistance. An interesting parallel can be drawn with the Japanese cross between Shinriki and Aikoku noted earlier in this chapter. The offspring was less sensitive to disease and more

Figure 2.3. Philippine farmer examining heads of IR5 rice. Source: Agency for International Development.

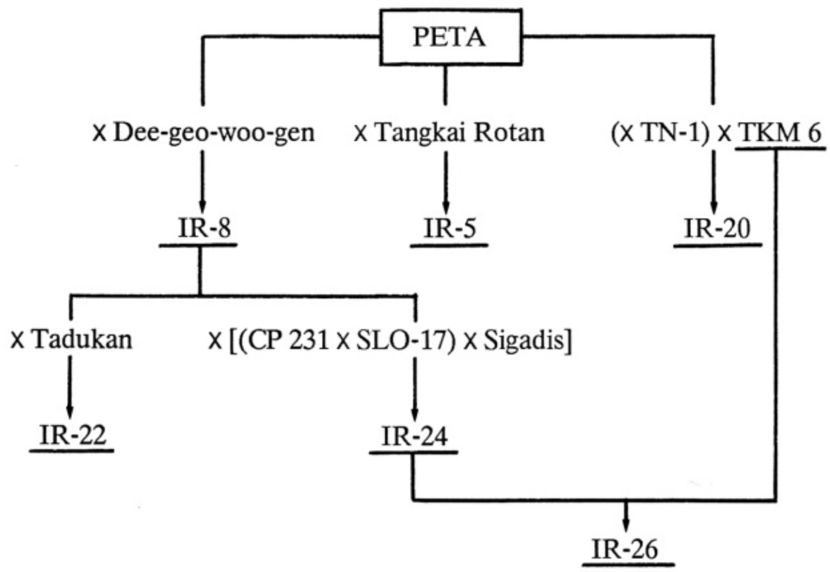


Figure 2.4. Genealogy of early semidwarf IRRI rice varieties. (The genealogy of some varieties has been simplified slightly for graphic purposes.)

tolerant of adverse conditions but was also taller and not as high yielding.[27]

In terms of the use of varieties and lines developed by IRRI, there are several different categories:

1. Direct use (planting) of IR varieties:
   a. Under IR name
   b. Under local name
2. Direct use of IR breeding lines or crosses:
   a. Under IR number
   b. Under local names
3. Use of IR varieties or lines as parents in local breeding programs.

It is not possible to cover all of these uses, although some will be reported in chapter 3. Items 1b and 2 (as reported in IRRI publications) are summarized in tables 2.3 and 2.4. In the latter case, it is surprising to see the extent to which IRRI crosses have been selected and named in country programs.[28] The addition of other IRRI crosses released by national programs would further raise the total.

Item 3 has been reported extensively for Asia by Hargrove, Coffman, and Cabanilla.[29] In their first studies in the mid-1970s, the three scientists surveyed 28 experimental stations in 10 Asian nations. Of the new varieties released from 1970 to 1975, 64% were progeny of lines provided by IRRI or developed at IRRI (42% had one or more IRRI parents, while 22% were IRRI varieties or lines). Their most recent study, conducted in 1984 and covering 129 crosses made at 23 stations in 9 Asian nations, revealed that the direct use of IRRI lines or varieties as immediate parents had decreased to 34%, while the use of locally developed semidwarfs as parents increased to 51%. However, when the pedigrees of the local semidwarfs were traced four generations, virtually all were found to have IRRI ancestry. The only exception was for those with TN-1 ancestry.[30]

Thus, the IRRI varieties and lines have found, through naming in local programs and use as parents in national breeding programs, a much wider degree of application throughout Asia and the world than would be assumed by reviewing the list of IR varieties.

Other research programs

Indica semidwarfs have also been used in breeding programs at two other international agricultural research centers—the International Center for Tropical Agriculture (CIAT) in Colombia and the International Institute for

Table 2.1. IR varieties released, 1967 to 1985

Variety	Date released	Selection number	Female parent	Male parent
Named by IRRI[a]				
IR5	Dec. 1967	IR5-47-2	Peta	Tangkai Rotan
IR8	Nov. 1966	IRH-288-3	Peta	Dee-geo-woo-gen
IR120	Dec. 1969	IR532-E-576	IR262-24-3	TKM6
IR22	Dec. 1969	IR.579-160-2	IR8	Tadukan
IR24	May 1971	IR661-1-140-3	IR8	IR127-2-2
IR26	Nov. 1973	IR1541-102-7	IR8	TKM6
IR28	Jan. 1975	IR2061-214-3-8-2	IR24	IR1561-149-l/IR1737
IR29	Jan. 1975	IR2061-464-4-14-3	(same as IR28)	
IR30	Jan. 1975	IR2153-159-1-4	IR26	IR20*4/O.nivara
IR32	July 1975	IR2070-747-6-3-2	IR20^2/O.nivara	CR94-13
IR34	July 1975	IR2061-213-2-217	(same as IR28 and 29)	
Named by Philippine Seed Board[a]				
IR36	1976	IR2071-625-1-252	IR1561-228-1-2/IR1737	CR94-13
IR38	1976	IR2070-423-2	(same as IR32)	
IR40	1977	IR2070-414-3-9	(same as IR32)	
IR42	1977	IR2070-586-5-6-3	(same as IR36)	
IR43	1978	IR1529-430-3	IR305-3-17-1-3	IR24
IR44	1978	IR2863-38-1	IR1529-080-3/CR94-13	IR480-5-9-3
IR45	1978	IR2035-242	IR1416-128-5/IR1364-37-3-1	IR1824-1
IR46	1978	IR2058-78-1-3-2	IR1416-131-5/IR1364-37-3-1	IR1366-120-3-1/IR1539-37-3
IR48	1979	IR4570-83-3-3	IR1702-74-3-2/IR1721-11-6-8-3	IR2055-481-2
IR50	1980	IR9224-117-2-3-3-2	IR2153-14-2-6-2/IR28	IR2070-625-1
IR52	1980	IR5853-118-5	Nam Sagui l9/IR2071-88	IR2061-214-3-6-20
IR54	1980	IR5853-162-1-2-3	(same as IR52)	
IR56	1983	IR13429-109-2-2-1	IR4432-53-33/PTB33	IR36
IR58	1983	IR9752-71-3-2	IR28/Kwang Chang Ai	IR36
IR60	1983	IR13429-299-1-1-3-1	(same as IR56)	
IR62	1984	IR13525-43-2-3-1	PTB33/IR30	IR36
IR64	1985	IR18348-30-3-3	IR5657-3-3-2-1	IR2061-465-1I
IR65	1985	IR21015-190-3-1-3	Batataes/IR36	IR52

[a] As of November 1975, IRRI stopped its practice of naming varieties. The Philippine Seed Board continued to use the IR designation for IRRI selections released in that country.

Source: International Rice Research Institute.

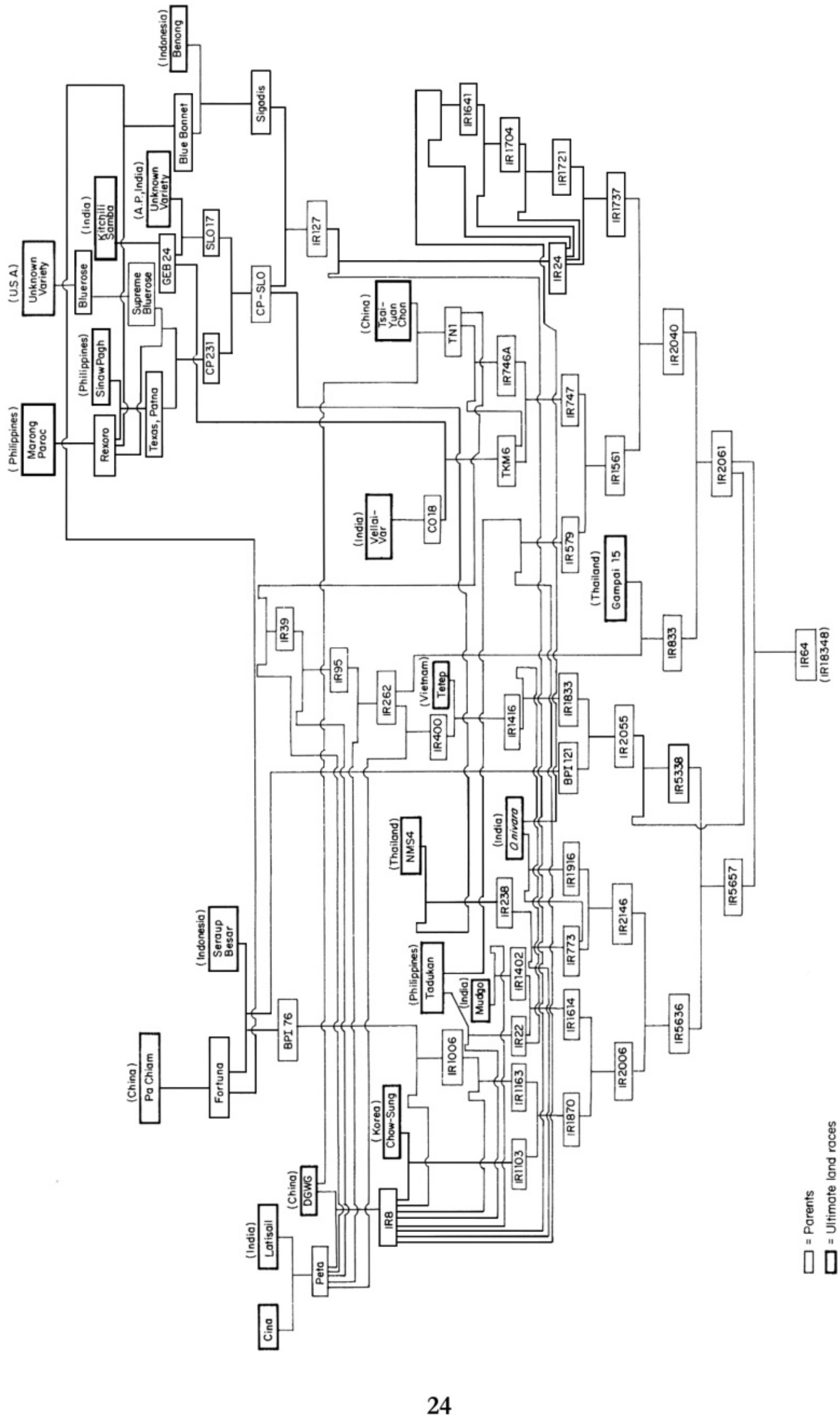


Figure 2.5. The ancestry of IR64 rice. Source: International Rice Research Institute.

Table 2.2. Height and lodging resistance ratings of IR varieties, Philippines (irrigated lowland unless otherwise indicated)

Variety	Height[a]	Lodging[b]
IR5	M	MR
IR8	S	R
IR20	MS	ME
IR22	S	R
IR24	S	R
IR26	S	MR
IR28	S	MR
IR29[c]	S	MR
IR30	S	MR
IR32	S	MR
IR34	MT	MS
IR36	S	R[d]
IR38	MS	R
IR40	S	MR
IR42	S	MR
IR43[e]	MS	MR
IR44	S	R
IR45[e]	MS	MR
IR46[f]	MS	MR
IR48	M	R
IR50	S	MS
IR52[f]	MS	MR
IR54	M	MR
IR56	M	MS
IR58	S	MS
IR60	S	MS
IR62	S	MS

[a]Height: S = short (100-110 cm), MS = medium short (111-120 cm), M = medium (121-130 cm), and MT = medium tall (131-140 cm).

[b]Lodging character: R = resistant, MR = moderately resistant, and MS = moderately susceptible.

[c]Glutinous.

[d]MS at Los Baños.

[e]Upland.

[f]Lowland rainfed.

Source: A.J. Bueno, "Rice Varietal Improvement in the Philippines," *International Rice Commission Newsletter* (June 1983):15-23; letters from Bueno, April 1984.

Tropical Agricultural (IITA) in Nigeria. Breeding work began at CIAT in 1967, under the leadership of Peter Jennings, and at IITA in 1972. CIAT focused on varieties for irrigated conditions, while IITA concentrated on varieties for upland conditions. The semidwarf characteristic has been of greater significance for irrigated than for rainfed conditions. The research programs of these two centers as well as national research systems are further noted in chapter 3.

Table 2.3. IR varieties released under local names[a]

IR variety	Local name (country)
IR5	ROK-6 (Sierra Leone)
	Pankaj (India) (sister of IR5)
	Yagyaw-2 (Burma)
	Nong Nghiep 5 (Vietnam)
IR8	Ria (Malaysia)
	Yagyaw I (Burma)
	Nong Nghiep S (Vietnam)
	Zarate 8 (Iraq)
IR20	Irrisail (Bangladesh)
	Shwe-war-hnan (Burma)
IR22	INIAP-2 (Ecuador)
	Navalato A-71 (Mexico)
	Lone-thwe-shwe-war (Burma)
IR24	PR103 (India)
	Shwe-war-yin (Burma)
IR28	BR6 (Bangladesh)
	Amol/2 (Iran)
	She-war-lay (Burma)
IR34	Sin-shwe-thwe (Burma)
IR36	NN3A (Vietnam)
IR38	NN8A (Vietnam)
IR42	Pyi-lone-chan-tha (Burma)
	NN4B (Vietnam)
IR43	Saavedra 5 (Bolivia)
	IR1529 (Cuba)
IR46	Pesagro 102 (Brazil)
IR48	NN5B (Vietnam)

[a]Listing is probably incomplete.

Sources: IRRI annual reports and data accumulated for this report.

Table 2.4. IRRI crosses named in developing countries

IRRI selection no.[a]	Local name	Location	Year[b]	Sister of IR variety[c]
IR5-198-1-1	ROK-6	Sierra Leone	1974	IR5
IR5-114-3	Pankaj	India	c. 1970	IR5
IR-250	SM 1	Malaysia	1974	IR5
IR5-278	Bahagia	Malaysia	c. 1970	IR5
IR6-156-2	Mehran 69	Pakistan	c. 1970	-
IR160-25	CS-2	Ivory Coast	c.1970	-
IR160-27-4	Nilo 9	El Salvador	?	-
	Sinaloa A68	Mexico	c. 1970	-
		Cuba	c. 1970	-
IR253-4	RD-2	Thailand	c. 1970	-
IR253-16-1	CS-3	Ivory Coast	c. 1971	-
IR262-7-1	CS-1	Ivory Coast	c. 1971	-
IR262-43-8	IR262	Sri Lanka	c. 1972	-
IR269-26-3-3-3	FARO 26 (TOS-78)	Nigeria	1981	-
IR272-4-1	BR-1 (Mala)	Bangladesh	c. 1972	-
IR400-29-9-73	Parwanipur 1	Nepal	1973	-
IR442-2-24	Pani Dhan 1	India	1975	-
IR442-2-50	IR50	India	1975	-
	Huallaga	Peru	c. 1972	-
IR442-2-58	Arroz BR-2	Brazil	1978	-
	IR58	India	1975	-
	Pani Dhan 2	India	1975	-
IR480	CS-6	Ivory Coast	?	-
IR480-5-9	Ajral	Fiji	c. 1972	-
IR506	CS-5	Ivory Coast	?	-
IR532-1-18	IR532	Sri Lanka	c. 1972	IR20
IR532-1-176	BR-1 (Chandina)	Bangladesh	c. 1970	IR20
IR532-E-208	N.G.6637	Papua New Guinea	1974	IR20
IR579-48-1	Nilo 11	El Salvador	c. 1972	IR22
	Palman 579	India	c. 1972	IR22
IR579-48-1-2	Sakha 1	Egypt	1975	IR22
IR579-48-1-2 sel.	Himalaya	India	1982	IR22

	IR579	India	1972	IR22
IR579-97-2-2-1	Rajinder Dhan 201	India	1979	IR22
IR627-1-31-4-3-7	FARO 22	Nigeria	1976	-
IR655-79-2	FARO 27	Nigeria	?	-
IR661	Chainung-sen 8	Taiwan	1974	IR24
IR661-1-140-3	PR103	India	1978	IR24
IR665-4-5-5	?	Brazil	1974	-
IR665-79-2-4	PR106	India	1976	-
IR667-98	Tongil	South Korea	c. 1971	-
IR747B2-6-3	GPL 1	Solomon Islands	1974	-
IR751-592	Shwe-thwe-lay	Burma	1981	-
IR758-15-2	BAU 63 (Varasha)	Bangladesh	1983	
IR789-59-3-1	Marisa	Malaysia	1973	-
IR790-35-5-3	FARO 7	Nigeria	1983	-
IR822-81-2	CR1113	Costa Rica[d]	1974	-
IR837-20-3-6	Piedras Negras A74	Mexico	1974	-
IR837-46-2	Bomoa A74	Mexico	1974	-
IR841-36-22	841	Pakistan	1973	-
	Abbasi 72	Pakistan	1974	-
IR841-63-5-18	IR841	Argentina	1981	-
	?	Brazil	c. 1972	-
IR930-2-6	Naylamp	Peru	c. 1972	-
IR930-31	CICA 4[e]	Colombia	c. 1972	-
	Chancay	Peru	c. 1972	-
	IRGA	Brazil	?	-
IR930-67-2-2	Sita	India	1984	-
IR1052	R (also G, J?)	Guyana	1973	-

Key: — =Not a sister of an IRRI variety.

[a]The parentage of crosses listed here is provided in International Rice Research Institute, *Parentage of IRRI Crosses, IR1-IR 50,000* (Los Baños, Philippines: IRRI, 1985).

[b]May have been released prior to year noted when marked “c.”

[c]From same parents, but a different selection.

[d]Subsequently introduced with help of CIAT in El Salvador, Honduras, Nicaragua, Paraguay.

[e]Selected by CIAT. CICA 4 selections released as Advance 72 in the Dominican Republic and as INTAP 6 in Ecuador.

Table 2.4. IRRI crosses named in developing countries (continued)

IRRI selection no.	Local name	Location	Year	Sister of IR variety
IR1055	S (also N, K?)	Guyana	1973	–
IR1347-45-2	PY3	India	1984	–
IR1416-131-5	Suakoko 12	Liberia	1981	–
IR1529-430-3	Saavedra V4	Bolivia	1981	43
	IR1529	Cuba	1978	43
		Burkina Faso	1979	43
	TN73-1	Vietnam	1973	43
	Yar-5	Burma	1981	43
IR1529-680-3	Xiao-jia-huo	China	1975	43
IR1539-156	Bilo	Fiji	1976	–
IR1545-339-2-2	IR1545	Ecuador	1981	–
IR1561-216-6	Prasad	India	1978	–
IR1561-228-3	IR1561	Kenya	1981	–
		Mauritania	1981	–
		Senegal	?	–
	Sakha 2	Egypt	1975	–
	TN73-2	Vietnam	1973	–
IR1561-228-3-3	32 Xuan 5	China	1980	–
IR1614-138-3-1	GPL	Solomon Islands	1974	–
IR1820-210-2	Tamale 1	Ghana	1978	–
IR2053-87-3-1	BR 7 (BRRI Balam)	Bangladesh	1978	–
IR2053-206-1-3-6	IR2053	Sudan	1979	–
IR2053-261-2-3	DR-83	Pakistan	1954	–
IR2058-78-1-3-2-1	Pesagro 102	Brazil	1983	IR46
IR2061-213-2-17	Sin-shwe-thwe	Burma	1979	IR28, 29, 34
IR2061-628-1-6-4-3	Laxmi	India	1978	IR28, 29, 34
IR2070-199-3-6-6	NN8A	Vietnam	1983	IR32, 38, 40
IR2070-734-3	NN4A	Vietnam	1978	IR32, 38, 40
IR2071-124-6-4	Sabitri	Nepal	1978	IR36, 42
IR2071-179-3	NN5A	Vietnam	1978	IR36, 42
IR2071-199-3-6	BR15 (Mohini)	Bangladesh	1983	IR36, 42
IR2071-621-2	Asahan	Indonesia	1978	IR36, 42

IR2071-625-1	NN3A	Vietnam	1978	IR36,42
IR2298PlpB-3-2-1-1B	Himali	India	1982	–
		Nepal	1981	–
IR2307-247-2-2-3	NN6A	Vietnam	1980	–
	Semeru	Indonesia	1980	–
IR2793-80-1	BR16 (Shahibalm)	Bangladesh	1984	–
IR2797-115-3	NN3B	Vietnam	1980	–
IR2823-399-5-6	NN2B	Vietnam	1980	–
IR3941-4-Plp 2B	Kanchen	India	1982	–
		Nepal	1981	–
IR5657-33-2-2-3	Chitanduy	Indonesia	1983	–
IR8208	Pesagro 101	Brazil	1983	–
IR8423-132-6-2-2	CR203	Vietnam	1984	–
IR9129-192-2-3-5	NN7A	Vietnam	1980	–
IR9224-73-2-2-2-3	OM33	Vietnam	1983	–
IR13543-66	Kelara	Indonesia	1984	–
IR15529-253-2-2	Bahbolon	Indonesia	1983	–
IR19746-11-3-3	CN2	Vietnam	1984	–
IR21836-90-3	Hmawbi 2	Burma	1984	–
IR21841-91-2-3-3	Hmawbi 3	Burma	1984	–

Key: –=Not a sister of an IRRI variety.
Source: IRRI annual reports from 1970 to 1984.

Japonica Semidwarfs

Relatively few japonica semidwarfs have been identified. The reasons may be that japonica plants are naturally shorter than indicas and their height is usually controlled by several genes (polygenes), rather than by a single semidwarf gene (see Sources of Dwarfism, later in this chapter). Semidwarf japonicas often are the result of induced, rather than natural, mutations.

The principal japonica semidwarfs are found in Japan, Taiwan, and California. In Japan, the principal natural semidwarf appears to be Jikkoku; leading induced mutants include Reimi and Fukei 71. Several induced japonica semidwarf mutants have been developed in Taiwan. In California, Calrose 76 (an induced mutant of Calrose) has been used as a parent for a number of semidwarf japonica varieties in common use in the state.[31]

Dwarfing genes can be transferred from indica to japonica varieties in breeding programs, as has been done in California by hybridizing IR8 with japonicas varieties, but it is easier to make use of genes found in the same type of rice.

Japonica × Indica Crosses

In the mid-l960s, a cooperative project between South Korean and IRRI scientists was initiated to transfer some of the desirable characteristics of the semidwarf indicas, particularly with respect to resistance to lodging and blast, to the japonicas. The scientists also aimed to retain the ecological adaptability and eating quality of japonicas. One of the first crosses (IR8/Yukara/TN1) was made in 1969; six Suweon numbered lines were developed and one, Suweon 213, was named Tongil (Tong-11) in 1971. It was highly productive except in the cool mountainous regions. Several other crosses subsequently were made, and 18 Tongil-type varieties were released to farmers during the 1974-79 period. The varieties had improved grain and eating quality, cold tolerance, adaptability to late-season cultivation, and resistance to insects and diseases.[32] Some problems, however, persisted with the Tongil varieties. (See chapter 3.)

SOURCES OF SEMIDWARFISM

Short stature in rice is caused by the influence of polygenes, or by a major gene or pair of genes. Polygenes are thought to be responsible for the relatively short height of a number of japonica varieties. It appears, however, that virtually all of the semidwarf rice varieties in commercial use in developing countries (mostly indicas, and a few japonicas) contain one simple major recessive gene, sd_1, plus minor gene modifiers. This is true whether the source was a natural or an induced mutant. The sd_1 gene appears to be a recurring mutant; many spontaneous and induced mutations have occurred at the same site. Further, sd_1 may be pleiotropic (having multiple effects), and all of the effects may not be desirable.[33]

IRRI has been collecting and analyzing differing sources of semidwarfism since it was established in 1960. It has identified about 145 short-statured accessions, excluding those which were known to have been derived from DGWG, I-geo-tze, Ai-jiao-nan-te, or Ai-zai-zhan sources. Following hybridization tests, the varieties were sorted into three groups:

- Identical locus.
- Compound locus. The two parents differ slightly in the fine structure of the sd_1 locus. The presence of modifiers was frequently indicated.
- Nonallelic sources. The semidwarf genes have a different location or locus on the chromosome than sd_1.

A number of varieties have genes that are nonallelic to sd_1 and, hence, are thought to have different genes for semidwarfism, but most have extremely poor agronomic characters. A few have relatively good characteristics, but none of them can compare with TN-1, IR8, or IR36 in growth, vigor, and yield.[34]

Two of the varieties classified as nonallelic to sd_l by IRRI, Reimi and Hoyoku, are well-known japonicas from Japan.[35] Japanese research suggests, however, that Reimi is allelic.[36]

A number of semidwarf japonicas have been developed in California, several of which trace their dwarfing characteristic to Calrose 76, an induced mutant of Calrose. Although all the cultivars released in California carry the sd_1 gene, several of the germ plasm lines carry other genes that are nonallelic. Four categories have been identified: sd_2, sd_4, $sd_1 + sd_2$, and $sd_2 + sd_4$. (The latter two are double dwarfs created by recombining the genes noted.) None, however, has been found as agronomically useful as the sd_1 source. The general usefulness of the sd_1 locus suggests that there is some basis, as yet unknown, for productivity with this particular locus.[37]

The fact that virtually all of the semidwarf varieties in use have the same dwarfing gene, sd_1, could be a source of concern. Other semidwarf nonallelic genes have been found. However, from an agronomic point of view, none are equal or superior to sd_1. The existence of two nonallelic varieties in Japan, Hokuriku 100 and Kochihibiki, suggests that other sources are possible. Clearly, it would be desirable to have useful backup semidwarfing genes that are nonallelic to sd_1.[38]

HYBRIDS

The principal developmental work on hybrid rice has been done in China.[39] Research began in 1964 in Hunan. In 1972 the use of hybrids was declared a major research thrust for all of China; the Chinese Academy of Agricultural Sciences was assigned to coordinate work in 14 provinces, municipalities, and regions. In 1974 the first small demonstration field was planted with hybrid rice. The area climbed sharply from 1976 to 1980, followed by a 2-year period of retrenchment. In 1983 the acreage increased to 6.7 million ha. It is expected that the area will expand to at least 10 million ha during by 1990. Expansion in multiple-cropping areas is expected to be enhanced by the development of shorter maturity hybrid varieties.

Although China developed semidwarfs independent of IRRI, it has made extensive use of IRRI varieties and lines as male restorer lines to produce hybrid seed for farm planting. In fact, the restorers of the most promising and widely cultivated hybrids have come from IRRI. Included are IR24, IR26, IR30, IR661, IR665, and IR9761-19-1, plus several others (GU154 and Tai Yun) with some IRRI ancestry. IR58, which matures in only 108 days, is likely to be widely used as long as high cropping intensities are emphasized.[40] The IRRI varieties have not only proved adaptable, but they have also provided increased insect and disease resistance, an area that has been relatively neglected in Chinese breeding efforts. The major disadvantage of IRRI varieties is their relatively long growing season.

The four principal hybrids as of 1980 were Shan-you, We(V)-you, Si-you, and Nan-you, all indicas. Few keng (sinica or japonica) types are cultivated (roughly 40,000 ha in 1980) because the yield advantage or heterosis is less than for the hsien types. This may be due to lower genetic diversity among keng germ plasm.

The hybrid varieties are considered to be definitely higher yielding than nonhybrid varieties; increases of 20% to 30% are commonly mentioned by the Chinese, and trials in other nations have confirmed the yield advantages.

Despite relatively wide adoption of hybrids in China, there are several biological and economic problems that constrain their use. Some could be solved through the selection and breeding of appropriate parental lines. Problems related to seed production are most critical.

Whether hybrid rice technology is suitable for other developing countries is questionable. The accomplishments in China have stimulated renewed research at IRRI, and in Indonesia, India, and South Korea. Two commercial firms, including one doing hybrid research in Texas, have purchased international rights to the cytoplasmic sterility system used by the Chinese.

Considering the large labor inputs needed for the production of seed and the resulting high cost, the use of hybrids initially may be restricted to favored growing areas. The introduction of chemically induced male sterility or other innovations in seed production could bring the cost down and broaden the potential market. Even so, IRRI expects that it will take several more years to establish the potentials and problems of this technology for the tropics. Even then, substantial problems will remain in terms of seed distribution. Thus, the widespread use of hybrid varieties would seem to be a long way off for most developing countries.[41]

REFERENCES AND NOTES

[1] G. Hambidge and E.N. Bressman, "Better Plants and Animals-Foreword and Summary," in U.S. Department of Agriculture, *Yearbook of Agriculture, 1936* (Washington, D.C.: the Department, 1936), p. 132.

[2] *See* D.H. Perkins, *Agricultural Development in China, 1368-1968* (Chicago: Aldine, 1969), pp. 38-41; and L.T.C. Kuo, *The Technical Transformation of Agriculture in Communist China* (New York: Praeger, 1972), pp. 143-160.

[3]T.T. Chang places the point of origin of rice as central Vietnam in "The Rice Cultures," *Philosophical Transactions of the Royal Society of London* 275 (series B, 936) (July 27, 1976): 148. Also noted by T.T. Chang in "The Origin, Evolution, Cultivation, Dissemination, and Diversification of Asian and African Rices," *Euphytica* 25 (1976):43S.

[4]P. Ho, "Early Ripening Rice in Chinese History," *The Economic History Review* 9 (December 1956): 200-216. Rice in northern China is discussed by Ho in "The Loess and the Origin of Chinese Agriculture," *American Historical Review* 75 (October 1969): 19-26.

[5]K. Arashi, *Kinsei Inasaku Gijitsu Shi [History of Modern Rice Technology]* (Tokyo: Nosangyoson Bunka Kyokai, 1975), pp. 322-352, 366-384. Summary note provided by I. Watanabe, IRRI, April 1984. Also cited by P. Francks, *Technology and Agricultural Development in Pre-War Japan* (New Haven, Conn.: Yale University Press, 1984), pp. 61, 77. Although short statured, Shinriki probably was not a semidwarf. Fertilizer levels during its time were relatively modest compared to today. When grown with high fertilizer levels in the 1960s, Shinriki averaged 85 cm in height, compared with a height of 65 cm for newer varieties.

Statistics on the area planted with Shinriki are provided by Y. Hayami and S. Yamada in "Agricultural Productivity at the Beginning of Industrialization," in *Agricultural and Economic Growth: Japan's Experience,* ed. K. Ohkawa, B.F. Johnston, and H. Kaneda (Princeton, N.J.: Princeton University Press, 1970), pp. 130-133. Also noted in Y. Hayami and V.W. Ruttan, *Agricultural Development: An International Perspective* (Baltimore, Md.: The Johns Hopkins Press, 1971), pp. 157, 350-351; and Franks, op. cit *(see* footnote 5), pp. 62, 77-79.

[7]C. Chambliss and J.M. Jenkins, *Some New Varieties of Rice,* Bulletin No. 1127 (Washington, D.C.: U.S. Department of Agriculture, 1923), pp. 14-17 (quotation on p. 15); J.W. Jones, "Improvement in Rice," in U.S. Department of Agriculture, *Yearbook of Agriculture, 1936* (Washington, D.C.: the Department, 1936), p. 442.

[8] N. Parthasarathy, for example, notes that Shinriki was crossed with D17-88 in Burma in 1928. (N. Parthasarathy, "Rice Breeding in Tropical Asia Up to 1960," in International Rice Research Institute, *Rice Breeding,* (Los Baños, Philippines: IRRI, 1972), p. 11.

[9] T. Matsuo, *Rice and Rice Cultivation in Japan* (Tokyo: Institute of Asian Economic Affairs, 1961), pp. 20-27, 91-93; Hayami and Yamada, op. cit. *(see* footnote 6), pp. 130, 131.

[10] C.H. Huang, W.L. Chang, and T.T. Chang, "Ponlai Varieties and Taichung Native 1," in International Rice Research Institute, *Rice Breeding* (Los Baiios, Philippines: IRRI, 1972), pp. 31-34. For further discussion, *see* the following articles in *Technical Change in Asian Agriculture,* ed. R.T Shand (Canberra, Australia: Australian National University Press, 1973): C. Carr and R.H. Meyers, "The Agricultural Transformation of Taiwan: The Case of Ponlai Rice, 1922-42," pp. 29-50 and Y. Hayami, "Development and Diffusion of High-Yielding Rice Varieties in Japan, Korea, and Taiwan, 1890-1940," pp. 18-20.

[11] Huang et al., loc. cit. *(see* footnote 10); letter from T.T. Chang, IRRI, May 1984.

[12] This section is based on the following references: *Risicolture* 38(12) (1948):281; R. Piacco, *Le Razze di Riso Coltivate in Italia,* Quaderno No. 5 (Milan: Ente Nazionale Risi, 1955), pp. 6, 8, 9, 22; G. Baldi, G. Fossati, and M. Moletti, *Varietá di Riso in Italia* (Milan: Ente Nazionale Risi, 1981); and letter from G. Baldi, Ente Nazionale Risi, Mortara, Italy, June 1984.

[13] Parthasarathy, op. cit. *(see* footnote 8), pp. 8, 15, 16, 29. In a subsequent letter pertaining to semidwarf mutants, Parthasarathy notes that two lines were isolated in the X3 (F_3) generation of irradiated GEB in 1935. Unfortunately, due to dislocations of the researchers resulting from study abroad and reassignment and a lack of interest by the government in raising yields (it was cheaper at the time to import rice from Burma), the activity was not given much attention, and the seed was lost or not preserved. These lines might have been of considerable value later when greater interest was placed on increasing yields. (Letter from Parthasarathy, Madras, India, August 1984).

[14] Based on Parthasarathy, op. cit. *(see* footnote 8), pp. 10-11, 21 and G. Hambidge, *The Story of FAO* (New York: Van Nostrand, 1955), pp. 145-148. Background on the government's program to introduce ADT-27 is provided in S.J. Heginbotham, *Cultures in Conflict: The Four Faces of Indian Bureaucracy* (New York:

Columbia University Press, 1975), pp. 77-155, 175-186.

[15]Mahsuri is also known as Ponni in India and was a parent of PY 1 Pundurai Ponni released in 1979 (N. Van Luat, B. Ba Bong, H. Huu Duoc, and N. Ny, "Mashuri for Cultivation in the Cou Long Delta of Vietnam," *International Rice Research Newsletter* (August 1984):4-5.

[16]This section is, except as noted, based on Huang et al., op. cit. *(see* footnote 10), pp. 39-45; and a letter from T.T. Chang, IRRI, May 1984, citing C-S. Huang, "Evolution of Rice Cultures in Taiwan," PID-SC-57 (Taipei: Joint Commission on Rural Reconstruction, 1970). Also, Y-K. Lu, "The Origin of Semi-Dwarf Genes," *International Rice Research Newsletter* (April 1979):9.

[17]T.S. Miu, ed., A *Photographic Monograph of Rice Varieties of Taiwan,* Special Publication No. 2 (Taipei, Taiwan: Taiwan Agricultural Research Institute, 1959), p. 67.

[18]Lu, loc. cit. (see footnote 16); C-H. Hu, "Evaluation of Breeding Semi-Dwarf Rice by Induced Mutation and Hybridization," *Euphytica* 22 (1973):566.

[19]Huang et al., op. cit. *(see* footnote 10), p. 43. It is not certain whether TN-1 was in the group of varieties that was provided to the Missouri team.

[20]Details on the introduction of TN-1 in India are provided in R.F. Chandler, *An Adventure in Applied Science: A History of the International Rice Research Institute* (Los Baños, Philippines: International Rice Research Institute, 1982), p. 113. Also see C.P. Streeter, A *Partnership to Improve Food Production in India* (New York: Rockefeller Foundation, 1969), p. 28.

[21]This section is, except as noted, based on J-H. Shen, "Rice Breeding in China," in International Rice Research Institute, *Rice Improvement in China and Other Asian Countries* (Los Baños, Philippines: IRRI, 1980), pp. 19-24; W.R. Coffman and S.S. Virmani, "Advances in Rice Technology in the People's Republic of China," in *Agricultural and Rural Development in China* Today, ed. R. Barker and B. Rose, Cornell International Agriculture Mimeograph 102 (Ithaca, N.Y.: Cornell University, 1983), pp. 3-6; and Y-K. Lu, "Semi-Dwarf Gene Sources of Rice in China." *International Rice Research Newsletter* (April 1979):2,3. *Also see* R. Barker, R.W. Herdt, and B.W. Rose, *The Rice Economy of Asia* (Washington, D.C.: Resources for the Future, 1985), pp. 60-61.

[22]Chandler, op.cit. *(see* footnote 20), pp. 52-54; *The International Rice Research Institute, Annual Report, 1961-1962* (Los Baños, Philippines: IRRI, n.d.), pp. 12-13; and P.R. Jennings, "Plant Type as a Rice Breeding Objective," *Crop Science* 4(1) (January/February 1964):13-15.

[23]Chandler, op. cit. (see footnote 20), pp. 104-109. When Chandler was asked who among the senior scientists should receive the coveted John Scott Award for the creation of IR8, he replied:

> The prize should be split among the three: Jennings for selecting the parents and making the cross, Beachell for identifying IR8-288-3 from among the multitude of segregating lines, and Chang for having brought to the immediate attention of IRRI breeders at the start the value of the short-statured varieties from Taiwan. . . . (Ibid., pp. 53-54.)

[24]Peta is an Indonesian variety produced from a cross of Tjina and Latisail by H. Siregar. Tjina is synonymous with China; Latisail came from Bengal. Peta had good plant type and resistance to tungro virus and green leafhopper. Other varieties produced from the same cross by Indonesian-Dutch breeders in 1940-41 included Mas, Intan, and Bengawan (Z. Harahap, H. Siregar, and B.H. Siwi, "Breeding Rice Varieties for Indonesia," in International Rice Research Institute, *Rice Breeding* [Los Baños, Philippines: IRRI, 1972], p. 142).

[25]Various characteristics of the individual IR varieties are provided in G.S. Khush, "IRRI Breeding Program and Its Worldwide Impact on Increasing Rice Production," in *Gene Manipulation in Plant Improvement,* ed. G.P. Gustafson (New York: Plenum Press, 1984), pp. 66, 69, 72; and International Rice Research Institute, *International Rice Research: 25 Years of Partnership* (Los Baños, Philippines: IRRI, 1985), pp. 51-53.

[26]International Rice Research Institute, *Parentage of IRRI Crosses IR1-IR50,000* (Los Baños, Philippines: IRRI, Genetic Evaluation and Utilization Program, 1985); International Rice Research Institute, op. cit. *(see* footnote 25), pp. 15,56-57.

[27]Arashi, op. cit. *(see* footnote 5).

[28]A comprehensive list of IRRI varieties and lines recommended in various countries and

regions is provided in Khush, op. cit. *(see* footnote 25), pp. 84-87.

[29]T.R. Hargrove, *Division and Adoption of Genetic Materials Among Rice Breeding Programs in Asia,* Research Paper Series No. 18 (Los Baños, Philippines: International Rice Research Institute, June 1978), 25 pp. (summarized by Hargrove in *Crop Science* 19[5] [September/ October 1979]:571-574; and *Bioscience* 29[12] [December 1979]:731-735). T.R. Hargrove, W.R. Coffman, and V.L. Cabanilla, *Genetic Interrelationship of Improved Rice Varieties in Asia,* Research Paper Series No. 23 (Los Baños, Philippines: International Rice Research Institute, January 1979), 34 pp. (summarized by the same authors in *Crop Science* 20[6] [November/December 1980]:721-727; and *International Rice Research Newsletter* [February 1980]:3-4).

[30]T.R. Hargrove, V.L. Cabanilla, and W.R. Coffman, *Changes in Rice Breeding in 10 Asian Countries, 1965-84; Diffusion of Genetic Materials, Breeding Objectives, and Cytoplasm,* Research Paper Series No. 111 (Los Baiios, Philippines: International Rice Research Institute, October 1985), 18 pp.

[31] J.N. Rutger, "Applications of Induced and Spontaneous Mutation in Rice Breeding and Genetics," *Advances in Agronomy* 36 (1983):385-393. Offspring of Jikkoku include Shiranui, Hoyoko, and Kokumassari; offspring of Hoyoko include Toyotama and Reiho. Reiho was released as Giza 173 in Egypt. Reimi was planted over wide areas of northern Japan; so was one of its descendants, Aluhikari. F. Kikuchi and H. Ikehashi, "Semidwarfing Genes of High-Yielding Rice Varieties in Japan," in Institute of Radiation Breeding, *Induced Mutants as Genetic Resources: Gamma-Field Symposia No. 22* (Ohmiya, Naka, Ibaraki, Japan: the Institute, July 1983), p. 18. *See* appendix A for details on California varieties.

[32]G.S. Chung and M.H. Heu, "Status of Japonica-Indica Hybridization in Korea," in International Rice Research Institute, *Innovative Approaches to Rice Breeding* (Los Baños, Philippines: IRRI, 1980), pp. 135-152.

[33]Rutger, op. cit. *(see* footnote 31), pp. 385-396.

[34]T.T. Chang, C. Zuno, A. Marciano-Romeria, and G.C. Loresto, "Semi-Dwarfs in Rice Germplasm Collections and Their Potential in Rice Breeding," IRRI, Los Baños, Philippines, October 1983, 13 pp. (unpublished paper summarized in *Rice Genetics Newsletter* [November 1984]:94-95). *Also see* T.T. Chang, "Conservation of Rice Genetic Resources; Luxury or Necessity?" *Science* 224 (April 1984):251-156.

[35]Chang et al. (op. cit. *[see* footnote 341) classified Reimi in the compound locus group (p. 6); in a subsequent section, they grouped it with nonallelic varieties (p. 9). Reimi was derived in the 1960s by gamma-ray irradiation of Fujiminori; for details, *see* Rutger, op. cit. *(see* footnote 31), p. 392. Rutger noted Hoyoku in a footnote, and it is briefly mentioned in S. Okabe, "Breeding for High-Yielding Varieties in Japan," in International Rice Research Institute, *Rice Breeding* (Los Baños, Philippines: IRRI, 1972), pp. 51-52.

[36]Kikuchi and Ikehashi, op cit. *(see* footnote 31), p. 27; F. Kikuchi, N. Itakura, H. Ikehashi, M. Yokoo, A. Nakane, and K. Maruyama, "Genetic Analysis of Semidwarfism in High-Yielding Rice Varieties in Japan," *Bulletin of the National Institute of Agricultural Sciences,* Series D (36) (March 1985):125, 143-144; H. Ikehashi and F. Kikuchi, "Genetic Analysis of Semi-Dwarfness and Their Significance for Breeding of High-Yielding Varieties in Rice," *Japan Agricultural Research Quarterly* (15) (1982):233 (also cited by Rutger, op. cit. *[see* footnote 31], p. 396).

[37]Rutger, op. cit. *see* footnote 31, pp. 389-392, 396.

[38]Rutger (op. cit. [*see* footnote 31], p. 396) suggests that these genes should preferably be "on a different chromosome or at least a location not closely limited to the DGWG locus . . . in linkage group three."

[39]The principal source for this section is Coffman and Virmani, op. cit. *(see* footnote 21), pp. 7-23. *Also see* Shen, op. cit. *(see* footnote 21), pp. 26-27; L. Shih-Cheng and Y. Loung-Ping, "Hybrid Rice Breeding in China," in International Rice Research Institute, *Innovative Approaches to Rice Breeding* (Los Baiios, Philippines: IRRI, 1980), pp. 35-51; S.S. Virmani and I.B. Edwards, "Hybrid Rice and Wheat," *Advances in Agronomy* 36 (1983):383-413; and B. Stone, "Trends in Chinese Hybrid Rice Production," International Food Policy Research Institute, Washington, D.C., April 1984,9 pp.

[40]IR58 contains a Chinese ancestor, Kwang Chang-ai—one of the first varieties provided by the International Rice Research Institute by the Chinese.

[41] Based on Coffman and Virmani, op. cit. (*see* footnote 21), p. 23; a letter from S.S. Virmani, rice breeder, IRRI, January 1984; and telephone conversations with representatives of the two firms. Indonesia, India, and South Korea are conducting their research in collaboration with IRRI. IRRI's research on hybrids is regularly summarized in its annual reports.

3. RICE VARIETIES AND AREA

Rice is the surest and most regular of great crops. It is probably the staple food of the greatest number of people. And men live on it more exclusively than upon any other food. The number of cultivated varieties probably exceeds that of all other grains combined.

—Edward Bingham Copeland, 1924[1]

Rice, a ubiquitous crop, grows to some extent in virtually every developing country, particularly in the tropics. Geographically, most of the rice area in the developing world is found in Asia (figure 3.1). In 1983, according to USDA statistics, about 90.9% of the reported developing-country rice area, including China, was in East and South Asia. Latin America followed with 5.5%; Africa, 2.8%; and the Near East, 0.8%. [2]

For the developing world as a whole, about 52% of the rice area is irrigated and about 48% is rainfed. Nearly 88% of the irrigated land is irrigated only in the wet season, while the remainder is irrigated during the dry season. The largest proportion of rainfed rice (45%) is grown in shallow water, followed by dryland, deepwater, and floating rice.[3]

Most of the HYRVs are semidwarfs (80-120 cm), but some are intermediate in height (121-140 cm), and a few are tall (more than 140 cm). Specifications of the precise height levels for each category vary by geographic region. The heights given here might be regarded as being on the tall side in some areas.

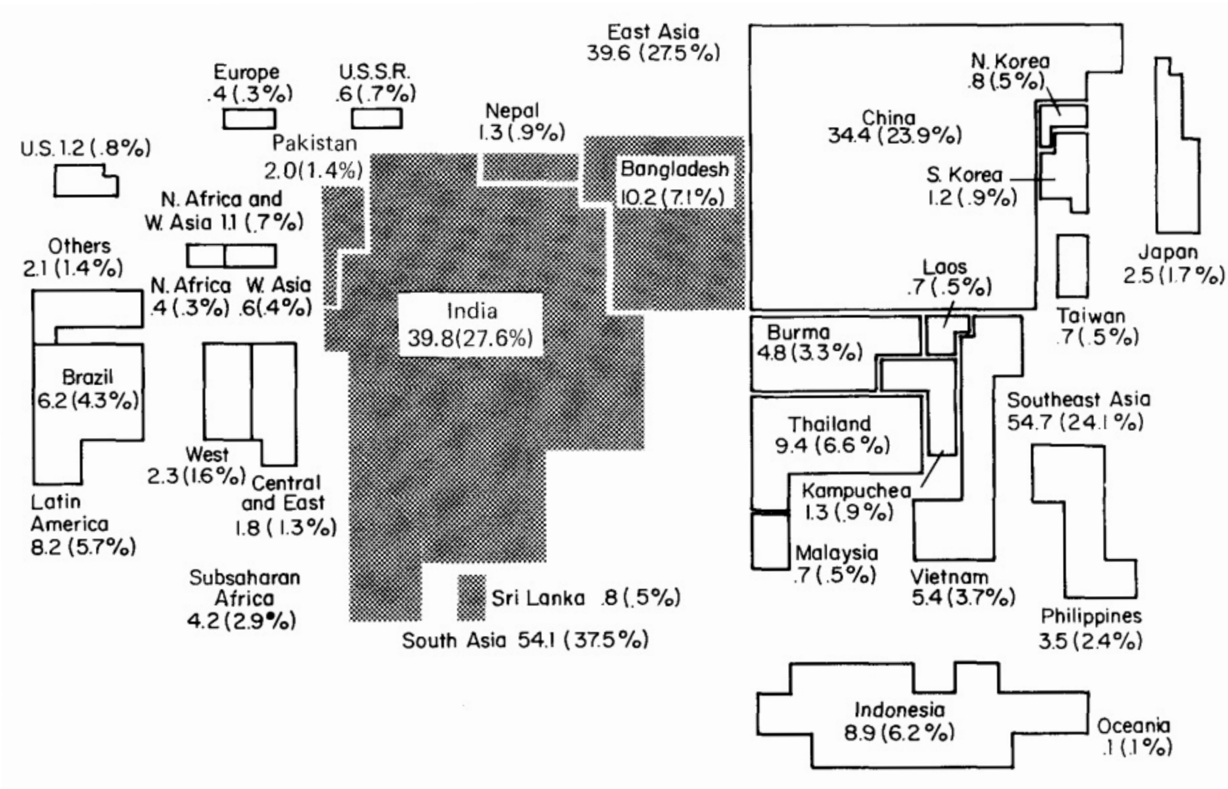
Intermediate height varieties are, compared to semidwarfs, receiving increased attention in some Asian breeding programs. The principal reason for this, particularly in southern India and Sri Lanka, is the higher yield of straw, which is used for cattle fodder and fuel. Other advantages sometimes cited for the taller varieties include greater ability to compete with weeds and lower fertilizer requirements per unit of land (though not per unit of product). While the importance of various characteristics varies from region to region, there is a need for high-yielding varieties of various heights.

The International Rice Testing Program (IRTP), operated by IRRI in cooperation with national rice testing programs, is a vital force in distributing and testing improved rice varieties. About two-thirds of all 1983 entries in IRTP nurseries came from national programs; the rest came from IRRI.[4] A 1984 survey of Asian rice breeders revealed that IRTP was the source of 70% of all introduced parents.[5] The same year, rice scientists in more than 60 countries participated in the program.

This chapter summarizes information on the development and adoption of HYRVs in 67 developing countries in 4 geographic regions.

SOUTH AND EAST ASIA

More than 90% of the developing world's rice area is found in South and East Asia. The two leading countries, in area, are India (with about 27.7% of the developing country total in 1983)



Source: International Rice Research Institute.

Figure 3.1. Land devoted to rice, 1978-80 average (expressed as millions of hectares and proportion of total area).

and China (with about 22.4%). Of the 10 next leading rice-producing countries, 8 are in Asia: Bangladesh (7.1%), Thailand (6.5%), Indonesia (6.2%), Burma (3.4%), the Philippines (2.1%), Pakistan (1.4%), Cambodia (1.2%), and Nepal (0.8%).[6] About 56% of the Asian rice area is irrigated; the balance is rainfed.[7]

Efforts to improve rice production have been under way in many Asian countries for years. As might be expected, the earliest and greatest application of the HYRVs was in this region. Several of the nations are communist. Information is readily available for China, but not for Cambodia, Laos, Vietnam, and North Korea.

Statistical coverage of the use of HYRVs in the noncommunist Asian nations has been the most complete in the developing world. In compiling tables, liberal use was made of data previously reported for an earlier period[8] and data reported in a recent IRRI publication by Herdt and Capule.[9]

Bangladesh

Rice improvement has been conducted in what is now Bangladesh since 1911, when an economic botanist was appointed to do rice selection work at the Dhaka Research Station in East Bengal, India.[10]

In 1965 a set of 303 IRRI varieties and lines was brought to Bangladesh for an accelerated rice production program sponsored by the Ford Foundation. By 1972 the following varieties had been identified and recommended for farm production: IR5, IR8, IR20 (Irrisail), Chandina (IR532-1-176), Mala (IR272-4-1-2), and Purbachi (Chen-chu-ai from China).[11] Chandina and Mala subsequently were named BR1 and BR2.

Table 3.1. Imports of high-yielding rice variety seed, Bangladesh, 1966-67 to 1975-76

Crop year	Quantity (t)	Variety and notes
1966-67	10	
1967-68	1,500	IR8 planted during *boro* season
1969-70	4.4	
1970-71	1,800	IR20 from commercial source in Philippines
1971-72	701	470 t of Jaya and 231 t of IR8 from India
1972-73	7,000	IR20 from the Philippines
1973-74	5,200	IR20 from the Philippines
1975-76	1,100	IR20 from India

Source: D.G. Dalrymple, *Development and Spread of High-Yielding Varieties of Wheat and Rice in the Less Developed Nations,* FAER No. 95 (Washington, D.C.: U.S. Department of Agriculture, September 1978), p. 72.

During the early 1970s, massive quantities of IR20 were imported from the Philippines and, to a lesser extent, from India. Jaya also was imported from India (table 3.1).

The Bangladesh Rice Research Institute (BRRI) was established in 1970 to develop varieties better suited to local growing conditions. BRRI introduced, in addition to BR1 and BR2: BR3. Biplab; BR4, Brrisail; BR6, IR28; BR7, BRRI Balam (IR2053-87-3-1); BR8, Asha; BR9, Sufala; BR10, Progati; and BR11, Mukta. Varieties scheduled for release in 1983 were: BR12, Monyna; BR14, Gazi; BR15, Mohini (IR2071-199-3-6); and BR16, Shahibalam (IR2793-80-1). BR5 and BR13 apparently have not been released. All releases selected from an IRRI line have IRRI ancestry. BR3 was reported in 1983 as one of the most popular varieties. [12]Pajam (Mahsuri) also is widely grown.

Rice is grown in three distinct seasons in Bangladesh: *aus* (spring-summer), *aman* (summer-fall), and *boro* (winter-spring). As of 1982-83, the HYRV area was distributed as follows: *aus,* 18.1%; *aman,* 40.8%; and *boro,* 41.4%. Since the mid-l970s, the relative importance of the *aus* HYRV area has declined, while that of the *aman* has increased. Average HYRV yields in 1981-82 were: *aus,* 2.15 t/ha; *aman,* 1.76 t/ha; and *boro,* 2.81 t/ha. HYRV yields from 1979-80 to 1982-83 were 2.2 times higher than the yields of local varieties. During 1981-82, the HYRVs represented 37.4% of total rice production (compared to 22.2% of total area).[13]

Table 3.2. Area of high-yielding rice varieties, Bangladesh

Crop year	HYRV area (ha)[a]	Proportion of total area (%)
1966-67	200	–
1967-68	63,100	0.6
1968-69	152,200	1.6
1969-70	263,800	2.6
1970-71	460,100	4.6
1971-72	624,000	6.7
1972-73	1,064,800	11.1
1973-74	1,548,300	15.7
1974-75	1,443,500	14.7
1975-76	1,551,900	15.0
1976-77	1,329,400	13.5
1977-78	1,526,100	15.2
1978-79	1,768,400	17.5
1979-80	1,998,000	19.7
1980-81	2,193,900	21.3
1981-82	2,325,100	22.2
1982-83	2,628,500	24.8

–=Negligible.

[a]Including Pajam (Mahsuri), which has been recorded separately in the official statistics.

Sources: 1966-67: D.G. Dalrymple, *Development and Spread of High-Yielding Varieties of Wheat and Rice in the Less Developed Nations,* FAER Report No. 95 (Washington, D.C.: U.S. Department of Agriculture, September 1978), p. 72. 1967-68 to 1981-82: R.W. Herdt and C. Capule, *Adoption, Spread and Production Impact of Modern Rice Varieties in Asia* (Los Baños, Philippines: International Rice Research Institute, 1983), p. 46. 1982-83: *Monthly Statistical Bulletin of Bangladesh* (Dhaka, Bangladesh: Bangladesh Bureau of Statistics, July 1984), p. 40.

The area of HYRVs in Bangladesh has grown gradually since the mid-1960s (table 3.2). A plateau was achieved during the mid-I970s, but expansion resumed in 1978-79 and has continued through 1983. Much of the increased area since 1977-78 came from the increasing practice of leaving the floating rice area fallow during the *aman* season and then planting HYRVs during the *boro* season after the water recedes. There are some environmental restraints on HYRV area expansion. Chief among these are a large area that requires deepwater and intermediate deepwater rice cultivation and a large shallow-water rainfed area. Present varieties are not well suited to these regions.

Burma

The first rice experiment station was opened in Mandalay in 1907 to cover Upper Burma; another was opened in 1914 in Hmawbi to cover Lower Burma. Subsequently three more stations were established. In 1932 the breeding work at Hmawbi was strengthened by a grant from the Indian Council of Agricultural Research. (Burma was a province of India until 1937.) Twenty-seven improved varieties were distributed by 1932.[14]

HYRVs

During the 1960s, Burma had relatively few links with outside rice research organizations. Even so, seed of IR8 was first imported from IRRI in 1966; seed of IR5 was first imported in 1968. C4-63 also was imported from the Philippines. As of 1971, IR20, IR22, IR24, and C4-113 were being tested. In 1972 Burma increased its contacts with IRRI and other groups.[15]

The varietal history then began to get more complex, partly because of the increased numbers of varieties and partly because the imported varieties were given local names, which were often transliterated.[16] The first HYRVs to be planted extensively in the mid-1960s were: Yagyaw-1 (IR8), Yagyaw-2 (IRS), Si-lay (C4-63), and Ngwetow (an improved local variety). In 1972, four more HYRVs were released: Shwe-war-hnan (IR20), Lone-thwe-shwe-war (IR22), Shwe-war-yin (IR24), and Manawhari (Mahsuri).[17] Shwe-war-tun (Shwe-war-htun), a mutant of IR5, was approved for cultivation in 1975 and was first grown in 1976-77.[18]

Additional varieties were subsequently released. One group came from the International Rice Testing Program (table 3.3). Among other releases, Shwe-ta-soak has proved to be the most important. One report indicates that it was selected from a local variety in a farmer's field in Rangoon Division and first grown during the 1977-78 season. Pho-kaw-gyi is another local variety. Manaw-thukha is Mahsuri-M. Kyaw-ze-ya came from a cross of IR5 and Aungzeya, and

Table 3.3. Varieties from the International Rice Testing Program released in Burma, 1977 to 1981

Local name	Year	IRTP designation	Source	Use
Shwe-war-lay	1977	IR28	IRRI	Lowland
Sin-shwe-thwe	1978	IR34	IRRI	Lowland
Sin-thiri	1978	B90-2	Sri Lanka	Lowland
Sin-thein-gi	1978	BR4 (Brrisail)	Bangladesh	Lowland
Sein-lay	1979	C4-113	Philippines	Lowland
Pale-thwe	1979	Pelita 1-1	Indonesia	Lowland
Shwe-thwe-lay	1979	IR751-592	IRRI	Lowland
Yenet-1	1980	BKN6986-108-2	Thailand/IRRI	Deepwater
Yenet-2	1981	BKN6986-167	Thailand/IRRI	Deepwater
Yar-1	1981	C22	Philippines	Upland
Yar-2	1981	Kn 96	Indonesia	Upland
Yar-3	1981	Kn 117	Indonesia	Upland
Yar-4	1981	LG 240	Indonesia	Upland
Yar-5	1981	IR1529-680-3-2	IRRI	Upland

Source: International Rice Testing Program, IRRI.

Sein-ta-lay (Sim-ta-lay) from a cross of C4-113 and Ye-baw-sein. Shwe-thwe-tun (Shwe-thwe-hton) is an IR24 mutant.[19]

Area Planted

Changes in the overall area planted with HYRVs from 1967-68 to 1983-84 are indicated in table 3.4. The annual increase in area was fairly modest through 1977-78, but then it rapidly increased in 1980-81. Thereafter, expansion slowed and preliminary data suggest a decline in 1983-84. The overall rice area dropped in 1982-83 and 1983-84.

The variations on the growth of HYRV area may be explained by several factors. Three constraints existed during the period through 1977-78:

- Burma had a rice surplus and prices were low;
- the semidwarf stature of the varieties was not well suited to areas subject to water depths greater than 30 cm; and
- the IRRI varieties were not well accepted by consumers.

The situation began to change when a Whole Township Rice Production Program was initiated in the mid-1970s. It involved a package of improved production practices, including two new intermediate-statured varieties with improved grain quality (Shwe-war-htun and Sein-ta-lay), fertilizers, and instructions on transplanting, weeding, insect control, etc. The program was initiated on a trial basis in 1975-76, established on a more formal basis in two townships in 1977-78, extended to 43 townships in 1979-80, and it reached 82 townships by 1982-83.[20]

Of the HYRVs initially introduced in Burma, only a few are still widely planted. Preliminary calculations for the 1983-84 season suggest that the total HYRV area was largely divided between three varieties—Shwe-war-tun (IR5 mutant), 38.7%; Shwe-ta-soak (local), 22.7%; and Manawhari (Mahsuri), 21.1%. Smaller areas were devoted to Yagyaw-2 (IR5), 3.4%; Shwe-ta-lay (local cross of C4-113), 2.6%; Si-lay (C4-63), 2.6%; Ngwetoe (local), 2.3%; Pho-kaw-gui (local) 1.1%; Shwe-war-yin (IR24), 0.2%; Shwe-war-hnan (IR20) trace; and other, 5.4%.[21]

Not much is known about either Ngwetoe or Shuwe-ta-soke. The Burmese government does not always include Ngwetoe in its HYRV category,[22] and IRRI holdings of Shwe-ta-soke are tall.[23] However, both varieties seem to qualify as HYRVs based on yield. Between 1974 and 1981, Ngwetoe yields averaged 3.8% higher than Manawhari. Shwe-ta-soke was even more impressive, with the second highest yields in the HYRV group during 1977-81.

Burma's HYRV program has expanded well beyond irrigated zones. Outside central Burma, rainfall is sufficient for one crop in the monsoon

Table 3.4. Area of high-yielding rice varieties in Burma, 1967-68 to 1983-84

Crop year	HYRV area (ha)	Proportion of total area (%)
1967-68	3,400	0.1
1968-69	166,900	3.3
1969-70	134,000	2.7
1970-71	183,000	3.7
1971-72	177,600	3.6
1972-73	192,100	4.0
1973-74	237,500	4.7
1974-75	316,000	6.1
1975-76	432,500	8.3
1976-77	463,400	9.1
1977-78	521,700	10.2
1978-79	822,900	15.7
1979-80	1,342,100	26.7
1980-81	2,210,000	43.1
1981-82	2,314,600	45.4
1982-83	2,501,700	51.2
1983-84[a]	2,370,100	49.1

[a] Preliminary data.

Sources: 1967-68 to 1981-82: Burma, Ministry of Agriculture and Forests, "Rice Production in Burma, 1962/63 to 1980/81," (Rangoon, Burma: Extension Division, the Ministry, February 1982), p. 9. 1982-83: K. Zin, *Burma and CGIAR Centers: A Study of Their Collaboration in Agricultural Research,* Study Paper 20 (Washington, D.C.: Consultative Group on International Agricultural Research, 1986). (Zin also reports data for the full period that agree with above source.) 1983-84: Department of State telegram 0395 from Rangoon, January 22, 1985.

season. In 1980-81 Burma had about 870,000 ha of irrigated rice area; the total area planted with HYRVs that year was 2.5 times as much. Despite the expansion of the HYRVs into the rainfed area, HYRV yields increased through 1980-81.[24] This is an exceptional accomplishment.

Cambodia

Little information is available about HYRVs in Cambodia. In previous editions of this report, it was noted that 35 t of IR20 seed was imported from Vietnam in July 1973, and 10 t in January 1975. Some additional information is now available, mostly from international relief efforts in the early 1980s.

A book published in 1976, describing agricultural development in Cambodia after April 1975, cites Phnom Penh domestic radio service as describing the use of several HYRVs. The variety Pram p. Taek was reported to yield up to 6.5 t/ha where water control was adequate and from 3 to 4.5 t/ha in areas of poorer water control. Trials with two other varieties, Ramoun Sar and Champous Kok, were reported.[25]

Bits of information concerning the early 1980s are provided in a series of assessments by the Office for Special Relief Operations[26] and in a publication by Oxfam America, a private voluntary organization.[27] The FAO reports indicated that during the 1980 wet season, IR36, RD 1, and RD 7 (Thai varieties) were grown. IR36 had the highest yields. It was recommended that IR36 be grown on 33,776 ha during the 1981 wet season with cultivation concentrated on the most fertile land free from flooding. This would require 2,700 t of seed (the figure later was given as 4,000 t), which seemed to be in hand or on order. Unfortunately, it was not confirmed whether the area was actually planted. The Oxfam report states that 66,000 ha of IR36 were planted in the 1982 wet season.

FAO assessments noted that Cambodian villagers preferred the IRRI varieties (presumably principally IR36) over the RD varieties from Thailand. But it was also noted that the initial response of farmers to IR36 was cautious and that local varieties were preferred because of their cooking and eating qualities. FAO cautioned that interest in IR36 might wane if fertilizer was not made available.

A few further fragments of information come from IRRI, which notes that more than 1,000 t of seed of IR36 were sent to Cambodia and some to Laos by various aid agencies during 1980 and 1981. The quantity of seed could not have come from IRRI but must have been obtained from Philippine seed growers. In March 1981 IRRI provided an Oxfam representative with 5 kg each of IR38, IR48, IR52, and IR54 for use in Cambodia. In March 1981 IRRI also supplied samples of 35 traditional varieties of seeds to an Oxfam representative to take to Cambodia to replace lost stocks. In March 1982 samples of another 103 traditional varieties were provided.[28]

It has subsequently been reported that about 100,000 ha were planted with IR36 in the dry season and an undisclosed area with IR42 in the wet season.[29]

China*

China, the world's largest rice producer, has the longest history of rice improvement. As in other countries, much improvement occurred as farmers simply selected and used improved varieties.

Both indica (hsien) and japonica (sinica or keng) rices are found in China. Indicas have traditionally been grown in southern China, and japonicas in Northern China. Both are grown in the area bordering the Yangtze River in east China.

Irrigation and use of fertilizers for rice have long been practiced in China. Traditional fertilizers are organic products, such as compost, green manures, oil meals, fish cakes, and night soil. Chemical fertilizers, which provide a much sharper yield boost, began to be widely adopted in the 1960s—about the same time HYRVs were introduced. The combination of irrigation, chemical fertilizers, and HYRVs have had a profound effect on Chinese rice production.

Development of HYRVs

China started the development of semidwarf varieties in the mid- and late 1950s (figure 2.1). There are numerous offspring of these varieties, mostly indica varieties developed and grown principally for the first crop in southern China.[30]

There were related developments in short varieties. In southern China, beginning in 1963, second-crop indica varieties were developed by

*See also Taiwan.

crossing them with first-crop varieties. Guang-qui-ai (Kwuang-chui-ai) was the first. Short-statured second-crop japonica varieties were introduced in 1957. The first was Nong-ken 58 (a selection from a Japanese variety); related varieties were Nong-hu 6 (80-90 cm), Hu-xuan 19, and Wu-nong-zao (the latter two a little more than 80 cm tall). In northern China, short-statured japonica varieties were developed and introduced. Principal varieties are Ji-keng 60 and Jing-yue 1.[31]

Mutation breeding, widely used in China, produced some of the first semidwarfs in the mid-1960s. Two recently developed varieties with short height (presumably semidwarfs) are Nanjing No. 34, grown on about 220,000 ha in 1981, and Dongting No. 3, grown on about 120,000 ha in 1982.[32] The total area planted with such varieties is not known.

Hybrid rice in China was grown on about 8.2 million ha in 1984, nearly 25% of the total area (table 3.5). As shorter season hybrid varieties are developed, their use is expected to expand. Substantial yield advantages of hybrids over other semidwarfs are reported, but the system of producing hybrid seed remains complicated and expensive. Emphasis has been on development of varieties with early maturity and high yield potential, with less attention to disease and insect resistance.

Table 3.5. Area sown with hybrid rice in China, 1976-84

Year	Hybrid area (ha)	Proportion of total area (%)
1976	139,000	0.4
1977	2,133,000	6.0
1978	4,333,000	12.6
1979	5,067,000	15.0
1980	5,867,000[a]	17.3
1981	5,140,000	15.4
1982	5,600,000	16.8
1983	6,670,000[b]	20.2
1984	8,200,000	24.9

[a]Reported as 4,930,000 ha by Yuan (see below).

[b]Reported as 6,750,000 ha by Yuan (see below).

Sources: 1976-1982: B. Stone, "Trends in Chinese Hybrid Rice Production" (Washington, D.C.: International Food Policy Research Institute, April 1984), p. 7. 1983-1984: L.P. Yuan, "Hybrid Rice in China" (International Rice Research Conference, IRRI, June 1985), p. 22. (Yuan is Director, Hybrid Rice Research Institute, Hunan Academy of Agricultural Sciences.)

Area Planted With HYRVs

Large-scale dissemination of HYRVs began in 1964. By 1965 a total of about 4.3 million ha, 13% of China's total rice area, were planted. The main varieties were Nung-ken 58, 26%; Chen-chu-ai, 17%; and Ai-chia-nan-te, 17%. Adoption of these varieties (with Chang-nan-ai substituting for Numg-ken 58) was particularly rapid in Guangdong Province. By 1965, about 1.5 million ha were sown, accounting for two-thirds of the early crop. In Kiangsu Province, about 0.63 million ha were planted with Nung-ken in 1965. HYRVs were also heavily planted in Fujian and Hunan Provinces.[33] Record rice yields in 1960 were attributed to the introduction of new varieties.

By 1970 semidwarf varieties were used extensively in all early rice-producing provinces. (The area of early rice accounts for about one-quarter of the total rice output in China.) In late 1974 the Chinese Academy of Agricultural and Forestry Sciences indicated that 80% of the rice grown in south China was short statured and stiff-strawed.[34]

Coffman and Virmani suggest that semidwarfs covered about 90% of China's total rice growing area, or nearly 32 million ha by 1974.[35] Just how much the proportion has gone up since is uncertain. Rice breeders who recently visited China reported that virtually all of the rice was short statured; fields of taller rice were unusual except for some japonica varieties in the north.[36] The breeders noted that taller varieties may be more prevalent in some of the more remote areas, which they did not visit. On balance, it would seem likely that HYRVs occupied about 95% of the total rice area in China in 1985.

Role Played by IRRI Varieties

For some years it was questionable whether IRRI varieties played any direct role in Chinese production.[37] The first official Chinese comment was made to the American Plant Science Studies Delegation, which visited China in 1974. At that time the Guangdong Academy of Agricultural Science revealed that IR8 came into that province in 1967 and was planted in 1968. But IR8's growing season proved too long to fit the multiple-cropping patterns of the area, and it was not sufficiently cold tolerant or resistant to bacterial leaf blight. IR8 also was said to have been introduced in Shansi Province in 1971, but again the growing season proved to be too long. Other early IRRI varieties tested in Guangdong Province included IR20, IR22, and IR26. None however, fit the growing season requirements.[38] Similar IRRI variety results were obtained in Nanjing and Shanghai.

There were several different sources of the IRRI varieties used in China. In the 1960s and early 1970s some probably came through Vietnam and some from South Asia. in late November 1973, Philippines President Marcos presented a ton of IR20 and a sack of IR26 to a visiting Chinese trade delegation. The gift reportedly was in response to a request from Premier Chou En-lai. The delegation also visited IRRI.

The following August, then IRRI Director-General Nyle C. Brady received samples of Chinese rices while visiting China. In March and April 1976 teams of Chinese scientists and administrators visited IRRI, and teams of IRRI scientists went to China in October 1976 and October 1979.[39]

Between 1971 and 1981, China received 3,335 varieties and advanced lines from IRRI. Today the Chinese have all the IRRI varieties and elite breeding lines. Those used most widely are IR8, IR24, IR26, IR661 selection and IR1529-680-3 (Xiao jia-huo). Their maximum area in aggregate (years not specified) was about 1.5 million ha.[40]

Because the IRRI varieties have relatively high insect and disease resistance as well as other desirable characteristics, they have been used as parents in breeding programs, especially for hybrid varieties. Nearly all the Chinese hybrid varieties use an IRRI variety, or a variety with IRRI ancestry, as the restorer or male parent.

The IRRI varieties and lines also have been used in conventional and mutation breeding programs. One of the first significant crosses may have been between IR8 and Xiang-ai-zho 4, which produced Xiang-ai-zao, grown on more than 67,000 ha in 1978. In 1980, eight principal HYRVs (four series) had one IRRI parent. IR24 was a parent of Nan-you 2, Shan-you 2, and Ai-you 2; IR661 (a sister of IR24) was a parent of Nan-you 3, Shan-you 3, Ai-you 3, and Wei-you 3; and IR26 was a parent of Wei-you 6. An IRRI line (IR1561-228-3-3) was named as 32 Xuan 5 in Hunan Province in 1980. Yuang-feng-zao was developed by irradiation of IR8 and is grown in about 1.2 million ha along the Yangtze River.[41] The total area planted with such offspring is, however, not known.

India

Rice breeding work in India began early in the 20th century at the Coimbatore station in Madras. Emphasis was on pure-line selection, typical of that period. Starting in 1929, the Indian Council of Agricultural Research sponsored and aided rice breeding projects in the states.[42] The area planted with improved varieties and their proportion of the total area was as follows: 1920-21, 52,590 ha, 0.2% of the total area; 1928-29, 251,200 ha, 0.9%; 1930-31, nearly 526,300 ha, 1.6%; and 1937-38, 1,496,800 ha, 5.3%.[43] By 1939 the proportion had reached 6%, but the Rice Committee of the Imperial Council of Agricultural Research expressed disappointment in the rate of growth.[44]

The pace of development increased as institutional changes were made following World War 11. In 1946 India's Central Rice Research Institute (CRRI) was established at Cuttack. CRRI cooperated with the International Rice Commission in 1950 in an indica-japonica crossing program, which produced ADT 27 (and Malinja and Mahsuri in Malaysia). In the mid-1950s, CRRI was involved in a program to develop nonlodging, stiff-strawed japonica varieties. One product was CR 1014. During the mid-1960s, the introduction of the improved plant type concept and the establishment of the All India Coordinated Rice Improvement Project (AICRIP) provided new horizons and organizational arrangements for rice improvement.[45]

Semidwarfs

The introduction of semidwarf varieties proceeded in two stages. The first stage involved Taichung Native 1 (TN-1). In 1964 an Indian official visiting IRRI was given 2 kg of TN-1. It was planted in India with good results. In early 1965, the Ford Foundation purchased 1 t of TN-1 from IRRI. In October 1965, 5 t were obtained from Taiwan, and in 1966 the Taiwan government gave India 60 t of TN-1.

The second stage involved IR8. By 1966 IR8 and other IRRI selections were being tested in India. The trials showed that the IRRI lines were generally more resistant to diseases than TN-1. In December 1966 the Ford Foundation bought 10 t of IR8 for India; in February 1967, the Rockefeller Foundation bought another 10 t. Smaller quantities of other IRRI varieties and lines were shipped over the next 3 years.[46]

Although TN-1 and IR8 produced high yields, they had some drawbacks in Indian rice fields—mainly susceptibility to diseases and insects and poor cooking quality. The TN-1 and IR8 plant type needed to be more fully tailored to the wide range of rice environments in India.

In response, a crash breeding program coordinated by AICRP was established. Emphasis was placed first on yield, and then on quality and resistance to insects and diseases. Early maturity also was considered important. By 1979, 142 improved varieties had been released with 20 designated for nationwide cultivation (table 3.6). Of the 20 varieties, 12 had TN-1 for a parent and 5 had IR8 for a parent.[47] By 1983, 221 varieties had been released. Some represented selections from IRRI crosses, particularly at the state level.[48]

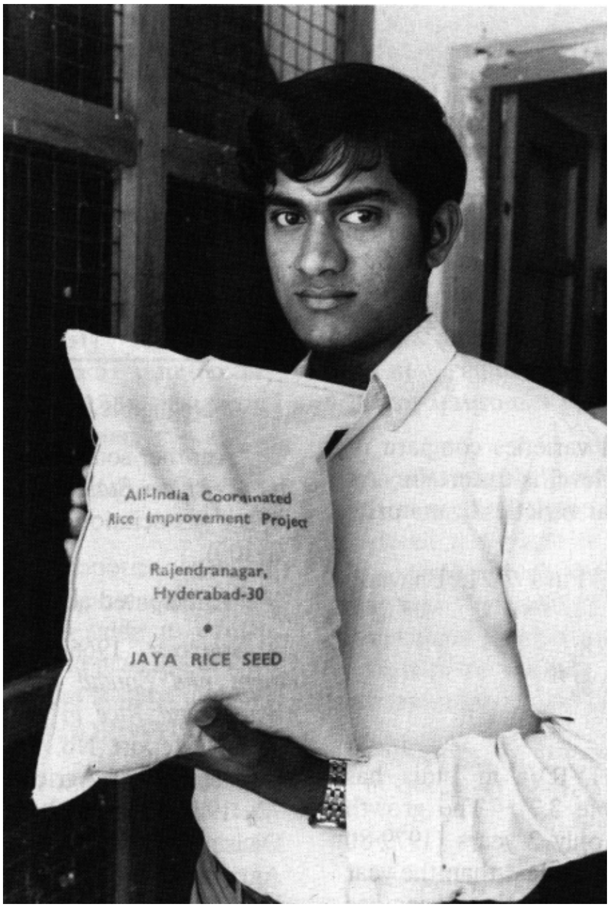


Figure 3.2. Jaya rice, a cross between TN-1 and T141, was one of the first two Indian high-yielding varieties and was released in 1968. Source: Agency for International Development.

Table 3.6. High-yielding rice varieties released for nationwide cultivation in India, 1966 to 1977

Year of release	Variety and parentage
1966	IR8
1968	Jaya (TN-l/T141), Padma (T141/TN-1)
1969	Pankaj (Peta/Tongkai Rotan), Jagannath (T141 mutant)
1970	Bala (N22/TN-1), Cauvery (TKM6/TN-1), Kanchi (TN-1/CO 29), Ratna (TKM 6/IR8), Krishna (GEB 24/TN-1), Sabarmati and Jamuna (TN-1/*5 Basmati 370), IR20, Vijaya (T90/IR8)
1973	Sona (GEB24/TN-1), Jayanti (190/IR8)
1975	Vani (IR8/CR1014)
1977	Rasi (TN-1/CO 29), Akashi (IR8/N22), Prakash (TN-1E90)

Source: H.K. Pande and R. Seetharaman, "Rice Research and Testing Program in India" in International Rice Research Institute, Rice *Improvement in China and Other Asian Nations* (Los Baños, Philippines: IRRI, 1980), pp. 40-41.

Just how the individual varieties compare in importance at the national level is uncertain. As of 1979, India's most popular varieties by maturity classification were—

- Early: Ratna, IR20, Pusa 2-21, Bhavani, Annapurna;
- Intermediate: Jaya, IR8;
- Late: Jagannath, Pankaj. [49]

Area Involved

The overall area of HYRVs in India has increased impressively (table 3.7). The growth has been quite steady—in only 2 years (1979-80 and 1982-83) has the area been less than' the year before (and in the latter crop year the percentage of total area continued to increase). The HYRVs are thought to have exceeded 50% of the total rice area in 1983-84.

The geographic distribution of HYRV area in 1983-84, according to preliminary data, was as

Table 3.7. Area of high-yielding rice varieties, India, 1965-66 to 1983-84

Crop year	HYRV area (ha)	Proportion of total area (%)
1965-66	7,100	–
1966-67	888,000	2.5
1967-68	1,785,000	4.9
1968-69	2,681,000	7.3
1969-70	4,342,000	11.5
1970-71	5,588,000	14.9
1971-72	7,412,000	19.6
1972-73	8,168,000	22.3
1973-74	9,981,000	26.1
1974-75	11,208,000	29.6
1975-76	12,443,000	31.5
1976-77	13,337,000	34.6
1977-78	16,122,000	40.0
1978-79	16,882,000	41.7
1979-80	15,991,000	40.6
1980-81	18,230,000	45.4
1981-82	19,690,000	48.4
1982-83	18,670,000[a]	49.4
1983-84	22,180,000[b]	54.1[b]

– = Negligible.

[a]Another source suggests a total of 18,840,000 ha *(Fertilizer Statistics, 1983-84* [New Delhi: Fertilizer Association of India, November 19841], p. II-100).

[b]Anticipated achievement.

Sources: 1966-67: D.G. Dalrymple, *Development and Spread of High-Yielding Varieties of Wheat and Rice in the Less Developed Nations,* FAER Report No. 95 (Washington, D.C.: US. Department of Agriculture, September 1978), p. 72. 1967-68 to 1979-80: International Economics Division, ERS/USDA, (data from Ministry of Agriculture via Fertilizer Association of India). 1980-81: *Economic Survey, 1983-84* (New Delhi: Government of India, February 27, 1984), p. 92. 1982-83 to 1983-84: *AnnualReport, 1983-84* (New Delhi: Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India), p. 81.

follows: Andhra Pradesh, 14.5%; Uttar Pradesh, 13.5%; Bihar, 9.7%; West Bengal, 9.5%; Tamil Nadu, 8.9%; Orissa, 8.0%; Madhya Pradesh, 7.0%; Punjab, 6.0%; Assam, 5.4%; Maharashtra, 4.5%; Karnataka, 4.2%; and other, 8.9%. The proportion of rice area within each of the above states planted with HYRVs in 1982-83 varied substantially, ranging from highs of 95% in Punjab and 86% in Andhra Pradesh to lows of 31% in Madhya Pradesh and 33% in Bihar.[50]

Yields of HYRVs over the 10-year period from 1968-69 to 1977-78 averaged about twice those of non-HYRV varieties. Rice yields showed sharp increases in the northern states of Jammu, Kashmir, Punjab, and Haryana; moderate increases in the southern states of Tamil Nadu, Karnataka, Andhra Pradesh and Kerala; and the least change in the eastern states of Assam and Bihar.[51]

Indonesia

Rice breeding work in Indonesia began in 1905 with the establishment of the General Agricultural Research Station at Bogor. In 1956 a rice institute was created at Bogor. Reorganizations followed, culminating in the establishment of the Central Research Institute for Food Crops (CRIFC) in 1981. A national multidisciplinary rice improvement program was organized in 1975. AID and IRRI started a cooperative program in 1972.[52]

In the early years breeders screened local materials and introduced indica varieties from other nations. This process was not very successful except for the introduction of Tinja (Tjina) from China in 1914, which spread over a substantial area. Hybridization started about 1920. By the mid-1930s about 101,000 ha of impreved varieties were grown. By 1937 impreved varieties represented 3% of Indonesia's total rice area.

From 1940 to 1965 many national improved varieties such as Bengawan, Peta, Intan, and Mas were developed and released, and some were later used in IRRI's breeding programs. Emphasis was on varieties for soils with moderate-to-low fertilily. In the early 1960s breeders began to recognize the importance of nitrogen fertilizer in increasing yields. The first moderately short-strawed variety, Dewi Ratih, was released in 1969.

From the 1960s onward, two paths were concurrently followed in varietal improvement: continued breeding of local varieties and direct use of new IRRI varieties. IRRI lines and crosses also were used in Indonesian breeding programs. IR8 and IR5, renamed PB8 and PB5, were released in 1967 and were first planted in the 1968 dry season. C4-63 also was introduced from the Philippines in 1968 and was released in 1969. In 1971 Pelita 1-1 and 1-2, selections from a cross between IR5 and Syntha, were released.

Numerous other varieties were subsequently released by the government (table 3.8). Except for Semeru, none of the varieties has exceeded the yield potential of PB5 and Pelita I-1 and I-2. The Indonesian varieties tend to be somewhat taller than the IRRI varieties. A principal advantage of the newer varieties is in disease resistance. The cooking quality of the Indonesian varieties is much more apt to be rated good than the IRRI varieties. (Among the latter, only PB54 and PB56 are considered to have good cooking quality.)

A principal factor influencing the introduction and diffusion of the new varieties in Indonesia is their resistance to the brown planthopper (BPH). BPH was first recorded in 1854 but did not become a serious problem until the early 1970s, when intensive methods of production created favorable conditions for its spread.[53] As all varieties grown in Indonesia before 1975 were susceptible, new sources of resistance had to be found. This was done, but the process had to continue because new biotypes developed. Varieties involved were:

- Resistant to biotype 1: PB26, PB28, PB30, PB34, Brantas, Serayu, Citarum, Asahan.
- Resistant to biotypes 1 and 2: PB32, PB36, PB38, Semeru, Cisadane, Cimandiri, Ayung.

Biotype 2 appeared in the mid-1970s. Biotype 3 (officially known as North Sumatra Biotype) was noted in North Sumatra in 1983. IR(PB)56 was found to be resistant to biotype 3 and was sent to Indonesia in February 1983. Two Indonesian varieties have also been found to be resistant.

Until recently BPH biotypes have tended to limit the use of the Indonesian varieties. As noted by Bernsten and his colleagues, "As most of the other [Indonesian] releases became available, a new BPH biotype appeared and forced farmers to plant a new PB variety with resistance

Figure 3.3. Irrigated rice fields in Indonesia. Source: Agency for International Development.

Table 3.8. High-yielding rice varieties released by the Indonesian government, 1971 to 1984

Variety	Year	Height (cm)	Yield potential (t/ha)	Variety	Year	Height (cm)	Yield potentia1 (t/ha)
Developed by Indonesian scientists							
Lowland				High Elevation			
Pelita I/1	1971	130	5.5	Adil	1976	101	5.0
Pelita I/2	1971	130	5.5	Makmur	1976	100	5.0
Serayu	1978		4.5	Gemar	1976	125	5.0
Asahan[a]	1978		4.5	Semeru[a]	1980	85	6.0
Brantas	1978		4.5	Batang Agam	1981		5.0
Citarum	1978		4.5	Batang Ombillin	1984		4.0-4.5
Cisadane	1980	110	5.5				
Cimandiri	1980	103	4.5	Upland			
Ayung	1980	108	5.5	Gati	1976	80	4.0
Cipunegara	1981		5.0	Gata	1976	75	4.0
Krueng Aceh	1981		6.0	Sentani	1983		3.0
Atomita I	1982		5.0	Tondano	1983		2.0
Sandang	1983		6.0	Singkarak	1983		4.0
Bahbolon[a]	1983		4.5	Ranau	1984		2.0
Atomita II	1983		5.0	Arias	1984		3.0
Bogowonto	1983		4.5				
Porong	1983		4.5	Tidal swamp			
Citanduy[a]	1983		4.5	Barito	1981		5.0
Kelara	1983		4.5	Mahakam	1983		3.5
Cikapundung	1984		4.5-5.0	Kapuas	1984		3.5
Developed by IRRI scientists[b]							
PB5	1967	130	5.5	PB36	1977	81	4.5
PB8	1967	100	5.0	PB38	1978	97	4.5
PB20	1974	90	4.5	PB42	1980		4.5
PB26	1975	85	5.0	PB46	1983		4.5
PB28	1975	80	4.0	PB50	1981		4.5
PB30	1975	73	4.5	PB52	1981		4.5
PB32	1976	88	4.0	PB54	1981		4.5
PB34	1977	117	4.5	PB56	1983		4.5
Developed by Philippine scientists							
C4-63	1969	115	4.0				

[a] Named from IRRI line (see table 2.4).

[b] PB means *Peta Baru* or new Peta for the first three; *Padi Baru* or new rice for the remainder.

Sources: W.B. Ward, *Science and Rice in Indonesia* (Boston: Oelgeschlager, Gunn & Hain, 1985), p. 40; R.H. Bernsten, B.H. Siwi, and H.M. Beachell, *The Development and Diffusion of Rice Varieties in Indonesia,* Research Paper Series, No. 71 (Los Baños, Philippines: International Rice Research Institute, January 1982), p. 10 (source of data on height); letter from W.C. Tappan, IRRI liaison scientist, Cooperative CRIFC-IRRI Program, Bogor, November 1984.

to the new biotype."[54] The PB varieties have, in turn, eventually proved susceptible. The result has been successive waves of modern varieties. In the future, the new varieties will increasingly come from crosses made in Indonesia.

The overall area planted with HYRVs—including Indonesian varieties developed since 1968 and the IRRI varieties—has expanded sharply over time, as is shown in table 3.9. Since 1975-76, from 59% to 67% of the total modern rice area has been in the wet season and 33% to 39% in the dry season. The leading varieties as of the early 1980s were PB(IR)36 and Cisadane (a cross made in Indonesia).[55] Their

Table 3.9. Area of high-yielding rice varieties (modern), Indonesia, 1968-69 to 1981-82[a]

Crop year	HYRV area (ha)[c]	Proportion of total area (%)
1968-69[d]	485,600	6.1[e]
1969-70[d]	771,900	9.5[e]
1970-71[d]	1,072,200	12.9[e]
1971-72	1,848,000	31.0
1972-73	2,279,000	34.7
1973-74	3,227,000	47.7
1974-75	NA[f]	NA
1975-76	3,784,000	53.2
1976-77	4,150,000	57.7
1977-78	4,800,000	59.5
1978-79	5,216,000	63.3
1979-80	5,543,000	68.3
1980-81	5,687,000	68.0
1981-82	5,776,000	74.5
1982-83	5,884,000	82.9
1983-84	6,627,000	81.8

NA=Data not available.

[a]Through 1975, data were gathered by Bimbigan Massal (BIMAS) authorities. Beginning in the 1975-76 wet season, the Directorate for Plant Protection assumed responsibility for data compilation, and the quality of the data improved. However, some underreporting continued, particularly for the outer islands. Also, the dryland areas tend to be underreported.

[b]The Indonesian definition of crop year is followed. Thus, for example, 1971-72 covers the 1971-72 wet season (September-March) and the 1972 dry season (April-August).

[c] Planted area. Estimates of harvested area to be reported in "World Rice Statistics, IRRI, 1985," show noticeably lower HYRV totals from 1971-72 to 1981-82. The differences were in the 25% range through 1979-80, and then dropped to 9% in 1980-81, 4% in 1981-82, and -1% in 1982-83.

[d] Converted to Indonesian crop year; approximate only.

[e] Estimate.

[f] Data not available for the 1975 dry season. The wet season area totaled 2,244,000 ha, up 7.7% from the previous year.

Sources: 1968-69 to 1970-71: letter from L.H. Otto, USAID, Djakarta, September 1975 (data from BIMAS). 1971-72 to 1979-80: data provided by Mahyuddin Syam, head, Research Communication Department, Central Research Institute for Food Crops, Bogor, Indonesia, April 1984. 1980-81 to 1983-84: official data provided by W.C. Tappan, IRRI liaison scientist, Bogor, November 1984, June 1985.

relative importance as a proportion of the total area of modern varieties has changed as is shown in table 3.10.

Table 3.10. Area of PB36 and Cisadane as a proportion of the total area of modern varieties, Indonesia, 1980-81 to 1983-84

Season	PB36 (%)	Cisadane (%)	Total (%)
1980-81	54.5	4.8	59.3
1981-82	50.1	16.8	66.9
1982-83	45.7	24.2	69.8
1983-84	38.9	27.3	66.2

Source: Official data provided by W.C. Tappan, IRRI liaison scientist, Bogor, Indonesia, November 1984, June 1985.

North Korea (Democratic People's Republic of Korea)

Very little is known about HYRVs in North Korea. Rice yields, if the data are correct, are among the highest in the developing world. On the basis alone, it would seem that HYRVs must be widely used. Some confirmation of this assumption was provided in official government statements made in September 1982:

> Rapid increase of rice production in our country in recent years is greatly attributable to the overall introduction of new early-ripening and high-yielding strains based on the successes registered in the green revolution.
>
> Only when the new high-yielding varieties with strong resistance to lodging and high consumption of fertilizer were created and generalized, could the . . . rice yield constantly increase to ensure the fast growth of paddy rice production.

Reference also is made to "dwarf varieties for dense cultivation."

The leading varieties, divided by growing period and area, are:

- Sonbong and Gapsanchal. Short vegetative period, raised in north mountain area.
- Yomjul, Yomju 14, and Donghaechal. Middle-short vegetative period, raised in north-middle area.
- Pyongyang 8, Pyongyang 15, and Sohaechal. Middle vegetative period, raised in the plain area.

All the varieties are japonicas, and the average height is reported to be 80-85 cm. Pyongyang 15 is the leading variety and is planted on 60% of the rice area; it was developed by crossing rice with barnyard grass and then backcrossing. No further information has been found on the origins of the varieties. North Korea is too far north for the indica varieties from IRRI to be adapted, but they are used as a source of disease resistance.[56]

South Korea (Republic of Korea)

Rice is the staple food in South Korea. Production is intensive, with high levels of irrigation and fertilizer. Yields, in years of normal weather, are among the highest in the world. However, the weather has not been normal in recent years.

Varietal Improvement

Systematic rice improvement started in Korea in 1906. In subsequent years, the native varieties were gradually replaced by Japanese varieties. By the mid-1930s more than 70% of the total rice area grew improved varieties. The first locally developed variety was released in 1938; others followed. All were japonicas.[57]

By the late 1960s, despite good yields, South Korea had rice production deficits. The main breeding objectives during the 1960s were resistance to lodging and blast. Other factors limiting yield increases were stripe virus and low productivity of the plant type. Some breeders found it difficult to overcome these problems with the japonica varieties in hand.

During this period, IRRI varieties—which were high yielding, resisted lodging, and had blast (fungus) resistance—began to be released. The Koreans were interested in crossing the IRRI and South Korean types, hoping to merge the qualities of IRRI indicas with the ecological adaptability and the eating quality of the Korean japonicas. A cooperative agreement was signed with IRRI in 1968.

IR667 (IR8//Yukara/TN-l) was the first cross to be well adapted to South Korean conditions; six lines were derived from this cross. The first was Tongil (Tong-il), which was named in 1971 and released on a large scale in 1972. Although Tongil was high yielding and had a number of desirable characteristics, it also had several weaknesses. Its grain and eating qualities were less acceptable than those of japonicas; it lacked cold tolerance; it lacked resistance to blast and was susceptible to bacterial leaf blight and brown planthopper; and it was not adapted to late-season culture. An intensive breeding program was followed to develop improved varieties. The result was 18 Tongil-type varieties released between 1974 and 1979. Almost as many more were released from 1979 to 1983. [58]

The Tongil-type varieties resisted blast until 1976, when new blast races appeared. By 1978, blast prevailed throughout the country. South Korean breeders and IRRI collaborators adopted a gene rotation program and developed new varieties with broader spectrum blast resistance. However, cold susceptibility continues to be a problem. Improvement of resistance to bacterial leaf blight and brown planthopper and improvement of grain and eating quality remain important goals. [59]

Farmer Adoption

The new Tongil-type varieties were introduced to farmers with considerable government encouragement. There was a sharp increase in use up to 1978, a significant reduction through 1981, and then a slight increase through 1983. The drop in 1979 followed a bad blast year in 1978 (table 3.11).

Since 1977 the per-hectare yield advantage of the Tongil types over the traditional varieties has been considerably less than it was in previous years. It was particularly low from 1979 to 1981 (averaging only 3.4% higher than traditional varieties), and in 1980 the yield was nearly 2% less than for traditional varieties. This relative decline was presumably the result of a combination of weather, insect, and disease factors, as well as diminished genetic diversity among the major commercial varieties.[60]

Demand also may have affected the decline of the Tongils. South Koreans still prefer the taste and cooking qualities of traditional varieties of rice. There is also a difference in milling practices for the two types. Hence, the retail price for Tongil types is less—by 10% to 14%—than for traditional types. [61]

Table 3.11. Area of high-yielding rice varieties (tongil-type), South Korea, 1971 to 1983

Year	HYRV area (ha)	Proportion of total area (%)
1971	2,700	–
1972	110,000	9.3
1973	82,000	7.0
1974	180,900	15.2
1975	274,100	22.9
1976	533,200	44.6
1977	660,100	54.6
1978	929,000	76.2
1979	744,300	60.8
1980	604,300	49.5
1981	321,300	26.5
1982	386,400	32.9
1983	418.600	34.3

Source: Official South Korean statistics, principally published in the *Yearbook of Agriculture and Forestry Statistics* (Seoul, South Korea: Ministry of Agriculture and Forestry).

In 1984 the South Korean government decided to give farmers a choice of rice varieties to plant. In view of recent yield and price performance, it was expected that the area of the Tongil types would decrease. [62]

There is much conjecture about the success of the Tongil type program. There have been many technical improvements in the rice plant, and breeders have produced a large number of new varieties. But some major production and consumption problems remain. Also, while research work on the Tongil was being carried out, japonicas were neglected. The government may diversify its varietal activities to minimize the effects of crop pests and environmental conditions.

Laos

HYRVs were introduced in Laos in 1966 with AID help and were grown on a modest area. Additional seed inputs were made, and the HYRVs grew moderately (table 3.12).

No further information was available until the 1981-82 season when some data were received

Table 3.12. Seed imports and area planted with high -yielding rice varieties, Laos, 1966 to 1972

Crop year	Types imported	Amount imported (t)	Area planted (ha)
1966-67	IR8	0.1	360
1967-68			1,200
1968-69	IR5, IR253	6.0	2,000
1969-70			2,000
1970-71	IR20, IR22	10.2	53,600[a]
1971-72			30,000
1972-73			50.000

[a] The large increase in 1970-71 may have represented the theoretical area that could have been planted rather than the actual area.

Source: D.G. Dalrymple, *Development and Spread of High-Yielding Varieties of Wheat and Rice in the Less Developed Nations,* FAER Report No. 95 (Washington, D.C.: U.S. Department of Agriculture, September 1978), p. 96.

from an FAO/United Nations Development Program project. About 9,700 ha were planted with improved varieties (2,200 ha in the dry season and 7,500 ha in the wet season). The principal varieties were IR2823-103 (NN2B from Vietnam) and IR848-120 (glutinous). Smaller areas were planted with NN75-10 and NN75-2 from Vietnam and RD6 and RD8 from Thailand. In 1982-83, RD6 was replaced by RD16, and IR42 and IR52 were recommended. The project is involved in many IRTP-IRRI tria1s.[63]

Malaysia

Rice improvement work in Malaysia began when the Agriculture Department was established in 1915. Selection work was started in a special rice breeding station in Krian. Early breeding work concentrated on development of off-season varieties for double cropping. In 1951 Malaysia participated in the International Rice Commission project and received 13 japonica X indica crosses from India. From those, Malinja (Siam 29 X Pebifun) and Mahsuri (Mayang Ebos 80^2/Daichung 65) were picked. Malinja was released in 1964 and Mahsuri in 1965. Both were intermediate in height. A blast resistant version of Mahsuri was released in 1969.[64]

Domestic rice breeding was accelerated in 1960 and again in 1966, with the establishment of a Rice Research Unit in the Agriculture Department. The unit received 303 IRRI selections in 1965. In addition, 3 t of IR8 were imported from IRRI in 1966 and another 3 t in 1967. Smaller quantities of IR20 and IR22 were imported from IRRI in 1970. From the IRRI selections, IR82288-3 was selected and released as Ria in 1966. It was followed by a few other introductions and an increasing number of Malaysian crosses: Bahagia (sister of IR5), 1968; Murni (Bahagia/Ria), 1972; Marisa (IR789-59-3), 1972; Jaya (C4-63), 1973; Sri Malaysia I (sister of IR5), 1974; Sri Malaysia II (Rieankhari 203), 1974; and Pulut Malaysia I (Pulut Sutera/IR8), 1974.

Other Malaysian varieties subsequently released include:

- *1979*
  MR 1 or Setanjung: IR22/Pazudofuso
  MR 7 or Sekencang: $Jaya^3$/Tadukan
  MR 10 or Sekembang: IR8//Engkatek/Sacupak//Ria 163
- *1981*
  Kadaria: $(IR8/Engkatek/Sacupak)^4$///TKM-6
  Pulut Siding: $(Pulut\ Sutera/Ria)^2$//Tjina
- *1984*
  Manik: $(Radin\ Goi/Ria)^4$//Tadukan
  MR 71 or Muda: RU 243/BRJ 51
  MR 77 or Seberang: 67009/Zenith//Iron 171 (IR 4215)
- *1985*
  MR 73 or Makmur: MR 1^2/Pongsu Seribu

Three other varieties were not officially released but have been widely adopted: Mat Candu, a sister of Malinja; Seribu Gantang or 1000 Ganting (IR8/Engkatek/Sacupak); and Anak Dara (IR8/Mahsuri).[65]

Statistical estimates on the use of HYRVs in West Malaysia are readily available for the 1965-66 to 1977-78 period but are more difficult to obtain thereafter; some were found for 1981-82 (table 3.13). There was a moderate growth in area from 1965-66 through 1971-72, a relative plateau through 1975-76, and a substantial increase in 1976-77. The HYRV figure in 1981-82 was down somewhat in terms of total area but represented more than half of the total area in

West Malaysia. Over the 10-year period from 1968-69 to 1977-78, the intermediate varieties represented nearly half of the HYRV total; by 1981-82, this proportion had dropped to less than 28%. In 1981-82, 55.6% of the HYRV area was planted in the main season and 44.4% was planted in the off-season. No HYRV data were found for Sabah and Sarawak.[66]

Table 3.13. Area of high-yielding rice varieties, West Malaysia, 1965-66 to 1981-82

Year[a]	HYRV area (ha)[b]	Proportion of total area (%)[c]
1965-66	42,300	7.5
1966-67	62,700	11.3
1967-68	90,700	16.7
1968-69	96,100	15.2
1969-70	132,400	19.3
1970-71	164,600	23.6
1971-72	197,400	28.0
1972-73	212,200	29.1
1973-74	217,000	28.9
1974-75	213,200	28.8
1975-76	222,300	29.6
1976-77	317,800	43.4
1977-78	316,100	43.7
1981-82	261,900	53.5

[a] Data were not obtained for 1978-79 to 1980-81.

[b] Includes both intermediate and semidwarf varieties.

[c] The percentages through 1977-78 are underestimates. They are derived by dividing the West Malaysia HYRV area by the total national area, including Sabah and Sarawak, as reported by USDA. Separate area totals were not readily available for West Malaysia.

Sources: 1965-66 to 1977-78: D.G. Dalrymple, *Development and Spread of High-Yielding Varieties of Wheat and Rice in the Less Developed Nations,* FAER Report No. 95 (Washington, D.C.: U.S. Department of Agriculture, September 1978), p. 79; R.W. Herdt and C. Capule, *Adoption, Spread, and Production Impact of Modern Rice Varieties in Asia* (Los Baños, Philippines: International Rice Research Institute, 1983), pp. 12, 13. 1981-82: Calculated from data provided in *Paddy Statistics, Peninsular Malaysia, 1982* (Kuala Lumpur: Ministry of Agriculture, Division of Planning and Development, 1984), pp. 11, 37.

The leading HYRVs in 1981-82 were, as a proportion of total HYRV area in West Malaysia: 1000 Gantang (Seribu Gantang), 45.5%; Anak Dara, 15.2%; Mahsuri, 14.4%; Mat Candu, 13.3%; MR7, 5.7%; and Bahagia, 2.9%. Each of the remaining six HYRVs was less than 1% of the total. It is interesting that three of the four leading HYRVs, accounting for 74% of the total HYRV area, were not official releases.

Some further, but not fully comparable, 1984 varietal data are available for four of the main irrigation developments and regions in West Malaysia. As a proportion of the respective total rice areas, they are:

- Muda Development (95,000 ha). Main season: IR42, 27%; MR1, 20%. Off-season: IR42, 41.5%; MR71, 26.3%; MR1, 17.8%.
- Kemubu Development (28,300 ha). Off-season: Anak Dara, 29.1%; MR27, 25.5%.
- Tanjong Karang/Sabak Bernam (21,000 ha). Main season: MR1, 41%; Mat Candu, 14.9%; MR10, 11.1%; MR7, 8.1%. Off-season: MR1, 33.4%; MR10, 25.4%; Mat Candu, 9.8%.
- Krian (23,900 ha). MR10, 22%, MR52, 9.1%.

By 1984 the relative importance of Seribu Gantang had decreased, and that of varieties in the MR series had increased. The most striking development, however, was the appearance of IR42 as the dominant variety in the Muda Development. IR42 was released in 1983 as a stop-gap measure because of its resistance to Tungro. It became popular among Muda farmers because of this quality and its high yields. IR42 is not, however, recommended for general planting due to a low percentage of head rice (whole grains) and poor cooking quality. An IRRI plant breeder was told in April 1985 that 85% of the total rice area was planted with HYRVs.[67]

Seeds of the foregoing varieties, particularly MR71 and MR73, have been distributed to Sabah and Sarawak (East Malaysia) for testing, but nothing is known of the extent of adoption.

Nepal

HYRVs are principally grown in Nepal's terai (southern plain) and to a lesser extent in the Kathmandu Valley. The terai produces a surplus, which traditionally has been exported to India. Farmers in the hills prefer to produce local varieties for personal consumption. Nepal has a low rate of fertilizer use; few farmers except for those in the Kathmandu valley have access to fertilizer. Hence, the value of HYRVs is muted. [68]

HYRVS in Nepal are composed of several varieties or lines introduced from Taiwan, India, and IRRI. Substantial quantities of seed were sent from IRRI to Nepal for the 1968-69 season (60 t of IR8 and 0.5 t of IR5) and from India for the 1969-70 season (75 t of IR8). Smaller quantities (0.32 t of IR20 and 0.19 t of IR20) were imported from IRRI in 1970.[69]

A list of varieties released by the Nepal Department of Agriculture and an appraisal of their importance as of March 1983 provides the following breakdown, which includes the year of release: [70]

- Very important: CH45 (1960), Taichung 176 (1966), Chianung 242 (1966), Masuli (1973), Durga (1979), Laxmi (1979). Sabitri (1979), Janaki (1979), and Bindeswari (1981);
- Important: IR8 (1968) and IR20 (1970);
- Less important: Chianan 2 (1966), Tainan 2, Parwanipur 1 (1973), and IR24 (1975).

Background information is available on some of these varieties. Masuli is Mahsuri, and Durga and Bindeswari are from India (IET 2935 and IET 1444 respectively). Laxmi and Sabitri were selected from IRRI lines (IR2061-628-1-6-4-3 and IR2071-124-6-4, respectively). Janaki is B90-1 from Sri Lanka. In terms of height, CH45 was 124 cm, Taichung 176 was 84 cm, and Laxmi was 95 cm.

In 1982 two selections from IRRI lines were introduced by the National Rice Improvement Program: Kanchan (IR3941-4-PLP2B) and Himali (IR2298-PLPB-3-2-1-1B). Kanchan is 68 cm tall and Himali is 61 cm. Both are high yielding and blast resistant. [71]

The area planted with HYRVs grew steadily until 1978-79, when the area stabilized at about the 25% level (table 3.14). Another jump was made in 1981-82 and appears to have held through 1983-84. Some of the improved varieties, such as CH-45, might not qualify as a HYRV; hence the actual HYRV area, as more tightly defined, would be less than shown. Moreover, it has been suggested that the HYRV area may have been overestimated. [72]

Table 3.14. Area of high-yielding rice varieties, Nepal, 1965-66 to 1983-84

Crop year	HYRV area (ha)[a]	Proportion of total area (%)
1965-66	6,700	0.6
1966-67	13,200	1.2
1967-68	26,500	2.3
1968-69	43,000	3.7
1969-70	50,400	4.3
1970-71	67,400	5.7
1971-72	81,700	6.8
1972-73	172,100	15.1
1973-74	204,900	16.7
1974-75	223,200	18.0
1975-76	216,000	17.2
1976-77	220,900	17.5
1977-78	290,700	23.0
1978-79	312,100	24.7
1979-80	314,800	25.1
1980-81	325,400	25.5
1981-82	436,100	34.1
1982-83	458,800	36.3
1983-84[b]	478,900	35.9

[a] Improved varieties.

[b] Preliminary data.

Source: Letter from C.T. Hash, USAID, Kathmandu, September 1984. Data from Department of Food and Agricultural Marketing Services, Kathmandu, Nepal.

Pakistan

Rice research in what is now Pakistan originated in the Sind region in the 1920s. A rice research station was established in Dokri in 1938; it was upgraded as a multidisciplinary rice research institute in 1973. Rice research in the Punjab region started at the Kalashakaku research station, now the Rice Research Institute, when it was established in 1926.[73]

About 95% of Pakistan's rice production is concentrated in Punjab and Sind. Nearly all the rice is grown on irrigated land. Punjab concentrates on Basmati types of rice for export, while Sind produces HYRVs and traditional varieties for domestic consumption. The aromatic Basmati

Table 3.15. Area planted with major types of rice by region, Pakistan, 1982-83 crop year

Region	Area (ha)			Total
	IRRI	Basmati	Other	
Punjab	202,400	821,900	48,600	1,072,900
Sind	585,400	–	133,200	718,600
North-West Frontier	15,300	12,700	42,500	70,500
Baluchistan	112,600	1,700	1,800	116,100
Total	915,700	836,300	226,100	1,978,100

– = Negligible.

Source: Pakistan, Ministry of Food, Agriculture, and Cooperatives, *Agricultural Statistics of Pakistan, 1983* (Islamabad, Pakistan: the Ministry, 1984), p. 18.

Table 3.16. Area of high-yielding rice varieties, Pakistan, 1966-67 to 1982-83

Crop year	HYRV area (ha)	Proportion of total area (%)
1966-67	80	–
1967-68	4,000	0.8
1968-69	308,000	19.8
1969-70	501,000	30.9
1970-71	550,000	36.6
1971-72	728,400	50.0
1972-73	646,800	43.7
1973-74	668,700	44.2
1974-75	630,700	39.3
1975-76	665,600	38.9
1976-77	677,500	38.7
1977-78	852,200	44.9
1978-79	1,015,400	50.1
1979-80	964,100	47.4
1980-81	841,100	43.5
1981-82	872,800	44.3
1982-83	915,700	46.3

– = Negligible.

Sources: 1966-67 to 1971-72: D.G. Dalrymple, *Development and Spread of High-Yielding Varieties of Wheat and Rice in the Less Developed Nations,* FAER Report No. 95 (Washington, D.C.: U.S. Department of Agriculture, September 1978), p. 81; R.W. Herdt and C. Capule, *Adoption, Spread, and Production Impact of Modern Rice Varieties in Asia* (Los Baños, Philippines: International Rice Research Institute, 1983), p. 14. 1972-73 to 1982-83: Pakistan, Ministry of Food, Agriculture, and Cooperatives, *Agricultural statistics of Pakistan, 1983* (Islamabad, Pakistan: the Ministry, 1984), pp. 16-18.

varieties sell at premium prices in foreign markets. The Basmati plant is tall, however, and lodges when liberally fertilized. Basmati yields average about half those of IRRI varieties. The government purchase price for Basmati is about twice that for lRRI varieties.[74]

As of the 1982-83 crop year, the rice-growing area of Pakistan was divided among three categories of rice (table 3.15). Sind accounted for 63.94% of the IRRI area, Punjab 22.1%, Baluchistan 12.3% (a considerable increase over previuos years), and the North West Frontier Province, 1.7%. IRRI varieties represented 81% of the area in Sind, but only 18.9% in Punjab.

IRRI varieties were first introduced in Pakistan in 1966; 2 t of IR8 were imported in 1966-67, and 77 t in 1967-68. IR8 was quickly adopted by farmers in Punjab and Sind, but interest in IR8 in Punjab soon declined. Adoption of IR8 in Sind was steadier.[75] The overall HYRV area peaked initially in 1971-72, and then settled back to a lower level until 1977-78. There were peaks in 1978-79 and 1979-80 due to a higher than usual level of adoption of HYRVs in Punjab (for reasons that are not clear). Thereafter, the 1977-78 level held through 1981-82, and there was a slight rise in 1982-83 (table 3.16).

The HYRV varieties remained remarkably few in number throughout this period. Virtually the total IRRI area for a decade was composed of two varieties. IR8 came and went rather quickly in the late 1960s. It was replaced by Mehran 69 (IR6-156-2, a cross between Siam 29 and Dee-geo-woo-gen), which had better grain quality and began to be planted in 1968-69. IR841 (IR841-26-2) a slightly aromatic, early maturing variety was released in 1973.

During the early 1980s, three new varieties were released:

- KS-282 (Basmati 370/IR95), which is replacing IR6 in Punjab;
- DR-82 (IET4994), expected to replace IR6 in Sind; and
- DR-83 (IR2053-261-2-3), expected to replace IR841 in Sind.[76]

As of 1983, some 12,000 ha of KS-282 were being grown in the Punjab. The DR varieties were approved in February 1984.[77]

Because of the height of the Basmati plant (170 cm) and its tendency to lodge, there has been interest in developing semidwarf varieties. One such variety, PK-177 (120 cm), which includes IR8 in its parentage, was developed in the Punjab and approved for release in the Sahiwal District in April 1977. An even shorter variety, PK-196 (95 cm), was under test in 1984, as was IR9561. Higher yielding variants of Basmati 370, Pakistan's favorite variety, are being developed. Rutger suggests that "Basmati rice appears to be a classic situation in which semi-dwarf mutants would be useful."[78]

Despite the increase in the area planted with HYRVs, rice yields still are low considering the extensive use of irrigation. In the Punjab, yields have stagnated or declined since 1970-71. Part of that stagnation may have resulted from insufficient priority given to rice research, and part may have been due to government price policies. Since the late 1970s, relative returns to rice production declined while returns to cotton, sugar cane, and wheat increased. Another factor may be the fact that more than 70% of the rice in the Punjab is grown in a rotation after wheat—an extremely exhaustive pattern. Plant density in the rice crop is also low.[79] Yield increases should be possible.

Philippines

Rice improvement in the Philippines started in 1914. A hybridization program in the Bureau of Plant Industry (BPI) from 1928 to 1937 produced, among other varieties, Raminad Strain 3. By 1948, 35% of the rice area reportedly was planted with new hybrid varieties.[80]

In 1954 BPI, the College of Agriculture at the University of the Philippines at Los Baños (UPLB), and the Bureau of Agricultural Extension started a cooperative rice improvement program, and the Philippine Seed Board was established. When IRRI was established in 1960, it was included in the program. The main emphasis was on breeding high-yielding varieties.[81]

Philippine varieties were issued under two series designations—the BPI series and the C and UPLB series. Two of the better known early releases were BPI-76, released in 1960 (an improved version, BPI-76-1 or BPI-76 [NS], was released in 1971), and C4-63 (which had BPI-76 as one parent).

As noted earlier, Philippine varieties were named by IRRI through IR34; thereafter, naming was delegated to the Philippine Seed Board,

Figure 3.4. Irrigated rice cultivation in the Philippines. Source: World Bank.

Table 3.17. Rice varieties developed by Philippine agencies and recommended by Philippine Seed Board, 1969 to 1983

Variety	Year of release	Type[a]	Height[b]	Lodging character[c]
BPI-3-2	1973	IL, RL	MS	R
BPI-76 (NS)	1971	IL, U	MS	MR
BPI Ri-1	1979	IL (G)	S	R
BPI Ri-2	1975	IL	S	R
BPI Ri-3	1981	IL (G)	S	R
BPI Ri-4	1978	IL	S	R
BPI Ri-6	1978	U	M	MR
BPI Ri-10	1983	IL	S	R
C-12	1972	IL	M	MR
C-22	1972	U	M	MR
C-168	1973	IL	M	R
C4-63G	1968	IL	MS	R
C4-137	1969	IL	M	R
UPL Ri-1	1977	IL (G)	S	MR
UPL Ri-2	1978	RL	MS	MR
UPL Ri-3	1969	U	M	MR
UPL Ri-4	1982	IL	M	R
UPL Ri-5	1980	U	M	MR
UPL Ri-6	1978	U	M	MR
UPL Ri-7	1981	U	M	MR

[a]IL=irrigated lowland; IL(G)=irrigated lowland, glutinous; RL=rainfed lowland; U=upland.
[b]S=short (100-110 cm); MS=medium short (111-120 cm); M=medium (121-130 cm).
[c]R=resistant; MR=moderately resistant.

Source: A.J. Bueno, "Rice Varietal Improvement in the Philippines," *International Rice Commission Newsletter* (June 1983):15-23; letters from Bueno, April and August 1984.

which retained the IR designation. IR8 was released for use in the Philippines in July 1966.[82]

The HYRVs, including IRRI varieties and those developed by Philippine agencies, were quickly adopted by farmers (table 3.17). By 1970-71, 50% of the total area was planted with HYRVs.[83] Thereafter, the rate of growth was slower but reached 81% by 1981-82. (See table 3.18.)

The HYRVs are planted in three distinct ecological zones: irrigated lowland, rainfed lowland, and upland. In 1982-83, irrigated lowland comprised 59.7% of the area; rainfed lowland, 39.346; and upland, 1%.[84] The Philippines grow a relatively large proportion of its HYRVs as rainfed lowland compared to other nations, which grow HYRVs mostly on irrigated land.

In 1976-77, 81% of the HYRV area was planted with IRRI varieties, 14.6% with the C series, and 4.5% with the BPI series. A breakdown of area by source of variety is not available for recent years. IRRI has varietal information from various recent surveys, but those relate to specific areas and do not represent the national average. At an IRRI 1983 workshop, it was estimated that IR36 and IR42 would occupy about 90% of the Phlippines' rice growing during the 1984 dry season. Seed from IR56 and IR58 is not

Table 3.18. Area of high-yielding rice varieties, Philippines, 1966-67 to 1982-83

Crop year	HYRV area (ha)[a]	Proportion of total area (%)
1966-67	83,000	2.7
1967-68	702,000	21.2
1968-69	1,352,000	40.6
1969-70	1,390,000	43.5
1970-71	1,607,000	50.3
1971-72	1,863,000	55.9
1972-73	1,680,000	52.6
1973-74	2,232,000	63.3
1974-75	2,226,000	61.3
1975-76	2,361,000	64.3
1976-77	2,456,000	67.4
1977-78	2,556,000	71.0
1978-79	2,608,000	73.2
1979-80	2,746,000	75.5
1980-81	2,710,000	78.3
1981-82	2,786,000	80.9
1982-83	2,757.000	85.1

[a]Includes upland HYRV area.

Source: C. David, agricultural economist, IRRI, June 1985 (data from Bureau of Agricultural Economics, Philippines).

yet available on a large enough scale to have an impact on production. IR60 is expected to expand in Mindanao. Among the varieties developed by Philippine agencies, UPLB RI-4 and BPI RI-10 are the most popular.[85]

Sri Lanka

Sri Lanka once grew only one long-season crop, but increasing population pressure and food prices prompted increased interest in multiple cropping that, in turn, created interest in shorter season varieties that were fertilizer receptive. Sri Lanka had several stages of rice improvement through breeding, beginning in the 1950s. The Central Breeding Station was established in 1952.

Sri Lanka's rice improvement program has produced a large number of varieties. These varieties represent local crosses and are not selections from IRRI lines. IRRI varieties were imported in substantial quantities during the late 1960s and were planted for a while, but their more lasting role has been as parents in Sri Lanka's breeding programs.

Role of IRRI Varieties

In 1967, with support from the Ford Foundation, an IRRI scientist was assigned to a Sri Lanka project, and IRRI seeds were imported in the following quantities:[86]

- 1967-68—0.5t of IR8 from IRRI;
- 1968—210t of IR8 from the Philippines and 0.45 t each of IR5 and IR8 from IRRI;
- 1969—about 0.1 t of IR20 from IRRI; and
- 1970—about 0.1 t of IR20 and 0.35 t of IR22 from IRRI.

IRRI varieties IR8, IR26, and IR262 were planted on about 30,000 ha from 1969-70 through 1971-72 but then declined and disappeared by the mid-1970s. IR8 was susceptible to bacterial leaf blight and was too short for Sri Lanka's farmers; it rarely reached a height of 60 cm in a country where a height of 75-80 cm was considered desirable.

Breeding of Varieties

The variety situation in Sri Lanka can be confusing to the outsider.[87] The clearest portion refers to the *old improved varieties,* which began to emerge in 1957 and which include the H series of varieties (in particular H-4, H-7, H-9, and H-10) and 62-355. They are moderately responsive to fertilizer.

A second phase of development placed greater emphasis on lodging resistance and created the *new improved varieties.* These were released after 1970 in several batches. They were initially developed at the Batalagoda Research Station and were known as the BG(Bg) series.

- The first group, released in 1970, included Bg3-5, Bg11-11, Bg33-2, Bg34-6, Bg34-8, and Bg34-11. The first two (Bg3-5, Bgll-11) were intermediate in height and were designed to replace H-9 and H-4 respectively. The last four were semidwarfs and shared IRS-246 as a parent. Bg34-6 was designed to replace H-7.
- The next group, designed for high yield, was released in the mid-1970s. It was composed of Bg90-2, Bg94-1, and Bg4-2. All had IR262 on their parentage.
- In the third group, with releases starting in 1979, increased attention was given to breeding for disease and insect resistance. Varieties

Figure 3.5. Planting rice in Sri Lanka. World Bank photo by Tomas Sennett.

included Bg276-5, Bg379-2, Bg400-1, and Bg750. Bg276-5 is a semidwarf with Bg34-8 as one parent (which had IR8-246 as a parent); it was developed to replace Bg34-8. Bg400-1, which has IR20 as a parent, was intended to replace Bg90-2. Bg750 is a short-duration variety and is tall.

- A fourth group, developed at the Bombuwela Research Station, is labeled the BW(Bw) series and includes Bw78, Bw100, Bw266-7, Bw267-3, and Bw272-6B. The last three were released in 1981 and are designed for problem soils. Bw266-7 is semidwarf, Bw267-3 is intermediate, and Bw272-6B is tall.
- At16, does not fit into the above categories. This variety was released in 1978 for areas where red pericarp rices are in demand. At16 is a semidwarf and has IR8 in its parentage.

Thus, the new improved varieties are a mixture in terms of height. They are principally semidwarfs but include some varieties of intermediate height (Bg3-5, Bg11-11, and Bw267-3) and two tall varieties (Bw272-6B and Bg750).

The varieties are commonly sorted into four categories on the basis of the length of their growing season: 3 months, 3.5 months, 4-4.5 months, and 5-6 months. Increased emphasis has been placed on the shorter duration varieties. As of the 1982-83 crop year, 64% grew 3 and 3.5 month varieties, 35% grew 4-4.5 month varieties, and less than 1% grew 5-6 month varieties. Of the 20 varieties recommended by the Sri Lanka Department of Agriculture, 10 are in the 3-3.5 month class. Of those, three (Bg34-8, Bg94-1, and Bg276-5) are grown widely and comprise about 52% of the total area. The other seven (Bg34-6, Bg750, Bw266-7, Bw267-3, Bw272-6B, At16, and 62-355) are limited to problem areas. Varieties in the 4-4.5 month class include Bg11-11, Bg90-2, Bg379-2, and Bg400-1. Bg3-5 is in the 5-6 month class.

Area Planted

The area planted with the new improved varieties increased rapidly and steadily through 1973-74, declined in 1974-75, and then rose more or less steadily through 1981-82 (table 3.19). A particularly sharp increase was recorded in 1982-83. The proportion of the area planted with new, improved varieties increased in a similar fashion and reached 87% in 1982-83.

Some of Sri Lanka's improved varieties have been planted in other developing countries for some time, particularly in Asia and Africa. Bg90-2 has been especially widely used. In 1983, Bg90-2 was grown on about 140,000 ha in China and outyielded the local HYRVs.88

Table 3.19. Area of high-yielding rice varieties, Sri Lanka, 1968-69 to 1982-83

Crop year[a]	HYRV area (ha)[b]	Proportion of total area (%)
1968-69	9,700	1.4
1969-70	31,200	5.0
1970-71	73,600	10.2
1971-72	118,600	17.1
1972-73	250,500	39.2
1973-74	396,200	48.0
1974-75	293,000	42.1
1975-76	320,100	44.6
1976-77	437,400	52.8
1977-78	495,700	56.6
1978-79	491,300	58.0
1979-80	562,400	66.5
1980-81	612,100	70.8
1981-82	624,700	75.2
1982-83	749,700	87.1

[a] Composed of *Maha* season plus following *Yala* season (i.e., *Maha* 1981-82 plus *Yala* 1982).

[b] Known as new, improved varieties (virtually all the B series) in Sri Lanka. Principally semidwarfs but includes several intermediate and tall varieties.

Sources: 1968-69 to 1980-81: R.W. Herdt and C. Capule, *Adoption, Spread, and Production Impact of Modern Rice Varieties in Asia* (Los Baños, Philippines: International Rice Research Institute, 1983), p. 17. 1981-82 to 1982-83: official data provided by M.J. Korin and S. Abeyratne, USAID, Colombo, Sri Lanka, February and September 1984, February 1985.

Thailand

Rice research in Thailand began in 1916 with the establishment of the Rangsit Research Station. The research program was accelerated in the early 1950s with AID support and the technical assistance of H.H. Love of Cornell University.

Pure-line selections from Thai varieties were emphasized.[89]

During the mid-1960s attacks by tungro virus, plus the concept of a new rice plant type emerging at IRRI, caused a change in the rice breeding program in Thailand. The new semidwarf types were extensively used in crosses with taller Thai varieties in an effort to introduce virus resistance, stiff straw, and greater responsiveness to fertilizer. In 1966 the rice breeder Ben R. Jackson was sent by the Rockefeller Foundation to its Thailand program. Jackson spent several months at IRRI and carried a large collection of IRRI materials to his new post.

Rice production and marketing conditions in Thailand proved to be particularly challenging for HYRVs. Most of the rice growing zone is not irrigated and does not have water control.

Table 3.20. The Rice Department (RD) series in Thailand, 1969 to 1981

RD number[a]	Year released	Height[b]	Type of culture[c]	Source of dwarfism
1	1969	SD	I	IR8
2	1969	SD	1	IR253-4-1-2-1
3[d]	1969	SD	I	IR8
4[e]	1973	SD	I	IR8
5	1973	I	RM (dw)	
6	1977	I	RM	
7[f]	1975	S	I	
8	1978	SD	RM	IR262
9	1975	SD	I	RD2
10	1981	SD	I	RD1
11	1977	SD	I	IR661
13	1978	T	RM	
15	1978	T	RM	
17[g]	1979	SD	RM (dw)	IR262
19	1979	SD	RM (dw)	IR262
21	1981	SD	I	IR26
23	1981	SD	I	IR32
25	1981	SD	I	IR26, IR2061
27	1981	T	RM	

[a] Odd numbers are nonglutinous types; even numbers are glutinous types. All are photoperiod insensitive except for 6, 8, 13, 15, 19, and 27.

[b] SD = semidwarf; S = short; I = intermediate; T = tall.

[c] I = irrigated; RM = rainfed monsoon; dw = deepwater.

[d] No longer in use.

[e] Limited use.

[f] Most popular variety to date.

[g] Retains semidwarf height under shallow water but has capability of elongating stem to maximum of 1 m if necessary. Has not received widespread acceptance in Thailand, possibly because of some plant and grain (slightly chalky) characteristics, but it is reportedly performing well and finding acceptance in Burma and Vietnam.

[h] Same parentage as RD 17. Also has not spread rapidly. Recent reselection for nonchalky grains may enhance use.

Source: [B.R. Jackson] *The RD Varieties for Thailand* (Bangkok: Rice Research Institute, Department of Agriculture, Ministry of Agriculture and Cooperatives [1985]), 12 pp.

Flooding, sometimes deep, occurs in the wet season, and varieties must be able to withstand rapidly rising water levels. On the other hand, Thailand has developed a large export market for high-quality rice that has a long, slender clear grain and good cooking quality.

The early IRRI varieties tried in Thailand, with their short stems and poor eating quality, were not well suited for production in large areas of the country and did not meet market standards. The IRRI varieties were, however, used in a number of crosses with local varieties to develop varieties to meet local conditions. The first such varieties, RD1, RD2, and RD3, were officially named and released in 1969. RD1 and RD3 were selected from a cross of Leuang Tawng × IR8; RD2 had Gam Pai 15 and TN-1 for parents. Even numbers were assigned to glutinous varieties, odd numbers to nonglutinous.[90] Eight of the first 12 releases were semidwarfs. By 1981 the series had reached RD27 (table 3.20). As of 1984, the most popular varieties in the irrigated areas were estimated to be (in decreasing order of popularity): RD7, RD9, RD21, and RD25. RD15 and RD6 were popular in rainfed fields.

Although the RD varieties were improvements over the earlier introductions, it was soon recognized that those with a semidwarf growth habit, which were usually grown in irrigated fields in the dry season, were not suitable in large parts of the country because of lack of irrigation or water control. Also, some of the RD varieties, due to photoperiod insensitivity, may mature during the wet season, leading to lower grain quality and lower price. Hence, two other approaches were taken in the breeding program. One was to try to breed shorter, stiffer straw into native varieties. The other was to breed for deepwater tolerance.

A plant type was needed that remains relatively short and resistant to lodging during years when flooding is shallow, yet is capable of elongation when deep flooding occurs. One tactic was to try to transfer elongation ability to semidwarf varieties. IRRI line 442 played a large role in those efforts. In 1979 a modern variety tolerant of water depths of up to 1 m was released as RD19. It has begun to spread into parts of the Central Plain. Its major constraint is excessive chalkiness of the grain, which is being overcome by reselection. Several other crosses involving CA-63 are being considered as alternatives.

Table 3.21. Area of high-yielding rice varieties, Thailand, 1969-70 to 1981-82

Crop year	HYRV area (ha)[a]	Proportion of total area (%)
1969-70	3,000	-
1970-71	30,000	0.4
1971-72	100,000	1.4
1972-73	300,000	4.1
1973-74	400,000	5.0
1974-75	450,000	5.5
1975-76	600,000	7.1
1976-77	960,000	11.3
1977-78	960,000	11.2
1978-79	1,100,000	11.8
1979-80	800,000	8.5
1980-81	1,100,000	11.7
1981-82	1,200,000	13.0

−=Negligible.

[a]Principally RD series, some C4-63 (about 10% as of mid-1970s). In recent years, area reported is double cropped.

Sources: 1969-70 to 1976-77: D.G. Dalrymple, *Development and Spread of High-Yielding Varieties of Wheat and Rice in the Less Developed Nations,* FAER Report No. 95 (Washington, D.C.: U.S. Department of Agriculture, September 1978), p. 85. 1977-78 to 1979-80: R.W. Herdt and C. Capule, *Adoption, Spread and Production Impact of Modern Rice Varieties in Asia* (Los Baños, Philippines: International Rice Research Institute, 1983), p. 17. 1980-81 to 1981-82: letter from B. Jackson, Department of Agronomy, University of Arkansas, Fayetteville, January 1984.

The area planted with HYRVs increased rapidly during the early 1970s, then grew more slowly until an area of about 1.1 million ha was reached in 1978-79 (table 3.21). There was a drop in 1979-80, a year of low rainfall (which limited irrigation water), and then a resumption of earlier levels. HYRVs occupy all the irrigated rice area during the dry season (recently estimated as 650,000 ha) and perhaps 5% or a little more of the rainfed area (estimated as 9.6 million ha in 1985). Further expansion of the HYRV area will depend on the expansion of irrigation and the development and adoption of deepwater tolerant varieties for the rainfed zones.

Vietnam

Our review of the HYRV situation in Vietnam is initially divided into two geographic sections—north and south—which take us up to 1975. In that year, the Socialist Republic emerged. The subsequent discussion treats the country as a whole.

North

Short-season rice strains were introduced in the mountain areas of North Vietnam in 1948. They were planted after the traditional fall crop. Beginning in 1957, steps were taken to introduce short-season rice into the midlands and delta areas. Although these varieties were early maturing, they were not classified as high yielding.[91]

New strains with short stems were introduced in 1966-67. During the 1969-70 winter-spring season, about 18.5% of the spring rice area was planted with new varieties. By the 1971-72 season, the proportion was placed at 65% to 70% and was thought to have remained in this range. Because the spring crop accounted for about 58% of the annual crop, as of the mid-l970s, 38% to 41% of the total rice area was planted with the improved varieties. In addition, some of the fall (10-month) crop was sown with improved varieties.

Two of the most important improved varieties were Nong Nghlep (Agriculture) 5 and Nong Nghiep 8—named from IRRI varieties IR5 and IR8. As of September 1969, the two were reported growing experimentally over large areas. A subsequent newspaper account indicated that emphasis was being placed on IR8. Seed was allegedly obtained through Hong Kong and elsewhere. In December 1972, Nong Nghiep 8 was reported to be the predominant spring variety. Both it and Nong Nghlep 5 also appeared to be the principal new varieties used during the fall crop. A new variety, A2, was selected from IR8.

Table 3.22. Seed imports and areas of high-yielding rice varieties, South Vietnam, 1967-68 to 1974-75

Year	Quantity imported (t)	Variety	Area HYRV grown (ha)
1967-68	4.5	IR8	500
1968-69	2,000.0	IR8	40,000
	5.0	IR5	
1969-70	0.1	IR20	204,000
1970-71	1.0	IR22	502,000
	<0.1	IR20	
1971-72	55.0	IR20	647,000
	1.0	RD1	
1972-73	–	–	835,000
1973-74	2.0	IR26	890,000
1974-75[a]	–	–	900,000

–=Negligible.

[a] Estimated.

Source: D.G. Dalrymple, *Development and Spread of High-Yielding Varieties of Wheat and Rice in the Less Developed Nations,* FAER Report No. 95 (Washington, D.C.: U.S. Department of Agriculture, September 1978), p. 93.

A2 also was one of the parents of A3 and A4. As of 1982-83, Nong Nghiep 8 was still listed as being grown in the north, along with Nong Nghiep 22 (IR22).[92]

South

During the period from the mid-1960s to the mid-l970s, when there was a substantial U.S. presence in South Vietnam, there was a great deal of interest in using HYRVs to expand rice production. The Agency for International Development (AID) was heavily involved in these activities. Seed imports were substantial, and the area planted with HYRVs also grew substantially (table 3.22). Of the 1973-74 area, perhaps 500,000 ha were composed of IR20. Much of the remaining area was planted with IR5, IR8, and C4-63. In 1974-75, the area planted with IR20 dropped and was replaced by IR26 and TN73-2 (IR1561-228-3).

Overall

The Socialist Republic was established in 1975. At that time, there was a great deal of IRRI material in the country, especially in the south. Presumably, its use continued. Various IRRI publications list several varieties as releases based on IRRI lines and varieties (table 3.23). These varieties are grown principally in the south.

In 1977 the brown planthopper destroyed thousands of hectares of rice in southern Vietnam. IRRI reports: "In the latter part of 1977, more than 250 tons of seed of IR36 were imported into Vietnam from the Philippines and distributed to farmers in 1978 on a crash planting basis."[93]

A recent report by several Vietnamese rice researchers indicates that NN4B (IR42) and NN58 (IR48) were introduced in the Cuu Long (Mekong) Delta in 1981 and that their performance, particularly in adverse soils, is "encouraging." Both varieties are popular with farmers because they are generally free of disease and insect damage in normal field conditions and produce high yields.[94] Other IRRI varieties or lines reported having been released or recommended in 1982-83 are IR46, IR1561, IR2151, IR2153, and IR8423. Other lines under study include IR1523, and IR2058 in the north and IR2058, IR8423, IR9129-163, and IR9129-169 in the south.[95]

The overall impact of the IRRI varieties in Vietnam has been substantial. According to Vietnamese rice researchers in an article published early in 1983:

> IRRI early and intermediate maturity varieties and breeding lines have revolutionized rice cultivation in Vietnam. Two rice crops each year are now grown where one low-yielding, late maturing local variety once grew. More than a dozen IRRI lines have been named and released for large-scale cultivation. More than 65% of

Table 3.23. IRRI varieties and lines named and released in Vietnam, 1978 to 1983

Name	Year	IRRI variety or line
NN3A	1978	IR36
NN4A	1978	IR2070-734-3 (sister line of IR32,38,40)
NN5A	1978	IR2071-179-3 (sister line of IR36,42)
NN6A	1980	IR2307-247-2-2-3
NN7A	1980	IR9129-192-2-3-5
NN8A	1981	IR2070-199-2-6-6 (sister line of IR32,38, 40)
NN2B	1980	IR2823-309-5-6
NN3B	1980	IR2797-115-3
NN4B	1981	IR42
NN5B	1981	IR48
OM33	1983	IR9224-73-2-2-2-3

Source: Various IRRI reports.

the rice area in Cuu Long (Mekong) Delta is planted with IRRI varieties.[96]

Since the Mekong Delta occupies about 40% of the rice area in Vietnam,[97] sown IRRI rices in that area represented at least 26%, or 1.47 million ha, of the total national rice area in the early 1980s.

IRRI varieties undoubtedly are planted elsewhere in Vietnam, but there is no authoritative estimate of their extent. If they occupied 10% of the remaining 60% of the area, this would add another 0.34 million ha, bringing the total IRRI area up to 1.81 million ha, or 32% of the total of 5.65 million ha, as estimated by USDA. If they occupied 20% of the remaining area, the total IRRI area would be increased to 2.15 million ha, or 38% of the total area. By comparison, IRRI estimated that in 1981 IR36 alone was planted on 60% of the area in the south and in pockets in the north. IRRI placed the total area of this variety at 2.1 million ha, which seems high on the basis of the above calculations.[98]

In total, it might be conservatively suggested that by the early 1980s, IRRI varieties represented at least one-third, or about 1.88 million ha, of the total rice area in Vietnam. The total may well have been higher.

Taiwan

Taiwan's native varieties are indicas, although aborigines have grown japonicas in the mountains since the recorded history of Taiwan began.[99] The Japanese introduced the ponlai (japonica) varieties in the 1920s and they soon became the dominant variety. They represented over 93% of the total rice area in 1983.[100] Early breeding work was summarized in chapter 2.

The leading ponlai variety from 1927 to 1959 was Taichung 65. It was a parent, among other varieties, of Chianan 2 and Chianan 8. The latter replaced Taichung 65 as the principal variety in 1960. (It also became widely grown in Madagascar.) Chianan 8 was a parent of Tainan 5, released in 1965. Tainan 5 was quickly adopted and by 1975 was planted on 53% of Taiwan's total rice area. Tainan 5 had some deficiencies, however, including a relatively long stem and a tendency to lodge that slowed yield increases.[101]

The early ponlai varieties were not semidwarfs. In the late 1970s, a new variety, Tainung 67, was tested. It was semidwarf in nature, a characteristic obtained through a bridge variety (Taichun 187) from the indica variety Taichung Native 1.[102] Tainung 67 was lodging resistant and responsive to nitrogen fertilizer. It was planted on 101,000 ha in 1978. It, however, proved susceptible to brown planthopper and was succeeded by Tainung 68, selected in 1976 from a cross involving Tainan S. Over 3 years of testing (1979-81), Tainung 68 proved to be 5 cm shorter than Tainung 67 in the first crop and 10 cm shorter in the second crop. Yield was slightly less than the first crop. In spite of its short stature, it is not thought to have a semidwarf gene.[103]

Taichung Native 1 (TN-1) was the leading indica variety through 1977. While TN-1 yields well and is drought resistant, it is poor in cooking and eating quality, is highly susceptible to bacterial leaf blight and brown planthopper, and is sensitive to low temperature. In an attempt to find a replacement, seven long-grain varieties involving IRRI germ plasm have been developed and released: Chianung sen 6 (not used commercially) and Chianung sen 8 in 1974, Taichung sen 3 in 1976, Taichung sen 5 in 1977, Kaochsiung sen 7 in 1978, and Taichung sen 10 and Tainung sen 12 in 1979.

Through 1978 Taichung sen 3 was the most popular of the group, replacing TN-1 as the leading indica. About 25,000 ha were planted in 1979. Although the six indica varieties released had a number of improved characteristics, they tended to mature late, be sensitive to low temperature, lack swelling during cooking, and have less popular eating quality than the short-grain japonica varieties.[104] They are planted on a small proportion of the total rice growing area (6.8% in 1983).

Although Taiwan was the direct source of the dwarfing gene used in most of the HYRVs used in developing countries, semidwarf varieties represent a small proportion of Taiwan's rice area. Nevertheless, the japonica varieties are clearly high yielding, and overall national yield levels in Taiwan have been among the highest in the developing world for many years.

NEAR EAST (WEST ASIA AND NORTH AFRICA)

Rice is, overall, a minor crop in the Near East. In terms of rice-growing area, Egypt is the leader, followed by Iran, Afghanistan, Turkey, and Iraq.

Rice is of some significance in these countries but is not particularly important elsewhere in the region. HYRVs provide the core of a program to increase yields in Egypt where rice is grown in the upper area of the Nile Delta. Information on Iran is limited, but HYRVs apparently are planted on a significant area. Varietal research has been conducted in Afghanistan under the Indian Agricultural Assistance Program. In Turkey all rice is grown in irrigated fields; local and Italian varieties predominate and virtually no varietal improvement work has been done.[105] HYRVs have been used in Iraq, but no recent information is available.

Afghanistan

Varietal improvement in Afghanistan during the 1970s was by introductions and crosses. Saturn and Della, both of intermediate height, were introduced from the United States. Some 571 Indian varieties were tested from 1970 to 1980. Among the fine-grained varieties, CR44-11 (a sister of Ratna) proved to have a yield potential nearly twice as high as the best local variety and was released in 1975 for the eastern zone. Among the coarse-grained varieties, IET 355 proved promising and was released in the northern zone in 1975. Padma was released in the eastern zone in the same year. KH7194, as of the early 1980s, was being tested as a replacement for IET 355.

Rice breeding focused on improving Barah and Lawangin, two of the most popular local varieties. Both are tall and have weak straw. The two were crossed with IR790-28 at IRRI in the early 1970s. Bulk seed for growing the F_3 generation was sent to Afghanistan in 1973 for selection and testing of desirable lines. Lines 76-1-1 and 89-4-2 from IR790-28/Barah yielded particularly well.[106]

Little is known about the extent of farm use—if any—of these improved lines and varieties. One specialist estimates that 10% to 15% of the area is planted with CR44-11, Saturn, Della, and KC15.[107]

Egypt

Rice has been grown in Egypt for about 1,400 years, but it was not considered of economic importance until the beginning of the 1900s. Starting in 1917, breeding and selection focused on a relatively narrow base of imported japonica strains. In 1954, the variety Nahda, a local selection from a Japanese introduction, was released and was soon grown on more than 85% of the rice area. Nahda retained its popularity for about 20 years but then became susceptible to blast.[108]

Nahda has been replaced by two of its progeny, both released in 1977: Giza 171 (Nahda/Calady 40) and Giza 172 (Nahda/Kisame). In 1965 a salt-tolerant variety, Giza 159 (Agami/Giza 14), was released. In 1977 Giza 180 (IR579-48-1-2), a long-grain variety also known as Sakha 1, was introduced.[109] As of 1982, the leading varieties, in terms of proportion of total rice-growing area, were: Giza 172, 49.5%; Giza 171, 43.6%; Giza 159, 3.7%; Nahda, 2.9%; and other, 0.3% (not including Giza 180).[110]

There were two basic problems with Egypt's rice variety package:

- While yields were high by world standards, they increased only slightly from 1955 to 1981. The average yield in 1955 was 4,945 kg/ha; in 1984, it was 5,506 kg/ha, an increase of only 11%.[111]
- Giza 171 and 172 had a long growth duration of about 115 days. To increase cropping intensity, it is necessary to have varieties that mature more quickly. At the same time, yields need to be maintained or increased.[112]

An AID-sponsored Rice Research and Training Project involving collaborative work between the Ministry of Agriculture and the University of California (with IRRI and the University of Arkansas as subcontractors) was established in 1980. A three-stage program was established involving introductions, hybridization, and mutation breeding. Varieties were identified or developed that mature about 20 days earlier than Giza 172 (95 days versus 115 days). The new varieties were also about 32 cm shorter than Giza 172. Production per day increased and water use decreased.[113]

Varietal replacements were:

- For Giza 171: Giza 951-7//IR24/Giza 260-65. May be released as Giza 174. Shorter, earlier maturity and more resistant to blast than Giza 171.
- For Giza 172: Giza 173 (Reiho). Giza 173 matures 15 days earlier than Giza 172, is about 20 cm shorter, and yields about 10% more grain.
- For Giza 180: May be released as Giza 181. Long-grain indica. Similar to Giza 180, but

Figure 3.6. Transplanting rice in demonstration fields in Egypt–a comparison of traditional and improved techniques and varieties. Source: Rice Research and Training Project, University of California, Davis.

superior in yield and grain quality and more resistant to stem borer.

Giza 173 (Reiho) was introduced from Japan in 1973. Reiho is a leading early maturing variety and was derived from a cross of Hoyuko/Ayanishiki; it is thought to carry a semidwarf gene. (Hoyuko is a semidwarf.) It was grown on a small area in Egypt in 1982, on about 2% of the total rice-growing area in 1983, and on 25% or more of the area in 1984 (100,000 ha or more). Although Reiho showed resistance to blast during a prolonged period of testing, in late 1984 it developed severe susceptibility to blast in most areas of the country. It is now thought that a new race of blast is involved. As a result, Reiho was not recommended in 1985, and the area planted dropped to about 1.5% of the total area.[114]

To fill the gap, the area planted with Giza 171, Giza 172, and IR28 expanded in 1985. IR28 did not suffer from blast during 1984. IR28 has been grown for several years, in part under the name Philippini. It represented about 1.5% of the total rice area in 1983 and 42,400 ha or 10.9% of the area in 1985. IR50 was also planted on about 2,100 ha or 0.5%. Although it is high yielding, it is not liked by farmers because–as is true of other IRRI varieties–it has a long grain, which causes some milling and consumer - acceptance problems in a population used to short-grain rice.[115]

IRRI varieties have been available in Egypt since the mid-1960s. IR8 was introduced in 1967 but was rejected because of relatively late maturity and unpopular grain quality. IR22 and its sister line IR579-48 subsequently were reported to be the most promising introductions and, as noted earlier, IR579-48 was later named Giza 180 and Sakha 1. Sakha 2 also was named from an IRRI selection (IR1561-228-3).[116]

A number of Egyptian semidwarf crosses under testing in 1985 are very promising in terms of yield (over 10 t/ha) and blast resistance. Some may be released in 1986.

Iran

Rice is second to wheat in importance as a food grain in Iran. Traditional varieties are tall and subject to lodging following application of nitrogenous fertilizer. An FAO-assisted rice improvement program was established in the early 1970s at the Rasht Rice Research Station to develop short, stiff-strawed, high-yielding varieties. The variety collection was enlarged with introductions from other nations and a hybridization program initiated. TN-1 was one of the parents in the six most promising crosses. Three varieties have been introduced under the Amol series:

- Amol 1 was the first semidwarf to find producer and consumer acceptance in Iran. It was developed from a 1963 cross between Tarom Firoze Kanda (a tall local variety) and TN-1. Amol 1 was released for cultivation in Mazandaran Province in 1973. It was planted on about 2,750 ha in 1974 and 11,000 ha in 1976.
- Amol 2, IR28, was introduced through IRRI's International Rice Testing Program in 1975. It is early maturing and has a reasonable yield and medium-grain quality.
- Amol 3 is Sona, an Indian variety derived from the cross GEB 24 × TN-1. It was introduced through the IRTP in 1976. It is late maturing and high yielding.

In 1984 one report stated that Amol 2 and Amol 3 were planted on about 60,000 ha in Mazandaran Province, representing about one-third of the total rice growing area in Iran. Another report indicated that Amol 2 was planted on 90,000 ha and that only a small area was planted with Amol 3. The remaining area was planted with local long grain varieties.[117]

Iraq

Rice production in Iraq is concentrated in the Mesopotamia valley where the land is irrigated from the Tigris and Euphrates Rivers. IR5 and IR8 were introduced from IRRI for tests in 1967. The Ministry of Agriculture imported 100 t of IR8 seed from the Philippines in early 1969. The seed was distributed in four provinces and about 7,500 ha were planted. IR8 was widely grown as Zarate 8 until 1977.

IR22 was introduced in 1970. It yielded well, had better grain quality than IR8, and was approved for general cultivation. Because of seed multiplication problems, IR22 was not widely grown. During the early 1970s, the total area of IR8 and IR26 was estimated by FAO as: 1972-73, 5,000 ha; 1973-74, 12,000 ha; and 1974-75, 15,000 ha.

IR26 and line IR1529-680-3-2 were introduced in 1973. IR1529-680-3-2 (a sister of IR43) yielded somewhat better than IR8 and IR26, but substantial quantities of seed were not available. In early 1977, 100 t of IR26 were imported from the Philippines and planted on 750 ha for seed multiplication, and about 6,000 t of seed were distributed to farmers for the 1978 crop season. As of late 1977, a 5-year plan called for the replacement of local varieties with IR26, with a goal of reaching 75,000 ha by 1982.[118]

Little is known about subsequent HYRV developments in Iraq. The total rice area was estimated by USDA to average 58,000 ha from 1981 to 1983. Presumably, HYRVs are grown on this acreage.

AFRICA (SUB-SAHARAN)

Rice, traditionally a minor crop in Africa, is becoming increasingly important. The overall area is still limited, but rice is grown to some extent in nearly every country. There is widespread interest in increasing output. In terms of rice-growing area in 1983, Madagascar was the leader followed by Nigeria, Sierra Leone, the Ivory Coast, Guinea Bissau, Zaire, Liberia, and Mali. Madagascar had the 12th largest rice area among developing countries.[119]

Two major cultigens (types) of rice are raised in Africa—*Oryza glaberrima* and *Oryza sativa. O. glaberrima* is grown mainly in Africa. *O. sativa* was introduced in Africa many years ago. *O. glaberrima* varieties are rarely grown as pure stands; they are usually grown as mixtures with *O. sativa.*[120]

The principal types of rice production in Africa, and their relative importance in terms of area, are estimated as is shown in table 3.24.[121]

Within West Africa, *O. glaberrima* varieties are grown by subsistence farmers in areas with highly variable water levels. Lowland rice is largely grown in mangrove swamp areas with no water control or in inland valley (hydromorphic) areas with varying degrees of water control. In East Africa, particularly in Madagascar, the proportion of rainfed lowland rice is high. Irrigated cultivation of rice is largely confined to government-assisted projects.

Rice development in Africa from 1920 through 1970 went through three phases:[122]

- large-scale irrigation schemes—such as those found in Mali, Guinea, Madagascar, and Kenya, which drew their inspiration from the Gezira scheme in the Sudan and which involved resettlement of farmers;
- mechanization, particularly for upland rice during the 1950s and 1960s; and

Table 3.24. Types of rice production by region in Africa

Type of culture	West Africa (%)	Central, East Africa (%)	Total Africa (%)
Upland	62	34	50
Lowland rainfed	18	47	31
Irrigated	5	19	11
Deepwater	15	0	8
Total	100	100	100

Source: T. Ton That, "Potentialities and Constraints of Rainfed Lowland Rice Development in Tropical Africa," *International Rice Commission Newsletter* (June 1982):6.

- intensification of irrigated rice farming, initiated by Taiwan and Chinese specialists working closely with farmers, beginning in the 1960s.

In the irrigation schemes, too little attention initially was given to agronomic problems and to the difficulties of introducing an intensive system in an area without a background of this type of culture. The small-scale Taiwan/Chinese projects were relatively successful.

Rice research programs in Africa have been limited in number, resources, and scope. Research began in several nations in the 1920s. The longest standing and most significant efforts have been those initially sponsored by the British at Rokupr in Sierra Leone, and those sponsored by the French through the Institut de Recherches Agronomiques Tropicales et de Cultures Vivres (IRAT) in several francophone nations. The Rokupr Rice Research Station, established in 1934, has gone through several phases. Other early research in anglophone Africa was conducted principally in Nigeria and Liberia. IRAT efforts started in Senegal in 1960, in the Ivory Coast in 1966, and subsequently involved other francophone nations. Although some breeding was done in those projects, rice improvement elsewhere in Africa largely consisted of making selections from lines and varieties introduced in trials.[123] Starting in the mid-l960s, technical assistance teams from Taiwan (Operation Vanguard), and later from China mainland, played a role in introducing short and semidwarf varieties from Asia.

In the 1970s, the International Institute for Tropical Agriculture (IITA) in Nigeria and the West Africa Rice Development Association (WARDA) began to broaden rice research in Africa. IITA initiated a substantial breeding program in 1972 for upland rice. Lines developed by IITA, which carried a TOX prefix, were first distributed for testing in 1973. WARDA limited its early activities to coordinating variety testing trials but is now moving into breeding programs.

In addition, several other cooperative activities are under way. An international rice testing program for Africa has been established involving IITA, IRRI, and WARDA; it is headquartered at IITA. IRRI has a liaison officer for Africa stationed at IITA. IRRI also is becoming involved in programs to help strengthen rice research programs in East Africa, with initial activities in Madagascar and Tanzania. FAO and UNDP have participated in several national rice improvement programs.

As a result of efforts by various groups, HYRVs arrived in Africa at an early date. IR8 reached the Ivory Coast and Liberia in 1967; IR5 and C4-63 followed in 1968.[124] The performance of the Asian varieties in West African fields varied. Where irrigated, as well as on some broad floodplains not subject to deep flooding, they show considerable potential and are commercially planted. They did not fare as well in upland, deeply flooded, and mangrove - swamp areas. They also were susceptible to local strains of diseases, particularly blast.

While varieties for irrigated areas and favored lowlands are emphasized in this section, they do not constitute all the HYRVs. IRAT has developed a number of notable short and semidwarf upland varieties through crossing and induced mutations. Some of the leading early varieties were:

- Crosses: IRAT 9, Ivory Coast, 1973; IRAT 11 and 12, Senegal, 1970 (all with TN-1 parentage); and IRAT 10 (63-104/Leung Shang 1); and
- Induced mutations (from irradiation of IRAT-2): IRAT 13, IRAT 78, and IRAT 79.[125]

Virtually all African countries have some kind of rice improvement activity. But varietal information is limited, and most countries lack statistics on areas devoted to individual varieties. No information has been found for the Central African Republic and Rwanda.[126] Even so, there are so many country entries (27) that this section is disproportionately long compared to the total HYRV area involved. It is clear, however, that the HYRVs are widely distributed and perhaps used to a greater degree than may be generally recognized.

Benin

All rice production in Benin, except for upland rice, is under the control of the Office Beninois d'Aménagement Rural (OBAR). OBAR's main activities are along the Oueme River and its floodplains.

As of 1977, some 600 ha had been developed with reasonable water control, with another 400 ha being improved. An additional 1,100 ha were scattered over the country. IR8 was the main variety but was being replaced by IR442 because of its greater adaptability to the water regimen. IR20 also was grown.

In 1982, two releases were made: Bg90-2 (from Sri Lanka) for irrigated areas and IR937-55-3 for upland areas. As of 1984, the irrigated area had dropped to about 400 ha. Varieties planted included IR8, IR22, ADNY11, and BW196. IR442 was reported growing on nearly 7,600 ha of rainfed lowland or upland.[127]

Burkina Faso

Roughly 43,000 ha are planted with rice in Burkina Faso (formerly Upper Volta). Rainfed lowland is most common, occupying about 40,000 ha, or 93% of the area. Irrigated rice occupies about 2,800 ha, or about 6.5% of the total. The balance is upland.

In the case of rainfed lowland fields, land at the top of the slope is used for rainfed varieties (IRAT 10, IRAT 144, IRAT 177) while land at the bottom is planned with short- and medium-cycle varieties (120-135 days). The latter category includes the short varieties shown in table 3.25.

IET 1996, IET 2885, and BR51-319-9 also are recommended for irrigated areas. Other taller varieties in the rainfed group include C-74 from the Philippines (130 cm) and Sintane Diofer (120 cm).

IR8 was the first semidwarf variety to be introduced but was dropped because of poor grain quality and susceptibility to blast. C-74 was replaced by IR1529-680-3 in rainfed lowland areas but has difficulty withstanding medium-deep submersion during flash floods.

FAO has been involved in rice improvement in this country, and AID has assisted a seed multiplication project that includes foundation seed rice. Both efforts were with the Centre d'Expérimentation du Riz et des Cultures Irriguées. There has been a slight but gradual increase in the area under irrigation, and several large irrigation schemes are in the construction or planning stage.[128]

Table 3.25. Short, medium-cycle high-yielding rice varieties grown in Burkina Faso

Variety	Source	Year introduced	Height (cm)	Yield potential (t/ha)
Vijaya	India	1973	85	5-7
IR1529	IRRI	1979	90	5-6
IET 1996	India	1976	84	4-6
IET 2885	India	1976	102	4-6
BR51-319-9	Bangladesh	1977	107	5-6

Cameroon

Rice production in Cameroon began after independence in 1960. In 1970 several hundred hectares of IR8 rice were planted in western Cameroon, but due to a variety of problems, they have mostly disappeared. By late 1975, an estimated 400 to 500 ha of IR20 and IR24 were being grown in an irrigated rice project at Yogoua in northern Cameroon. Other varieties included Taichung 178 and D114H (origin uncertain). IR22 was tried but was wiped out by neck blast. As of 1977, perhaps 1,500 ha of HYRVs were being raised. Major locations, beyond the project at Yagoua, included the northwest and the Mbo Plain in the west. Principal HYRVs were IR20, IR24, and Jaya (from India); some IR8 was still planted at Yogoua.

IITA has helped introduce several lines from IRRI and has participated in the AID-funded National Cereals Research and Extension project. IR46 has become the most popular variety in northern Cameroon, occupying more than 10,000 ha in 1983. An IITA line, ITA 212, which is short statured, is spreading in the same area. ITA 222 is being considered for release in a development project at Mbo Plain. The parentage of the two IITA lines is ITA 212, 6850//Bg90/Tetef I; ITA 212, Mahsuri/IET 1444. CICA 8 and IR3273-339-2-3 also are being tested for possible release for irrigated conditions at Mbo Plain. Near Bamenda, where the predominant variety is Taiwan 5, two other lines with superior grain quality, IR7167-33-2-3 and B2161-MR57-1-3 (from Indonesia), are being tested.[129]

Chad

Chad's first rice research station was established in 1952. Early research resulted in the release of several varieties that were widely planted. During the 1970s, many varieties were introduced, and some—such as IR8, IR20, and IR22—outyielded local varieties. IR24 yielded about the same as the local varieties, while CICA 4 yielded less. Nothing is known of the extent of subsequent adoption of HYRVs.[130]

Gabon

Swamp (mangrove) rice is a traditional but unimportant crop in Gabon. Irrigated rice was introduced by a Taiwan team in 1965 and was continued by a rice team from China in 1974. Recently, rainfed varieties have been introduced but are only experimentally planted. Principal varieties, in order of introduction, are: Jin-Guang 202 (China), Guang-Xun No. 3, Zhai-Lai No. 1, IR8, Jia-Nan (Taiwan), Tuan-Zao, Tai-Ying No. 1 (China), Tai-Xiun No. 1, 81-1 (local), and 81-III (local selection). No estimates of overall rice area are available.[131]

The Gambia

As of 1977, about 1,800 ha of small, pump-irrigation schemes had been developed along the Gambia River. One account indicated that the main varieties were TN-1, I-Kong-Pao, and XA 228. Another source indicated that IR22 was the main variety, and that others being increased included ROK-5, I-Kong-Pao, IR305, IR442, and IR528.

Recommended varieties undergoing seed multiplication as of October 1983 included IR442-2-58, IR134-450, IR22, IR28, Bg-90 (from Sri Lanka; to replace I-Kong-Pao), and IRAT 112 (to replace SE3026). All are intended for irrigated areas or for short- or medium-duration crops in nonirrigated areas. There is substantial potential for expansion of the irrigated area. The nonirrigated rice-growing area totals about 27,000 ha.[132]

Ghana

The principal HYRV area in Ghana is in the wide, flat lowlands in the north. C4-63 was introduced from the Philippines in 1969 or 1970; it was susceptible to blast but continued to be grown by a number of small farmers. A ton of IR20 seed was imported during 1971-72; it and IR5 were released to farmers between 1972 and 1975, replacing C4-63 on the larger farms. Nearly 3,000 t of IR20 and IR5 seed were distributed during 1976 for planting on about 64,800 ha in the northern region.

In 1977, WARDA reported that not less than 101,200 ha were planted with HYRVs in northern Ghana. The HYRV category included IR442, which was considered promising at one point but proved susceptible to blast, as did IR5. IRAT 10 and IRAT 13 also were released.

Developments in Ghana since the late 1970s are less well-known. WARDA helped introduce a number of additional lines and varieties, some of which, including IR1820 and CICA 4, are reported to be in use. IITA indicated in 1984 that IR20 was grown over an extensive area. Another report indicates that as of late 1984, IR5 and IR8 were the most popular varieties in the wetlands of northern Ghana; yields were high and farmer acceptance was good. A recent report indicates that IR42 and IR3273-P339-2 are very popular in irrigated conditions. Both performed well at WARDA trials from 1979 to 1983. In 1983 IR3273-P339-2 was planted on nearly 1,000 ha on three irrigation projects. About 1,000 t of certified rice seed was imported from the Philippines with the assistance of USAID and UNDP. Both varieties are expected to be officially named and released by the Ghana Rice Varietal Release Committee.

Ghana developed a relatively large rice seed multiplication program, which evidently declined in the early 1980s. The proportion of Ghana's rice area planted with seed provided by that program was 45% in 1975, 66% in 1979, and 31% in 1982. The overall rice-growing area in Ghana dropped sharply in 1982 and remained low in 1983 and 1984.[133]

Guinea-Bissau

Rice production in Guinea-Bissau principally is in mangrove swamps (75%); the remainder of the area is upland (20%) and lowland (5%). During the 1970s, the government distributed I-Kong-Pao for lowland culture. IR422 has been distributed for upland and lowland culture.[134]

Ivory Coast

The Centre de Semence (Center for Seed Multiplication and Improvement) was established at Dabou in 1967 by the Ivory Coast government and a Taiwan agricultural mission. From IRRI lines, the center selected and named seven varieties—CS-1 through CS-7.

In 1972, with assistance from the European Development Fund, the government established the Société Pour le Developpement de la Riziculture (SODERIZ) as a seed company. SODERIZ was replaced by Compagnie Ivoirienne des Textiles in 1978. Seeds of IR5, IR8, CS-5 (IR506-1-36), CS-6 (IR480-14), Taipei-309, and Chianan 8 were multiplied and distributed. Production of these and other irrigated varieties totaled 91 t in 1973-74 (27 t of IR5 and 64 t of IM-16) and increased to 1,486 t in 1978 (1,005 t IRS, 208 t Jaya, 150 t CS-6, and 123 t IM-16).

During the 1982-83 season, some 30,000 ha were reported planted with Boake 1896 and Bg90-2 (from Sri Lanka), replacing IR5 and Jaya.[135]

Kenya

Kenya has a relatively small irrigated rice area of about 9,000 ha in central and western parts of the country. Kenya's rice yields are the highest in tropical Africa. IR1561 is grown on about 1,300 ha in western Kenya. In the case of the Mwea Rice Irrigation Scheme in central Kenya, the principal varieties are Sindano (local) and a Basmati from Pakistan. Bg90-2 (from Sri Lanka) is being tested.[136]

Liberia

Liberia grows very little irrigated or rainfed lowland rice but has a substantial area of upland rice. From 1968 to 1975, FAO managed a rice program that took over collections of local varieties assembled at the Liberian Agricultural Company (LAC). One of these local varieties, LAC 23, performed well in upland bush-fallow cropping systems and was widely used. Among introduced varieties, IR5 was fairly successful in leveled and bunded valley swamps but suffered from iron toxicity.

IITA had a cooperative rice improvement program with Liberia's central experiment station at Suakoko from 1973 to 1979. Four varieties were released: Suakoko 8 in 1977, Suakoko 9 and Suakoko 10 in 1979, and Suakoko 12 in 1979.

- Suakoko 8 (Siam/Malinja 3) was well suited to cultivation in inland valley swamps where iron toxicity is a major problem. The variety quickly proved popular and covered an estimated 2,000 ha in 1978.
- Suakoko 9, a selection from LAC 23, was ideally suited for upland culture. It also spread quickly and reportedly covered more than 80,000 ha, replacing LAC 23.
- Suakoko 10, an improved Mahsuri, was released for cultivation in newly developed swamps during the wet season. It responded favorably to added fertilizer and soon replaced IRS.
- Suakoko 12 (IR1416-131-5) was released for cultivation in irrigated fields with high rates of

fertilizer applied. It resists blast and has moderate tolerance for iron toxicity. As of 1984, IITA reported Suakoko 12 was grown on about 3,000 ha.[137]

Total use of HYRVs in Liberia is unknown.

Madagascar

The Democratic Republic of Madagascar is by far the leading rice producer in sub-Saharan Africa. Rice is the staple food and is cultivated on about 1.3 million ha. Production is in a wide variety of environments and farming systems, but most of the rice-growing area is irrigated and utilizes local varieties. Yields are low, and the country moved from being a rice exporter to being an importer in the mid-1970s.

Research was initiated in 1927 and mainly involved selections of local varieties. Hybridization was initiated on a modest scale in 1960. Among the various introductions, Chianan 8 from Taiwan was outstanding and is fairly widely grown. (One estimate published in 1978 placed Chianan 8 area at 30,000 ha.) Other introductions that performed well in specific areas include IR8, IR20, TN-1, and Taichung Line 137. Of the recent introductions from IRRI, IR36, IR38, and IR45 have appeared promising, but none were found suitable for high altitudes. From 1960 to 1976, about 700 crosses were made. Some of the more promising areas included Madirat 27 (Balaoule/IR8), Madirat 123 (Makalicka 34/ Chianan 8) and Madirat 36 (Tsipala 90/Chianan 8).

Madagascar is interested in increasing rice production. Toward that end, a cooperative research program involving IRRI scientists is being established with AID support. An IRRI team that visited the country in 1982 reported:

> Judging from the rice growing environments and the cultivar needs, it is obvious that a great potential exists for augmenting rice production through the use of high-yielding cultivars with resistance or tolerance to common biological, physical, and chemical stresses.

Current fertilizer usage on rice is low.[138]

Malawi

Rice in Malawi primarily is a rainfed crop; about 2,700 ha are irrigated. Several foreign varieties have been introduced, but only the U.S. variety Bluebonnet is recommended for irrigated areas. It is largely exported. As of 1984, four lines were in prerelease trials: IET 4094, B2360-6-7-1-4, IR1529-533-2-3, and IR1561-250-2-2.[139]

Mali

The largest irrigated rice project in Mali is that of the Office du Niger, which had about 40,000 ha of rice planted in 1976. Although water control was not adequate for the use of semidwarf varieties, they were used in crosses with local varieties. As of 1977, Malirat B42 and Malirat DK3 had been obtained from a cross of Kading Thang and HK698, with the latter considered the most promising. For upland rice production, IRAT 112, introduced in 1978, is reported to be popular. Varieties introduced through WARDA and in commercial use include IR442, Vijaya, and Sigadas. As of 1980, as much as 63.5% of Mali's rice area was (or could have been) planted with HYRVs.[140]

Mauritania

Rice production in Mauritania, while quite limited, has increased as irrigated areas along the Senegal River have expanded. As of late 1976, some 1,000 ha had been developed for irrigated rice. Varieties are divided on the basis of the length of growing season. Among the most commonly grown short-duration varieties are TN-1 (introduced in 1972), IR1561-228-3, Bg34-8 (from Sri Lanka), and IR2071-625-1. The most commonly used medium-duration variety is Jaya from India. IR8, IR442, IR1529-680-3, and IR2070-414-3-9 also are grown. Estimates are that as much as 8% of the rice area was planted with HYRVs in 1982.[141]

Mozambique

Rice is grown on irrigated semi-arid plains in southern Mozambique by the Complexo Agro-Industrial do Limpopo (CAIL). During 1978-79, CAIL received 30 t of C4-63 from the Estacao Agraria do Chokwe. By 1982-83, C4-63 was planted on 13,500 ha of irrigated land. Because of lack of water, only about 4,500 ha were harvested. In 1980-81, an FAO/UNDP rice project received packets of eight varieties, including IR36, IR42, IR48, and IR52, for trials.[142]

Niger

In late 1975, Niger had some 14,000 ha of rice, with about 2,600 ha of it irrigated. IR22 and some IR8 were the only varieties grown under controlled irrigation. IR1529 was considered as a replacement for IR22 because it had longer grain and greater tolerance for drought. In areas of noncontrolled irrigation the main varieties grown were Sintane Diofor, Nang Kiev, and D52-37. D52-37 is a tall variety also raised near river edges. It was estimated in 1982 that about 4,000 ha of irrigated rice was grown, with IR1529 as the principal variety.[143]

Nigeria

Nigerian rice research began in the 1920s at Moor Plantation, Ibadan. A rice research station was established in 1953 at Badeggi for irrigated rice. From 1954 to 1981, 25 varieties were released to Nigerian farmers as the FARO (Federal Agricultural Research Oryzae) series.

IRRI varieties, particularly IR8 and IR5, arrived at an early date. IITA supplied about 2 t of IR20 seed multiplied from stock brought from IRRI in 1970. An estimated 600 ha of the IRRI varieties were grown in 1973. By 1976 IR20 was spreading wherever irrigation was adequate.

Nigerian designations for the IRRI varieties were: IR8 as FARO 13; IR5 as FARO 23, and IR20 as FARO 19. TN-1 was released as FARO 21 and was one of the parents of FARO 16 and FARO 17. IR8 was a parent of FARO 15; BPI-76 was a parent of FARO 20. FARO 13 was released in 1970, but most of the others were released in 1974.

IITA has cooperated with Nigeria's National Cereals Research Institute in its varietal improvement program. A number of IRRI lines have been studied and some have been released as varieties. Included are FARO 7 (IR790-35-5) and FARO 22 (IR627-1-31), 1976; FARO 26 (IR269-26-3), 1981; and FARO 27 (TOS-103, IR790-35-5), 1981. Other cultivars have been selected from IRRI lines (TOS-42, IR665-79-2) or have an IRRI parent (FARO 188A and 188B: IR8).

In 1984 IITA reported that FARO 26 and FARO 27 were being used extensively in irrigated lowlands. FARO 26 was planted on 10,000 ha in Kwara State. FARO 27 was planted on more than 50,000 ha in Anambra State, and also was grown extensively in the Lake Chad Basin. Several other HYRVs are being tested, and some may move into commercial use.[144]

Senegal

HYRVs are grown in the north along the Senegal River (irrigated), in the south in Casamance (rainfed and swamp), and in eastern Senegal. During the 1981-82 season, about 71,400 ha of HYRVs (as defined locally) were grown: 15.4% in the north, 82.6% in the south, and 2% in the east. Leading HYRVs by region are: I-Kong-Pao, KSS, IR8, Jaya, and D52-37 in the north; I-Kong-Pao, IR8, IR442-2-58, IR1529-680-3 in the south; and I-Kong-Pao in the east.

The origins of the varieties differ. I-Kong-Pao, from Taiwan, was one of the leading varieties in that country in 1939 and was brought to Senegal by a technical assistance mission from Taiwan. KSS is from China. D52-37 is from Guyana. Jaya was first imported from India by a Senegalese official who visited that country around 1970. Some 20 t of Jaya were imported during the 1974-75 season.

TN-1 and IR269 also were grown as of 1977. TN-1 was a parent of Se 3026 and Se 314g, two early semidwarf varieties for upland use.

Three new varieties, KH 998, Srymalaya, and Tatsumi-Mochi, have been developed in cooperation with WARDA at the Richard-Toll Research Station and are going into production in the north. In the south, IR442-2-58 gradually is replacing I-Kong-Pao in swamps.

Recently released varieties include IRAT 133 (intermediate height) and DJ.11.509 (semidwarf) for upland areas. DJ.12.519 (semidwarf) appears promising for shallow, drought-prone areas and could replace I-Kong-Pao, which has become susceptible to neck blast.[145]

Sierra Leone

The Rice Research Station at Rokupr, the oldest rice research station in West Africa, was established in 1934. Nine varieties were released between 1971 and 1974: BD 2, CP4, and ROK 1 to ROK 7. ROK 1, 2, and 3 were developed for rainfed areas and yielded 35% to 50% more than local varieties in field trials. ROK 6 was IR5-298-1-1. IRRI varieties, particularly IR5 and IR20,

Figure 3.7. Harvesting rice in Casamance region of Senegal. World Bank photo by Ray Within.

appear to have been introduced by a Taiwan team at Mange.

IITA became a subcontractor of a UNDP-funded rice project from 1974 to 1980 and did research in collaboration with the Rokupr Station and the Ministry of Agriculture. Under that project, five varieties were released in the ROK series: 11, 12, 14, 15, and 16.

- ROK 11 and 12 were HYRVs derived from the cross IR665-23-3 × Tetep and were introduced from IRRI or CIAT. Both are short; ROK 11 (formerly ADNY 2) is 80 cm, and ROK 12 (formerly ADNY 11) is 74 cm. They are blast resistant and are intended for swamp and irrigated culture. IITA estimates they are grown on about 40,000 ha. They yield about 30% more than CCA, the variety they replaced.

- ROK 14 is a selection made by the Taiwan rice team at Mange. Its ancestry is not reported, but it is short statured (79cm). It was released for cultivation in inland valley swamps and is recommended for irrigated lowlands. No estimates of area have been noted.

- ROK 15 and 16 are rainfed upland varieties that are relatively tall, but resistant to lodging. ROK 15 is a cross of Anethoda and BG79, and ROK 16 is a selection from Ngovie, a local variety. In 1984 the two varieties were grown on about 150,000 ha.

Promising varieties include ITA 231 for irrigated lowlands and ITA 257 for upland culture. The higher yields of these varieties have, according to IITA, encouraged Sierra Leone authorities to develop additional areas for rice cultivation.[146]

Sudan

Rice was not given much attention in Sudan until 1974, when it was first grown on a small scale in the Gezira Irrigation Project, where a Chinese technical team demonstrated paddy rice-growing techniques. The Chinese varieties, Chen Chu Ai 11 and Kuang Chu 15, yielded about 6 t/ha.

The Agricultural Research Corporation at Wad Medani (Gezira) began rice research in 1974 and found that IR22 and IR2053-206-1-3-6 yielded as well or better than the Chinese varieties. Nothing is known of more recent developments.[147]

Tanzania

Rice is fairly important in Tanzania, the second largest rice producer in East Africa. The harvested area in the early 1980s was about 280,000 ha, mostly rainfed. In 1984 irrigated rice covered about 20,000 ha.

Rice research in Tanzania started about 1935; the current rice breeding program was started at the Ilonga Research Institute in 1966. Several traditional varieties have been improved through selection. Hybridization work started in 1971 and one promising variety, Selemwa (Faya Theresa × IR8), was released in 1983. A variety from India, R.P. 143-4 (IET 2397; H.R. 19 × IR8), was released as Katrin in 1983 and was grown on about 500 ha in 1984. Selemwa has a height of 92 cm; Katrin is 98 cm. Many varieties and lines from IRRI and IITA have been introduced and are being tested.

IR8 and IR579 are the principal HYRVs in Tanzania, occupying about 75% of the irrigated area (15,000 ha) in 1984. Most of the two varieties are grown on three state farms (Mbarali, Ruvu, and Dakawa), where yields are high (averaging 8 t/ha). IR8 and IR579 have not been widely adopted by local farmers.[148]

The island of Zanzibar has some 12,000 ha of rice, of which 500 ha are irrigated. Several entries from the International Rice Testing Program have adapted well to culture on irrigated lands and have been released as varieties. Included are Bg90-2 and Bg94-1 from Sri Lanka; IET 1444 from India; and two IITA lines, ITA 212 and ITA 233. The latter two may be planted on 200 to 300 ha. Crosses between IRRI and local materials have developed promising semidwarf lines for dryland culture.[149]

Togo

Rice production in Togo is limited—only about 17,000 ha in 1983. Assistance was received from Taiwan teams in the 1960s and from mainland China in 1974. IR8 reportedly was the main variety grown through 1974; IR442 was also grown during the 1970s. The Chinese team introduced a variety known as Ainan-Zao (or Tsao), derived from Zenzhu Ai, a prominent semidwarf. As of 1984, IITA reported that ITA 212, a short-statured line, was spreading in the irrigated lowland areas and was expected to be adopted on about 2,500 ha.[150]

Uganada

Several thousand hectares of IR5 have reportedly been grown near Tororo since about 1970. This project evidently was not disturbed during the civil turmoil. Three Ugandan officials visited IRRI in 1984 to obtain more recent varieties. [151]

Zaire

Rice research in Zaire was initiated by the Belgian research organization, the Institut National pour l'Etude Agronomique du Congo (INEAC), in 1932 with the selection and purification of local varieties. Crosses were later made between local varieties and introductions.

Following independence, Zaire's first major rice improvement work was by a team of rice specialists from Taiwan from 1968 to 1972. In 1973 rice development work in northern Zaire along the Congo was taken over by a team from China. Technicians reportedly were working with a combination of US., Asian, and Filipino varieties for crossing with Zairian rice. The Chinese contract ended in 1978.

As of 1981, the principal irrigated varieties in the Mongala subregion (Equateur Province) were Peking 7-25, Tainan No. 5, Kao 17, and Junghe. IITA noted in 1984 that ITA 257 was found suitable for the northern Shaba region and was being multiplied for distribution to farmers. Zambia requested additional seed from IITA. [152]

Zambia

Zambia's rice area recently has expanded; by 1983, it was 6,000 ha with considerable potential. Systematic varietal testing was initiated in 1967-68 at the Luapula Regional Research Station. The pedigrees of the four basic varieties in current use (1632, Kalembwe, Malawi Faya, and Sindano) are not known, but ITA 225, IR36, and TOX 1008-15-15 (from IITA) are being considered for release. [153]

Zimbabwe

Commercial rice production is on irrigated land in the semi-arid region of the country. Rice research was initiated in the early 1950s. Commercial varieties include Bluebelle, Lebonnet, and IR403. The first two are long-grain types from the United States and are preferred, even though IR400 gives higher yields. The total rice area is not reported by USDA or FAO and is presumably small. [154]

LATIN AMERICA

Rice is a staple food throughout Latin America and the Caribbean. Some rice is grown in every country in the region. The largest rice growing area is in Brazil, the sixth largest among developing countries in 1983, followed by Colombia, Peru, Mexico, Venezuela, and Cuba. [155]

In terms of type of rice culture, as of the 1981-82 season, about 23.7% of the Latin American rice-growing area was irrigated, 4.5% was rainfed lowland, and 71.7% was upland. In the upland area, 10.7% was considered highly favored, 12.5% moderately favored, 38.3% unfavored, and 10.2% subsistence.[156]

Improved varieties have been grown in the commercial sector of most of the countries for some time. Some of those varieties, such as Bluebonnet and Bluebelle, originated in the United States. They are relatively high yielding but represent an earlier generation HYRV and generally are not semidwarfs.

The new generation of HYRVs was introduced in Latin America in the mid-1960s. Research on these varieties started in 1967 at the International Center for Tropical Agriculture (CIAT) in Colombia. Initially CIAT used breeding stock from IRRI and then developed its own breeding program. CIAT's first variety, CICA 4, was released in 1970. In 1976 CIAT and IRRI initiated an International Rice Testing Program (IRTP) for Latin America, which provides national programs with improved breeding materials (see table 3.26) for different growing conditions. CIAT's rice research is done in cooperation with the Instituto Colombiana Agropecuaria (ICA). IRRI has a regional liaison scientist stationed at CIAT.

CIAT reported in 1983 that more than 50 semidwarf varieties based on lines developed by its rice program have been released by 25 national programs in the regions. [157] The varieties generally are grown in irrigated areas, but they are raised on upland areas in Central America, and their use is expanding on more favored upland areas in South America. A CIAT estimate suggests that during the 1981-82 crop year, 71.1% of

Table 3.26. Rice varieties and lines from the International Rice Testing Program in Latin America that were released and used in national rice programs, 1967-1980

Variety or line[a]	Source	Year available for regional trials	Number of countries where released	Local name (if different from name in first column)
IR8	IRRI	1967	7	Milagro Filipino (Mexico)
IR822-81	CIAT-IRRI[b]	1968	5	CR1113 (Costa Rica, El Salvador, Honduras, Nicaragua, Paraguay)
IR930-31-10	CIAT-IRRI	1969	1	IRGA 408 (Brazil)
IR665	CIAT-IRRI	1970	1	
IR22	IRRI	1970	8	INIAP-2 (Ecuador)
Unidentified[c]	IRRI	1970	1	X-10 (El Salvador)
CICA 4 (Linea 4)	CIAT-IRRI	1970	17	Avance 72 (Dominican Republic), INIAP 6 (Ecuador), Naylamp (Cuba, Peru)
CICA 6 (P723-6-3-1)	CIAT-IRRI	1974	8	ICTA 6 (Guatemala), Saavedra V5 (Bolivia)
P780-55-1-1	CIAT	1974	1	EMPASC 101 (Brazil)
P738-137-4-1	CIAT	1974	1	EMPASC 102 (Brazil)
P791-84-14	CIAT	1974	1	EMPASC 103 (Brazil)
4444	CIAT	1975	3	INIAP 7 (Paraguay), ISA 44 (Dominican Republic), 44 (Panama)
4422	CIAT	1975	5	ISA 22 (Dominican Republic), Tikal 2 (Guatemala, Honduras)
CICA 7 (4461)	CIAT	1975	7	
CICA 8 (4440)	CIAT	1975	13	Adelaida 1 (Paraguay), ICTA Virginia (Guatemala), INCA 4440 (Brazil), ISA 40 (Dominican Republic)
CICA 9 (4421)	CIAT	1975	10	Ciarllacen 1 (Venezuela), ISA 21 (Dominican Republic), Linea 9 (Nicaragua)
4440-10	CIAT	1975	1	ICTA Cristina (Guatemala)
P790-B4-4-1-T	CIAT	1975	1	IRGA 409 (Brazil)
IR1055	IRRI	1975	1	N (Guyana)
IRl00	IRRI	1975	2	
IR1529-430-3	IRRI	1976	2	IR 1529 (Cuba), Saavedra V4 (Bolivia)
Unidentified[c]	CIAT-IRRI	1976	1	CR 201 (Costa Rica)

Unidentified[c]	CIAT-IRRI	1977	2	CR 5272 (Costa Rica)
P849-45-IM-40-4-3-IM	CIAT	1976	1	Araure 1 (Venezuela)
IR-841	IRRI	1977	2	
P1042-2-3-18	CIAT	1978	1	INLAP 415 (Ecuador)
5006	CIAT	1978	1	Metica 1 (Colombia)
5029	CIAT	1978	1	Metica 2 (Colombia)
5738	CIAT	1979	1	Oryzica 1 (Colombia)
P1008-8-16-6-113-53	CIAT	1979	2	CENTA A2 (El Salvador, Venezuela), Tempisque (Guatemala)
P1008-8-16-6-113-52	CIAT	1979	1	CENTA A3 (El Salvador, Venezuela)
P1278-17M-1-1B	CIAT	1979	1	IAC 1278 (Brazil)
P881-19-22-4-1B-1B-2-1-(5430)	CIAT	1979	1	Tocumen 5430 (Panama)
P1382-2-4M-2-1B-5-1-1	CIAT	1980	1	Araure 2 (Venezuela)
IR930-53/IR665-31-2-4 Cross P 798	CIAT	1975	1	IRGA 410 (Brazil)

[a]Does not include all HYRVs used by nations in region. Some varieties or lines may have been used in local breeding programs; the offspring of these crosses have not been identified here.

[b]CIAT-IRRI refers to selections by CIAT from IRRI. CIAT varieties or lines are developed in cooperation with ICA.

[c]Unidentified line taken by CIAT trainees.

Sources: "Rice Program Report, External Program Review," CIAT, 1984, pp. 54-56 (table 32); letter from P. Jennings, rice breeder, CIAT, February 1984; *CIAT Report, 1981,* p. 49. *CIAT Report, 1983,* pp. 60-61. A more complete listing through 1985, including parentage, has recently been provided by MJ. Rosera M. in "Variedades Semienanas de Arroz en America Latina y El Caribe," *Aroz en las Americas* (Cali, Colombia: International Center for Tropical Agriculture [CIAT], November 1985), pp. 10-11.

the HYRV area in Latin America was in irrigated areas and 28.9% in upland areas.[158] CIAT is giving increased attention to developing varieties suitable for upland areas.

CIAT, during periodic conferences of rice workers, has gathered statistics on the use of HYRVs in Latin America. The data, along with those from other national sources, are used in this section[159] and represent the most complete set of figures available for Latin America.[160] Information is summarized for 20 countries in this section. Rice-producing countries not included are Belize, Chile, Jamaica, and Uruguay.[161]

There has been steady expansion of Latin American HYRV areas, with room for further growth, particularly as irrigated areas are developed and as appropriate varieties and technologies are devised for favored upland areas.

Argentina

Argentina raises some rice in the northeast provinces of Corrientes, Formosa, and Chaco. IR841-63-5-18 is grown, although it is not registered by the Instituto Nacional de Technologia Agropecuaria (INTA) because of some quality problems. However, there is great interest in the line because of its high yield.

HYRV area in the three provinces is estimated by INTA to be: 1978-79, 200 ha; 1979-80, 5,800 ha; 1980-81, 13,000 ha; 1981-82, 23,000 ha; 1982-83, 15,000 ha; and 1983-84, 28,000 ha. The HYRV area represented the following proportions of the total area: 1979-80, 6.7%; 1980-81, 15.3%; and 1981-82, 19.6%.[162] The CIAT HYRV estimate for 1981-82 was 27,500 ha (irrigated only), more than twice the figure noted above.

Bolivia

Little is known about HYRV rice grown in Bolivia. HYRVs reported in use as of 1980 included Saavedra V4 and V5, and CICA 8 and 9. Saavedra V4 is IR1529-430-3; Saavedra V5 is CICA 6. One estimate provided at a CIAT workshop suggests that in 1981-82, CICA 8, CICA 9, and IR1529 were planted in roughly equal areas. CIAT places the HYRV area in 1981-82 as 29,600 ha, virtually all upland.

Brazil

Brazil is the largest rice producer in Latin America. Most of the rice is grown as nonirrigated upland, but roughly 15% is irrigated. Until recently all irrigated land was in the subtropical zone in the southern states of Rio Grande do Sul and Santa Catarina. Irrigated rice production has increased in tropical areas in the northern portion of the country, and there is increasing interest in improving upland rice. Rice farming is highly mechanized in both regions.

Rice research in Brazil began in 1937 with the establishment of a rice experiment station near Pôrto Alegre in Rio Grande do Sul. In 1959 the station, operated by the Instituto Rio Grandense do Arroz, released the first varieties in its EEA series. In 1977 the station worked with some lines developed at CIAT. Also, the National Rice Center of EMBRAPA (Empresa Brasileira de Pesquisa Agropecuaria—Brazilian Enterprise for Agricultural Research) was testing new HYRVs from IRRI and CIAT throughout the country.[163]

As of 1984, Brazil had released a number of HYRVs principally derived from crosses made by CIAT or IRRI. The CICA varieties developed at CIAT have been used in a limited area (table 3.27). In addition, three other introductions might be noted: CNA 4 from Indonesia (Pelita I-1/IR1082); CNA 7 from India (IET 2881, T 141/IR665-1-175-3), and CNA 1051 from CIAT.[164]

The area planted with HYRVs in Brazil has grown sharply; estimates of the exact area vary. A recent CIAT estimate shows the growth as:

Crop year	Area (ha)
1975-76	53,000
1976-77	66,000
1977-78	120,000
1978-79	112,000
1979-80	218,000
1980-81	496,000
1981-82	755,000

The 1981-82 rice area included 592,500 ha irrigated and 163,000 ha upland.

The CIAT HYRV estimate for 1981-82 (755,000 ha) is considerably higher than the total

Table 3.27. High-yielding rice varieties, Brazil, 1983-84

Variety	Source[a]	Estimated area (ha)	State[b]
BR-IRGA 408	IR930-31-10	6,000	RS and SC
BR-IRGA 409	P790-B4-51[c]	276,000[d]	RS and SC
BR-IRGA 410	IR930-53/IR665-31-2-4	105,500[e]	RS and SC
	Cross P798		
EMPASC 101	P780-55-1-1	20,000	SC
EMPASC 102	P738-137-4-1	10,000	SC
EMPASC 103	P791-84-14	4,000	SC
Pesagro 101	IR8208		
Pesagro 102	IR46 (IR2058-78-1-3-2-1)	3,000	RJ
Pesagro 103	SPR 72-108-67-2[f]		
CICA 4	CIAT	3,000	SC
CICA 8[g]	CIAT	–	–
CICA 9	CIAT	5,000	SC
IAC 1278	P1278-17M-l-1B	900	SP
IAC 4440	(CICA 8)	1,600	SP
INCA	(CICA 8)	2,000	MG
BR-2	IR442-2-58[h]	500	PI
Total		437,500	

—=No area planted.

[a]Designations starting with P came from cross made by CIAT.

[b]F.S = Rio Grande do Sul, SC = Santa Catarina, RJ = Rio de Janeiro, SP = Sao Paulo, MG = Minas Gerais, PI = Piaui.

[c] Selected and released by EMBRAPA. IRGA 409 is replacing Bluebelle.

[d] Another source places the area in Rio Grande do Sul alone as about 457,600 ha in 1983-84, much more than is indicated here for the two states.

[e] Another source places the area in Rio Grande do Sul as about 35,000 ha in 1983-84.

[f] Descended from the cross NSW x IR648 made in Thailand. Introduced through the IRTP.

[g] Known as IAC 440 and INCA in Brazil.

[h] IR95-31-4/Leb Mue Nahng. Introduced by EMBRAPA in 1976 for upland culture.

Sources: Column 2: tables 1.1 and 3.23; E.P. Silveira, "Brazil Releases Two New Rice Cultivars," *International Rice Research Newsletter* (February 1980):5. Columns 3 and 4: Attachment to letter from A. Blumenschein, Director, Centro Nacional de Pesquisa-Arroz, Feijao, Empresa Brasileira de Pesquisa Agropecuaria, Goiania, Goias, Brazil, April 1984. Footnotes d and e: E.P. Silveria, "BR-IRGA Plantings in Rio Grande do Sul, Brazil," *International Rice Research Newsletter* (April 1985):4.

reported for 1983-84 in table 3.27 (437,000 ha, or 548,800 ha if different estimates for the area of two varieties are used). The reason for the difference is not certain, but it may in part be that the 1983-84 area excludes the area planted with US. varieties (Bluebelle, Lebonnet, etc.).[165]

In any case, when the 1983-84 total is broken down by variety and state, the BR-IRGA, EMPASC, and CICA varieties accounted for virtually all (98.2%) of the HYRVs planted in Rio Grande do Sul and Santa Catarina. The remaining varieties were planted farther north.

Despite the differences in the HYRV estimates, their relative proportion was not greatly different. In 1981-82, according to CIAT data, they accounted for 11.4% of the total area. In 1983-84, on the basis of the data in table 3.27 and USDA estimates of total area, they accounted for

8.4% or 10.6%, depending on which estimates are used. It is hoped that more precise estimates will become available in the future.

Colombia

Rice improvement work began in Colombia in 1957. The Instituto Colombiano Agropecuaria (ICA) released several improved varieties–Napal, ICA-10, and Tapuripa (from Suriname). In 1967 ICA started developing semidwarf varieties and joined forces with the rice program of the newly established International Center for Tropical Agriculture, which was built near ICA at Cali.

IR8 had been introduced from IRRI in 1966 for use in irrigated tropical areas. Following that, ICA released IR22 and CICA 4 in 1971, CICA 6 in 1974, and CICA 7 and CICA 9 in 1976. CICA 8 was released in 1978, followed by Metica 1 (line 5006) in 1980, Oryzica 1 (5738) in 1982 and Oryzica 2 in 1984. All were recommended for irrigated lands. By 1975 all of Colombia's irrigated riceland was growing semidwarfs.[166]

Estimates of the area planted with the early varieties through 1977 follow.

Year	HYRV area (ha)
1968	100
1969	9,300
1970	41,000
1971	66,600
1972	125,400
1973	165,800
1974	273,000
1975	286,000
1976	260,600
1977	235,000

The following are varietal highlights from this period:

- IR8 declined from 100% of the HYRV area in 1968 to 7.1% in 1977;
- CICA 4 averaged 33.4% of the HYRV area from 1973 to 1977; and
- CICA 6 averaged 19.3% of the HYRV area from 1975 to 1977.

No comparable data for subsequent years were obtained. Looking only at the irrigated area (all planted with HYRVs by 1975), CIAT estimates are 328,000 ha in 1980-81 and 345,900 ha in 1981-82. CIAT places the upland HYRV area at 64,400 ha in 1981-82. Thus, the total HYRV area in Colombia in 1981-82 was about 410,300 ha.

Varietal data also are fragmentary since 1977. The HYRV breakdown for 1980 was as follows: IR22,18.5%; CICA 4,16%; CICA 6,1.5%; CICA 7,4.5%; CICA 8, 51.4%; CICA 9, 7.5%; and others, 0.6%. Estimates for 1984 were Oryzica 1, 26 %; CICA 8, 20 %; IR22, 16%; CICA 4, 15%; Metica 1, 12%; CICA 9,8%; and CICA 7, 3%.[167] Part of the 1981 area of both CICA 8 (16.6%) and Metica 1 (5.9%) represented nonirrigated areas.

Rice blast has been a constant threat to Colombia's rice crop; the *Hoja blanca* virus significantly restrains yield. Metica 1 and Oryzica 1 are resistant to that virus.

Costa Rica

Semidwarf varieties were adopted early and rapidly in Costa Rica. By 1975 about 96.2% of the total rice area was planted with HYRVs, mostly in nonirrigated areas. (Costa Rica has little irrigated cropland.)

Estimates of the early HYRV area are:

Year	HYRV area (ha)
1970	16,000
1971	22,900
1972	50,000
1973	55,500
1974	64,200
1975	81,600
1976	80,200

Information on the varietal breakdown is scarce. Scattered data suggest that as of 1972 the HYRV area was entirely IR8. IR22 and CICA 4 became of increasing importance in 1972 and 1973. By 1974 more than 90% of the HYRV area was planted with CICA 4. In 1975, the principal HYRV was CR-1113 (selected from IR822-81-2 at CIAT), which provided resistance to blast disease. By 1980 CR-1113 reportedly occupied about 85% of the total rice-growing area. It continued its dominance in 1983. Two subsequent releases were CR 201 and CR 5272, both developed from unidentified lines taken from CIAT by Costa Rican trainees in 1976 and 1977.

In terms of sale of seed in 1983, CR-1113 accounted for 90.6%, CR 5272 was 7.0% and CR 201 was 2.4%. CIAT estimates that 72,300 ha were planted with HYRVs in 1981-82, virtually all of it (97%) as upland rice.[168]

Cuba

The semidwarf HYRVs had an early entry in Cuba. One account suggests that Cuba originally obtained 1 kg of IR8 seed from Mexico. A Cuban newspaper reported in December 1968 that the seed was obtained after much difficulty. Two Cuban officials visited IRRI in March 1969 and obtained small seed samples of 26 experimental lines. Production of certified seed was scheduled to begin in 1971.

As of the early 1970s, IR8 was planted widely in Cuba. Of the area planted by late May 1970, 94,700 ha, or about 91%, reportedly was IR8. Sinaloa A68, an IRRI selection from Mexico, also was grown.

The subsequent status of HYRVs in Cuba is not precisely known. However, several teams from CIAT, as well as from IRRI, visited Cuba and gathered some impressions:

- The first team visited in July 1977. It appeared that virtually all of the rice area was growing HYRVs—about half Sinaloa and the other half divided between CICA 4 and Naylamp (a sister selection of CICA 4 from Peru).
- A joint CIAT-IRRI team visited Cuba in, May and June 1978 and gathered that CICA 4 had been replaced by a selection from IR880, which occupied 80% of the area. Naylamp occupied the other 20%.[169]
- Another group, as part of the external program review of CIAT, visited Cuba in February 1984. It learned that about 70% of the area was planted with J104, 15% with the IR880 selection, 10% with Naylamp, and 5% with Carribe 1. J104 is a selection from PNA 115 from Peru, a cross between IR480 and IR930. Carribe 1 is a selection out of material introduced from Thailand.[170]

CIAT estimated Cuba's HYRV area in 1982 as 130,000 ha, all on irrigated land.

Dominican Republic

IR8 was introduced in the Dominican Republic in December 1966. Other HYRV lines and varieties followed, and two were released in 1972: Juma 57 (IR8/Nilo) and Juma 58 (Tono Brea/IR8). CICA 4 was introduced and renamed Avance 72.

About 15% of the rice-growing area in 1972-73 (perhaps 10,000 ha) was planted with identified HYRVs. Four varieties, based on varieties and lines from CIAT, were released in 1975: 44/21 (CICA 9), 44/22 (line 4422), 44/40 (CICA 8), and 44/44 (line 4444). By 1976 the total HYRV area was about 19,900 ha. The main HYRVs were Juma 57, Juma 58, Avance 72, Tanioka (a local selection from IRRI materials), IR5, and IR6.

A CIAT report places the varietal breakdown, as of 1981-82, as: Juma 58, 28%; Juma 57, 23%; Tanicha, 25%, 44/40, 12%; IR8, 2%; and other locals, 20%. About 80% of the total rice-growing area was planted with HYRVs–83,000 ha, all irrigated.

Ecuador

The major rice areas of Ecuador are less than 10 m above sea level. Although HYRVs have been grown in Ecuador since the early 1970s, there is some question about their actual area. This is partly a definitional problem. If the HYRVs are defined as IR8 (Chato) and INIAP-6 (CICA 4), they were grown on 17,500 ha in the 1971-72 crop year, 24,200 ha in 1972-73, and 61,900 ha in 1973-74.

Similar estimates have not been found for subsequent years. Data were obtained, however, for the total area planted with IR8 and INIAP varieties by calendar year from 1970 to 1977.

Year	Area (ha)
1970	15,700
1971	9,900
1972	15,800
1973	41,700
1974	78,400
1975	98,000
1976	83,000
1977	79,400

The problem with this classification is that varieties included under the INIAP category are not fully identified. Those that are known—INIAP-2 (IR22), INIAP-6, INIAP-7

(CIAT line 4444), INIAP-9 (IR5-114-3-l), and INIAP-415 (based on P1042-2-2-3-18 from CIAT)—are HYRVs.[171]

CIAT placed the 1981-82 HYRV area at 85,000 ha, of which 85% was irrigated. As of early 1984, the National Rice Program indicated that mainly two improved varieties have been planted—INIAP-415on 60,000 ha and CICA 6 on 40,000 ha. INIAP 7 and INIAP 415 also were planted in nonirrigated areas.[172]

El Salvador

HYRVs grown in El Salvador include CR1113 (IR822-81), Nilo 9 IIR160-25), Nilo 11 (IR579-48-l), x-10 (unidentified from CIAT), CICA 4 and CICA 6, and CENTA A2 and CENTA A3 (Pl008-8-16-6-113-53/52). The latter two were released in 1982.

As of the 1977-78 season, the Rice Producers Cooperative estimated that at least 50% of the rice growing area was planted with HYRVs. CIAT placed the HYRV area in 1981-82 at 13,900 ha, of which only 10% was irrigated.

Guatemala

The first semidwarf HYRVs grown in Guatemala were probably CICA 4 and IR22. CICA 4 was grown on about 250 ha in 1974 and on nearly 1,500 ha in 1975. Other HYRVs raised on another 475 ha in 1975 included IR100, CR-1113, and ICTA-6 (CICA 6).

In 1977 Tikal 2 was introduced. It originated from CIAT line 4422, a sister line of CICA 9. It is estimated that about 4,000 ha of Tikal 2 were planted in 1978. It accounted for more than 50% of Ecuador's total rice area in 1979 and for about 60% in 1980.[173]

Other released varieties include ICTA Virginia (CICA 8), ICTA Cristina (4440-10), and Tempisque (Pl008-8-16-6-113-53). Tempisque was released in 1981. CIAT estimates that the HYRV area in 1981-82 was 3,100 ha, all upland.

Guyana

Despite its small size, Guyana is a relatively large rice producer. During the 1960s, a program was begun to improve the rice industry; in 1974, a new rice research station was opened as part of an AID loan.

IRRI and CIAT materials have been used as a basis for selecting varieties suited to local conditions. Two such varieties, N and S, were released in the early 1970s. Both were probably selections of IR1055. Two other varieties, Rustic and Champion, subsequently were released; no information is available on their parentage. In 1981 these varieties, particularly Rustic and N, occupied 57% of the area planted with rice. Further expansion reportedly continued in 1982.[174]

CIAT placed the HYRV area in 1977-78 as 24,300 ha. USDA reports the total rice area in 1981 as 110,000 ha (57% of which is 62,700 ha).

Haiti

Haiti annually raises about 45,000 ha of rice, 19,000 ha in the first crop and 26,000 in the second crop. Four HYRVs are grown—ODVA 1, MCI 3, Quisqueya, and CICA 8. The ancestry of the first three is not known. As of 1981-82, CIAT estimates the HYRV area at about 3,700 ha.

During the 1983-84 crop year, about 11,000 ha of HYRVs were grown. The overall area was fairly evenly divided among ODVA 1, MCE 3, and Quisqueya, with only a small area planted with CICA 8. During the first half of the 1984-85 season, the semidwarf area expanded to about 9,000 ha, an increase of 5,000 ha over the 1983-84 season. Based on these figures, the semidwarfs account for about 36% of the total rice area.[175]

Honduras

The HYRVs were quickly and widely adopted in Honduras. Acreage in the 1970s was: 1973, 2,500 ha, mainly IR8 with some CICA 4; 1975, 6,300 ha, principally CICA 4; and 1976, 6,000 ha, principally CICA 6. The 1976 HYRV area represented about 38% of the total rice area.

More recently, the HYRVs—principally the CICA series—are even more widely used. In 1981-82 CICA rices were grown on 18,000 ha, 85% of the total rice growing area. By 1983-84 CICA rices covered 21,400 ha, 97% of the total growing area.

CICA 8 has grown sharply in importance while CICA 9 declined. In 1983-84 CICA 8 represented 83% of the total area, followed by CICA 9 with 10%, CICA 4 with 2% and CICA 6 with 2%. CR1113 and Tikal 2 (line 4422) also have been released in Honduras but it is not known how much area they cover.[176]

CIAT estimates that the Honduran HYRV area in 1981-82 was 23,000 ha, 26% of which was irrigated. The CIAT figure is slightly high compared to the data above.

Mexico

HYRVs have long played an important role in rice production in Mexico. Mexican HYRVs include semidwarfs and varieties of medium height. The HYRVs are conveniently grouped on the basis of their suitability for various cultural conditions—irrigated only, irrigated or rainfed lowland, and upland. Varieties of medium height are most apt to fall in the rainfed and upland categories.[177]

HYRVs in use through 1983 were:

- Irrigated: Junchtan A74, Joachin A74, Piedras Negras A74 (IR831-20-3-6), Bamoa A75 (IR837-46-2), Sinaloa A80, Huastecas A80, Culiacan A82, and Morelos A83. The parentage of the Mexican crosses is Juchitan A74 ([CB572-A3-47-15] [B589-A4-18-1]), Joachin A74 (Corerepe A66^{3}AN-1//IR160-27-4), Sinaloa A80 (Sinaloa A68/Bluebonnet 50), Huastecas A80 (Sinaloa A68/Sinaloa A64), Culican A82 (SET 569-P204/Sinoloa, A68), and Morelos A83 (Jojutla Mejorado/Naylamp).
- Irrigated or rainfed lowland: Sinaloa A68 (IR160-27-4), Navolato A71 (sister of IR22), CICA 4, CICA 6, and Milagro Filipino (IR8).
- Upland: Grijalva A71, Mascupana A75, Campeche A80, Champoton A80, Cardenas A80, CICA 8, and CICA 9. The parentage of the Mexican crosses is Grijalva A7a (Bluebonnet 50^2/Gulfrose), Mascupana A75 (Venus A681 Peta//Tang Kai Rotan), Campeche A80 (Grijalva A71^3/Tetep), Champoton A80 (Grijalva A71^3/Carreon), and Cardenas A80 (C4-63//Gow Ruang 88/Sigadis).

The total area planted with HYRVs is reported in table 3.28. HYRVs expanded through the mid-l970s, dropped in 1978, increased to a peak level in 1982, and dropped again in 1983.

Varieties changed in relative importance over time. During the 1971-72 to 1973-74 period, Sinaloa A68 was the leading HYRV, followed by IR8. Throughout the 1974 to 1983 period, Navotaro A71 led by a wide margin, followed at various points by Sinaloa A68, Banoa A75, and CICA 4. As of 1983, Navolato A71 occupied 46% of the HYRV area, followed by Campeche A80 with 17.3%, Milagro Filipino (IR8) with 8.2%, and CICA 4 with 5.8%. The use of Campeche A80 expanded sharply in 1982 and 1983, and the use of Milagro Filipino gradually expanded from 1978 to 1983. The rainfed varieties represented 23.2% of the total area in 1983, compared to 14.5% in 1976.

The change in individual varieties in Mexico is tied to a larger shift in production patterns. From 1976 to 1979, the proportion of the total irrigated rice area rose from 54% to 74%. In 1980 the irrigated proportion dropped sharply to 55%, and,

Table 3.28. Area of high-yielding rice varieties, Mexico, 1970 to 1983

Year	HYRV area (ha)[a]	Proportion of total area (%)
1970	51,100	NA
1971	69,400	NA
1972	76,000	NA
1973	88,100	NA
1974	115,900	NA
1975	182,600	NA
1976	136,100	84.6
1977	158,000	87.6
1978	99,200	81.6
1979	114,700	81.5
1980	109,100	82.7
1981	150,800	84.0
1982	181,100	87.5
1983	145,500	92.0

NA=Data not available.

[a]Includes semidwarf and medium height varieties. Excludes tall varieties.

Sources: 1970-1975: Calculated from information provided by Mexican Department of Agriculture and sent in letter from R.S. Welton, agricultural attache, American Embassy, Mexico City, October 1975. 1976-1983: Calculated from information provided by L. Hernandez Aragon, plant breeder and coordinator, INIA-South Area Rice Program, Instituto Nacional de Investigaciónes Agricolas, Zacatepec, Morelos, Mexico, December 1984.

aside from a slight rise in 1981, continued to drop through 1983, when it reached 37%. Since 1980 rice production has, for economic reasons, been shifting from the irrigated production areas in the northwest, in Sinaloa and Veracruz, to rainfed upland growing areas in the southeast, in Campeche, Tabasco and Quintana Roo. Several of the rainfed varieties noted above—Campeche A80, Cardenas A80, and Champoton A80—were developed for this region.

Nicaragua

HYRVs were quickly adapted in Nicaragua and represented about 89% of the total rice area as of the 1976-77 crop-year. In 1977 the HYRV area was 18,700 ha, divided by variety as follows: IR100, 64.9%; IR22, 21.6%; CR-1113, 7.2%; CICA 4, 2.7%; CICA 6, 1.8%; and Linea 9 (CICA 9) 1.8%. About 85% of the total HYRV area was irrigated and 15% was dryland.

As of 1980 the CICA 4 area was about 10% and CICA 8 was being multiplied for release, with the expectation that 20% to 30% of the area would be planted with the two varieties.[178] As of the 1981-82 crop year, CIAT estimated the total HYRV area at 31,900 ha, of which about 70% was irrigated.

Panama

Rice is largely produced on large-scale mechanized farms in Panama. Most rice is grown without irrigation. The main rice region is Chiriqui Province along the Pacific Coast. Early data on HYRVs for Panama suggest that in 1974 the total area of CICA 4 and CICA 6 was about 5,600 ha. Estimates of the HYRV area for the period 1976-77 to 1982-83 are shown in table 3.29. By comparison, CIAT estimated Panama's HYRV area in 1981-82 at 55,200 ha, only 9.4% of which was irrigated.

Table 3.29. Estimated area of high-yielding rice varieties, Panama, 1976-77 to 1982-83

Crop year	HYRV area (ha)	Proportion of total area (%)
1976-77	22,600	50.6
1977-78	18,400	36.5
1978-79	17,300	37.1
1979-80	28,800	68.7
1980-81	36,300	87.1
1981-82	47,100	89.7
1982-83	57,200	NA

NA=Data not available

Much of the expansion in area after 1979-80 was due to an increase in the area planted with CICA 7 (33.9% of the total in 1982-83). Other varieties of particular importance at various points during the 1976-77 to 1982-83 period were CICA 8, CR5272, LA444, T-5430 (Tocumen), and CR-1113. T-5430 was released by the University of Panama in 1980. Varieties of lesser importance were CICA 4, CICA 6, CICA 9, Damaris (Linea 15), Anayansi (Linea 9), IR8, and IR25. IR25 increased in use in 1982-83.[179]

Paraguay

CICA 4 and CICA 6 were the third most important variety group in Paraguay in 1976. They were planted on about 5,200 ha, about 25% of the irrigated rice area. Other CICA varieties were in use by 1980. Additional varieties of CIAT origin included CR1113, INIAP 7, and Adelaida 1.[180] As of the 1981-82 season, about 63% of the total rice area was planted with CICA varieties. CIAT estimated the HYRV area in Paraguay that year as 20,700 ha, all irrigated.

Peru

The HYRV area in Peru grew substantially through the early 1970s.

Crop year	HYRV area (ha)
1971-72	25,500
1972-73	38,300
1973-74	36,700
1974-75	62,400
1975-76	70,300
1976-77	71,300

Varieties involved were IR8, Naylamp (IR930-2-6), Chancay (CICA 4), Huallaga (IR442-2-50), and Inti. After dominating the area the first 2 years, IR8 gave way to Naylamp, which averaged 65% of the HYRV area from 1973-74 to 1976-77.

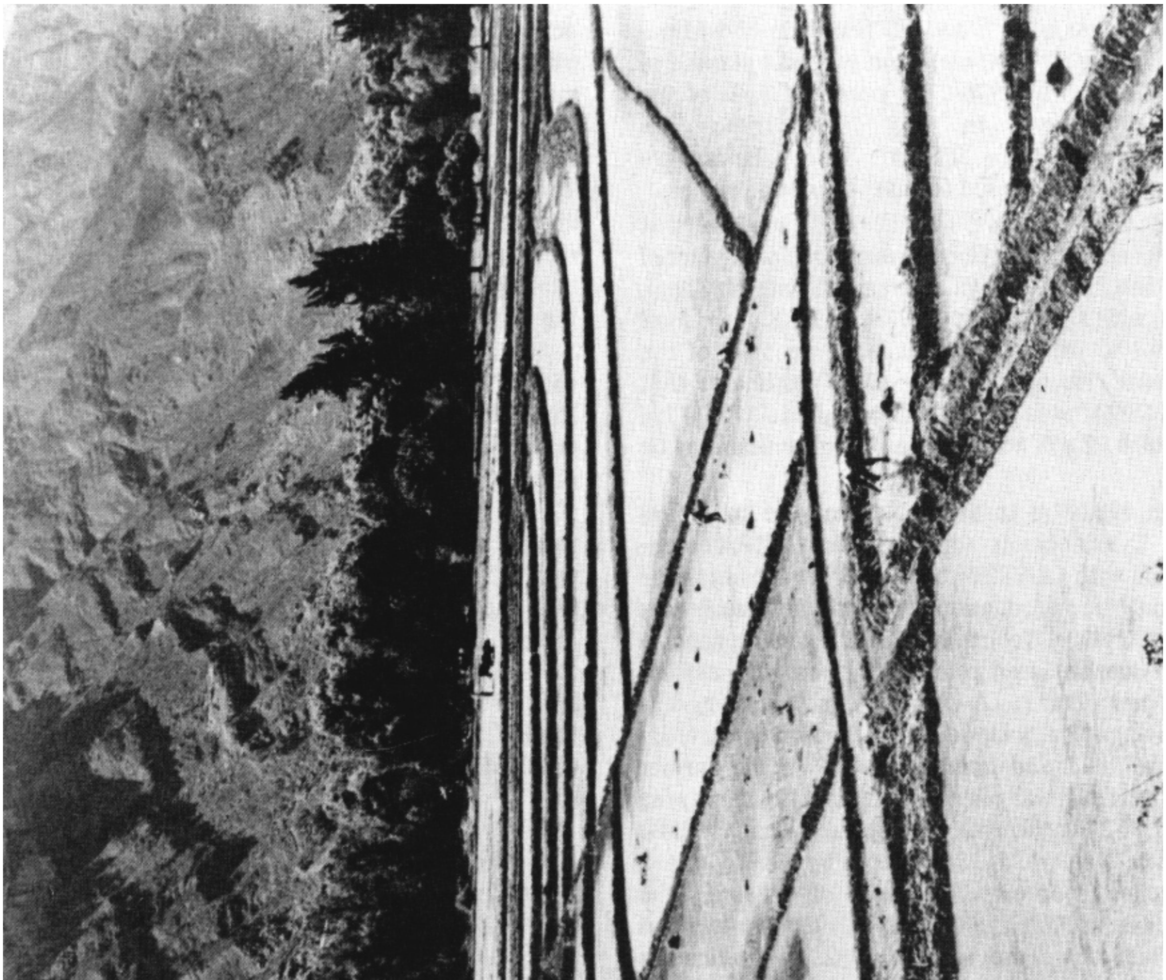


Figure 3.8. Paddy rice production in Peru. Source: Agency for International Development.

89

Inti was developed in the National Rice Program from a cross of IR8 and F5 (Fortuna and Minagra); it is short (100 cm). Inti was first planted in 1975-76, and in 1976-77 it occupied 21% of the HYRV area. In late 1982, three new HYRVs—VI-Flor, Tallan, and Huarangopampa—were released for use in coastal regions.

CIAT estimates for 1981-82 suggest that 52.4% of the total rice-growing area was planted with Inti, 5.8% with Chancay, 5.2% with Naylamp, 3.8% with Bg90-2, and 2.2% with IR 8, for a total of 69.4%. In 1981-82 Inti made up 56% of the national rice production. CIAT estimates that the HYRV area in 1981-82 occupied 111,400 ha, of which 92.8% was irrigated, a figure that may be high.

In 1982 the Instituto Nacional de Investigacion y Promocion Agropecuaria (INIPA) contracted with CIAT for a study of ways to increase national rice production. A cooperative team was established and concluded that the *selva* zone in the Amazon basin offered the best chances for production gains. A comprehensive strategy was developed that included the selection of varieties for irrigated and upland zones. In the former case, CICA 8 was released for the Alto Mayo area and PA-2 for the Huallaga Central area. By 1984 the rice area in Alto Mayo rose by 67%; CICA 8 was planted on more than 60% of the area. The rice area in Huallaga Central in 1984 was two and one-half times the area in 1982. Varieties for upland areas were, as of 1985, in farmers' fields for final evaluation.[181]

Suriname

Rice production in Suriname is largely irrigated and highly mechanized. The principal irrigated area is in Nickerie, a coastal district bordering Guyana. The Dutch established a large rice project in Nickerie in 1949. It now has an area of about 10,000 ha. Several projects in the area were expected to have increased the irrigated rice area by another 20,000 ha by 1985.

The research division of the Nickerie project developed several improved HYRV varieties, which are early maturing and semidwarf. The six main varieties as of the late 1970s were Camponi (1974), Ceysvoni, Diwani (1976), Eloni (1979), Siwini, and Pisari. Pedigrees are not known. Their early maturity characteristic facilitated double cropping and their extra-long grain provided good milling quality. Nearly half of Suriname's rice production is exported, principally to the European Economic Community.

Just how large an area in Suriname is planted with HYRVs is uncertain. As of 1977 essentially all of the irrigated rice area of about 30,000 ha was reported planted with HYRVs. CIAT estimated that all of the irrigated area of 35,700 ha in 1981-82 was sown with HYRVs. The upland area was estimated at 3,100 ha and was not planted with HYRVs. Other recent data suggest that the total rice area in 1983 was 43,000 ha and that double cropping raised the total annual crop area to 73,300 ha. Thus, if the irrigated portion of both crops was planted with HYRVs, the total HYRV area might be considerably higher than previously indicated.[182]

Venezuela

HYRVs were planted on a significant area in Venezuela in 1973: 30,000-40,000 ha were planted with IR8 and CICA 4. HYRVs were planted on 104,000 ha in 1974-75,120,000 ha in 1975-76, and 141,700 ha in 1976-77. CICA 4 was the principal variety (59.1% of the HYRV area) followed by IR22 (22.6%), and CICA 6 (18.4%).

Later releases were Ciarllacen 1 (CICA 9), Araure 1, Araure 2, CENTA A2, and CENTA A3 (all listed in table 3.26). CIAT estimated that Araure 1 represented about 80% of the HYRV area in 1981-82 and that CICA 4 occupied the remaining 20%. Subsequently, the Araure 1 proportion increased to 90% and CICA 4 dropped to 10%.[183] CIAT placed the total HYRV area in 1981-82 at 200,000 ha, of which 30% was irrigated.

REFERENCES AND NOTES

[1]E.B. Copeland, Rice (London: Macmillan, 1924), p. ix.

[2]U.S. Department of Agriculture, "Grain Data Base," Washington, D.C.: the Department, International Economics Division, Economic Research Service, January 1985 (computer printout).

[3]International Rice Research Institute, *A Plan for IRRI's Third Decade* (Los Baños, Philippines: IRRI, 1982), p. 26.

[4]International Rice Research Institute,

Research Highlights for 1983 (Los Baños, Philippines: IRRI, 1984), pp. 45-48. For more general information on the IRTP, *see* H.E. Kauffman and D.V. Seshu, "The International Rice Testing Program," in International Rice Research Institute, *Rice Improvement in China and Other Asian Nations* (Los Baños, Philippines: IRRI, 1980), pp. 65-74; D.L. Plucknett and N.J.H. Smith, "Networking in International Agricultural Research," *Science* 225 (September 1984):991; and "IRTP Entries Lead to New Varieties," *The IRRI Reporter* (3) (September 1984):l-2.

[5]T.R. Hargrove, V.L. Cabanilla, and W.R. Coffman, *Changes in Rice Breeding in 10 Asian Countries, 1965-84; Diffusion of Genetic Materials, Breeding Objectives, and Cytoplasm,* Research Paper Series No. 111 (Los Baños, Philippines: International Rice Research Institute, October 1985), p. 9.

[6] U.S. Department of Agriculture, op. cit. *(see* footnote 2). A vast amount of statistical and economic information on this region has recently been provided in R. Barker, R.W. Herdt, and B. Rose, *The Rice Economy of Asia* (Washington, D.C.: Resources for the Future, 1985), 324 pp.; and B. Rose, *Appendix to the Rice Economy of Asia* (Washington, D.C.: Resources for the Future, 1985), 404 pp.

[7]International Rice Research Institute, loc. cit. *(see* footnote 3). Data include China. For detailed information *see* R.E. Huke, *Rice Area by Type of Culture: South, Southeast, and East Asia* (Los Baños, Philippines: International Rice Research Institute, 1982), 32 pp.

[8]D.G. Dalrymple, *Development and Spread of High-Yielding Varieties of Wheat and Rice in the Less Developed Nations,* Foreign Agricultural Economic Report No. 95 (Washington, D.C.: U.S. Department of Agriculture, 1978), 134 pp.

[9]R.W. Herdt and C. Capule, *Adoption, Spread and Introduction Input of Modern Rice Varieties in Asia* (Los Baños, Philippines: International Rice Research Institute, 1983), 54 pp. Herdt and Capule in some cases updated statistics I had reported for earlier periods; in other cases they reported revised data for a longer period.

[10] N. Parthasarathy, "Rice Breeding in Tropical Asia Up to 1950," in International Rice Research Institute, *Rice Breeding* (Los Baños, Philippines: IRRI, 1972), p. 14.

[11] S.M.H. Zaman, M.A. Choudhury, and M.S. Ahmad, "Progress in Rice Breeding in East Pakistan," in International Rice Research Institute, *Rice Breeding* (Los Baños, Phlippines: IRRI, 1972), pp. 151-155; S.M.H. Zaman, "The Importance of the IRTP in IRRI's Varietal Improvement Work," in International Rice Research Institute, *Rice Improvement in China and Other Asian Countries* (Los Baiios, Philippines: IRRI, 1980), pp. 251-256; and R.F. Chandler, *An Adventure in Applied Science: A History of the International Rice Research Institute* (Los Baños, Phlippines: IRRI, 1982), pp. 140-142.

[12] Zaman, op. cit. *(see* footnote 11), pp. 251-252, 255-256; S.M.H. Zaman, "Rice," in *Agricultural Research in Bangladesh* (Dhaka: Bangladesh Agricultural Research Council, 1983), p. 32; letter from F.W. Sheppard, Jr., IRRI representative, Bangladesh Rice Research Institute, March 1984 (with attachment prepared by D.G. Kanter). BR4 is known as Sintheingi in India; BR6 is known as Semeru in Indonesia.

[13] Based on statistics from the Bangladesh Bureau of Statistics as (1) provided by B. Jadwin, USAID, Dhaka, March 1984; and (2) published in *Monthly Bulletin of Bangladesh* 10(7) (July 1981):56-57, and *Monthly Bulletin of Bangladesh* 12(3) (March 1983):29-30. Data on the distribution of the crop over the three seasons from 1968 to 1977 are provided in Dalrymple, op. cit. *(see* footnote 8), p. 72.

[14] Parthasarathy, op. cit. *(see* footnote 10), p. 19.

[15] H.M. Than, "Progress of Rice Breeding in Burma," in International Rice Research Institute, *Rice Breeding* (Los Baiios, Phlippines: IRRI, 1972), pp. 133-135. Details on the introduction of IR8 are provided in Chandler, op. cit. *(see* footnote 11), p. 113. For background, *see* H.V. Richter, "The High Yield Program in Burma," in *Technical Change in Asian Agriculture,* ed. R.T. Shand (Canberra: Australian National University Press, 1973), pp. 144-160.

[16] I have placed dashes between the components of the names. Another system replaces the dashes with spaces and capitalizes the letters following. A third variant involves no spaces or dashes.

[17] K. Zin, *Burma and the CGIAR Centers: A Study of Their Collaboration in Agricultural Research,* Study Paper 20 (Washington, D.C.: Consultative Group on International Agricultural Research, 1986).

[18]"Mutant Variety Success in Burma," *Mutation Breeding Newsletter* (19) (January 1982):l.

[19]Burma, Ministry of Agriculture and Forests, Extension Division, "Rice Production in Burma (1962-63 to 1980-81)," Rangoon, Burma, February 1982, pp. 9-14 (mimeographed). Department of State telegram 3995 from Rangoon, Burma, August 7, 1984; Zin, op. cit. *(see* footnote 17), p. 19.

[20]U. Khin Win, U. Nyi Nyi, and E.C. Price, *The Impact of a Special High-Yielding Rice Program in Burma,* Research Paper Series No. 58 (Los Baños, Philippines: International Rice Research Institute, March 1981), 11 pp.; "Rice Production Policy of Burma," *International Rice Commission Newsletter* (June 1982):ll; Zin, op. cit. *(see* footnote 17), p. 19; and International Rice Research Institute, *International Rice Research: 25 Years of Partnership* (Los Baiios, Philippines: IRRI, 1985), p. 73.

[21]Calculated from data provided in Department of State telegram 0395 from Rangoon, Burma, January 25, 1985, and supplemented by data from Agriculture Corporation forwarded by USAID, Rangoon, Burma, August 1984.

[22]In the case of "Rice Production in Burma" (Burma, Ministry of Agriculture and Forests, op. cit. [*see* footnote 19], p. 9), Ngwetoe is left out of the totals from 1959-1960 to at least 1973-74.

[23]One holding (Acc. 33697) is 182 cm; the other (Acc. 33698) is 165 cm (letter from T.T. Chang, geneticist, IRRI, September 1984). We cannot be certain that these accessions are typical of Shwe-ta-soke.

[24] *International Rice Commission Newsletter,* op. cit. *(see* footnote 20):22; and Burma, Ministry of Agriculture and Forests, op. cit. *(see* footnote 19), p. 9.

[25]G. Hildebrand, *Cambodia: Starvation and Revolution* (New York: Monthly Review Press, 1976), p. 93.

[26] The following unpublished reports are from the Office for Special Relief Operations, Food and Agriculture Organization of the United Nations. "Report of the Food Assessment Mission to Kampuchea," November 1980, p. 24; "Report of the Mission of the Rice Cultivation Consultant to Kampuchea," December 1980, pp. 8, 10, 13, 16, 23; "Report of the Review Mission on the Food and Agriculture Situation in Kampuchea," February 1981, pp. 13, 30; "Report of the Food and Agricultural Assessment Mission," December 1982, pp. 27-31,40.

[27]J. Spragens, Jr., and J. Charney, *"Obstacles to Recovery in Vietnam and Cambodia:* US. *Embargo of Humanitarian Aid,* Impact Audit Series No. 3 (Boston: Oxfam America, 1984), pp. 93, 100, 201.

[28]International Rice Research Institute, *IR36* (Los Baiios, Philippines: IRRI, 1982), p. 9.; letter from Chang *(see* footnote 23). Further detail on the traditional seed project is provided by J. Charney in "Background Report on Return of Khmer Traditional Varieties to Kampuchea," Oxfam America, Boston, March 1982,2 pp.

[29]G.S. Khush, D.W. Puckridge, and G.L. Denning, "Trip Report to People's Republic of Kampuchea, January 1986," Los Baños, Philippines, International Rice Research Institute, p. 8.

[30]S. Jin-Hua, "Rice Breeding in China," in International Rice Research Institute, *Rice Improvement in China and Other Asian Countries* (Los Baños, Philippines: IRRI, 1980), pp. 20-22.

[31]Ibid., pp. 23-24; letter from Chang *(see* footnote 23), August 1984.

[32] *Mutation Breeding Newsletter* (19) (January 1982):16 and (21) (January 1983):14. A detailed list of varieties developed through induced mutation from 1965 through 1981 is provided in the No. 25 (January 1985) issue, pp. 11-16.

[33]B. Stavis, *China's Green Revolution,* East Asia Papers, No. 2 (Ithaca, N.Y.: Cornell University, 1974), pp. 20-27.

[34]National Academy of Sciences, *Plant Studies in the People's Republic of China: A Trip Report of the American Plant Studies Delegation* (Washington, D.C.: the Academy, 1975), p. 48.

[35]W.R. Coffman and S.S. Virmani, "Advances in Rice Technology in the People's Republic of China," in *Agricultural and Rural Development in China Today,* ed. R. Barker and B. Rose, Cornell International Agriculture Mimeograph 102, Ithaca, N.Y., November 1983, p. 4.

[36]Based on conversations with W.R. Coffman, professor of plant breeding, Cornell University, and J.N. Rutger, rice geneticist, U.S. Department of Agriculture, March 1984.

[37]Several reporters pointed out the similarities between the IRRI and Chinese varieties. One reported that IR8 was being used in China: He indicated that the Chinese began their first

experiments with the seed in 1968 and then placed orders for seed through proxies in Nepal and Pakistan for spring planting in 1970 (R. Hughzs, "China Samples the Rockefeller Rice," *London Sunday Times,* February 15, 1970).

[38] National Academy of Sciences, op. cit. *(see* footnote 34), pp. 50-53. Also see "IRRI Director: China May Cooperate in Global Rice Improvement," *The IRRI Reporter* (1) (1974): 1-2.

[39] *See* "Scientific Exchange With China Would Stimulate Rice Production," *The IRRI Reporter* (1) (January 1977):l-3; International Rice Research Institute, *Rice Research and Production in China: An IRRI Team's View* (Los Baños, Philippines: IRRI, 1978), 119 pp.; and International Rice Research Institute, *Rice Improvement in China and Other Asian Nations* (Los Baños, Philippines: IRRI, 1980), 307 pp.

[40] C.S. Ying and S.Z. Yuan, "IRRI Varieties and Advanced Lines Used in China," *International Rice Research Newsletter* (February 1983):3. In addition, IR28 is raised in the single-crop mountainous areas of Hunan Province and IR36 in the single-crop area of An-Hui Province (letter from G.S. Khush, plant breeder, IRRI, May 1985). China also received varieties from other nations: Bg90-2 from Sri Lanka proved well adapted, and in 1983 about 140,000 ha were grown in Juangsu Province and other provinces in the Nanjing region along the Yangtze River. C.S. Ying, "Bg 90-2 Released in China," *International Rice Research Newsletter* (February 1985):6-7.

[41] Ying and Yuan, loc. cit. *(see* footnote 40); *Nongye Jichu* (1981), p. 220 (provided by L.F. Wong, Department of Agricultural and Applied Economics, University of Minnesota, December 1984).

[42] Parthasarathy, op. cit. *(see* footnote 10), pp. 14-17.

[43] C.E. Pray, "The Impact of Agricultural Research in British India," *Journal of Economic History* 19(2) (June 1984):430-437. Data for 1930-31 from J.W. Jones, "Improvement in Rice" in U.S. Department of Agriculture, *Yearbook of Agriculture,* 1936 (Washington, D.C.: the Department, 1936), pp. 435-436.

[44] V.D. Wickizer and M.K. Bennett, *The Rice Economy of Monsoon Asia* (Stanford, Calif.: Stanford University Press, 1941), p. 238.

[45] H.K. Pande and R. Seetharaman, "Rice Research and Testing Program in India" in International Rice Research Institute, *Rice Improvement in China and Other Asian Countries* (Los Baños, Philippines: IRRI, 1980), pp. 37-39. W.F. Freeman and S.V.S. Shastry, "Rice Improvement in India—the Coordinated Approach," in International Rice Research Institute, *Rice Breeding* (Los Baños, Philippines: IRRI, 1972), pp. 115-132. More recent information is provided by H.K. Jain, "India's Coordinated Crop Improvement Projects: Organization and Impact," in *Indian Farming* (July 1984). (Reprinted by the International Service for National Agricultural Research, Series No. 2, The Hague, April 1985).

[46] Chandler, op. cit. *(see* footnote 11), pp. 113-114; Dalrymple, op. cit. *(see* footnote 8), p. 74.

[47] Pande and Seetharaman, op. cit. (*see* footnote 43, pp. 39-41.

[48] R. Seetharaman, "Rice in India—Present Status, Prospects, and Approaches," *International Rice Commission Newsletter* (December 1983):12. Varieties named from IRRI crosses are listed in table 2.4. Many of these releases are noted in the quarterly issues of the *International Rice Research Newsletter* issued by IRRI.

[49] Pande and Seetharaman, op. cit. *(see* footnote 45), p. 39.

[50] Calculated from data provided by M. Landes, International Economics Division, Economic Research Service, U.S. Department of Agriculture. (HYRV data as reported in 1984 by the Fertilizer Association of America, New Delhi, India.)

[51] Herdt and Capule, op. cit. *(see* footnote 9), p. 49.

[52] R.H. Bernsten, H. Siwi, and H.M. Beachell, *The Development and Diffusion of Rice Varieties in Indonesia,* Research Paper Series, No. 71 (Los Baños, Philippines: IRRI, 1982), 25 pp. Also of value were Parthasarathy, op. cit. (*see* footnote 10), pp. 21-22; Z. Harshap, H. Siregar, and B.W. Siwi, "Breeding Rice Varieties for Indonesia," in International Rice Research Institute, *Rice Breeding* (Los Baños, Phlippines: IRRI, 1972), pp. 141-146; Herdt and Capule, op. cit. *(see* footnote 9), pp. 9-11,51; W.B. Ward, *Science and Rice in Indonesia* (Boston: Oelgeschlager, Gunn & Hain, 1985), pp. 13-21, 40; and information provided by W.C. Tappan, IRRI liaison scientist, Bogor, Indonesia, November 1984. Also see A. Affandi, "The Rice Revolution in Indonesia: The Indonesian Experience in Increasing Rice Production," in International Rice Research Insti-

tute, *Impact of Science on Rice* (Los Baños, Philippines: IRRI, 1985), pp. 32-39; and B. Nestel, *Indonesia and the CGIAR Centers; A Study of Their Collaboration in Agricultural Research,* Study Paper 10 (Washington, D.C.: Consultative Group on International Agricultural Research, 1985), pp. 42-46, 55-57, and 104-106.

[53] Indiscriminate use of insecticides is believed by some to have upset the ecological balance by killing the natural enemies of the BPH. For more general information, *see* International Rice Research Institute, *Brown Planthopper: Threat to Rice Production in Asia* (Los Baiios, Philippines: IRRI, 1969), 369 pp.

[54] Bernsten et al., op. cit. *(see* footnote 52), p. 13.

[55] The parentage of Cisadane is Pelita I-a/B2388 (IR789/IR2157).

[56] Official statements from "Overview of Stable High Yields of Paddy Rice in Korea," Study Tour and Asian Regional Consultation on Achievement of Stable High Yields of Paddy Rice in D.P.R. of Korea, Pyongyang, 1-10 September 1982 (ARC/82/04), pp. 4-6. Further information provided by P. Hendry, FAO, Rome, May 1985; MS. Swaminathan, G.S. Khush, and B.S. Vergara, "Rice Research and Production in the Democratic People's Republic of Korea" (trip report), International Rice Research Institute, Los Baños, Philippines, December 1985, pp. 19-23.

[57] For background, *see* Y. Hayami, "Development and Diffusion of High Yielding Rice Varieties in Japan, Korea, and Taiwan," in Shand, op. cit. *(see* footnote 15), pp. 20-24. Similar information is provided in Y. Hayami and V.W. Ruttan, *Agricultural Development: An International Perspective* (Baltimore: The Johns Hopkins Press, 1971), pp. 207-210.

[58] A table provided by G-S. Chun, director of the Yeongnam Crop Experiment Station in Milyang, South Korea (May 1984), lists 34 individual HYRVs, plus other varieties, that were released or used by farmers between 1973 and 1983.

[59] G.S. Chung and M.H. Heu, "Status of Japonica-Indica Hybridization in Korea," in International Rice Research Institute, *Innovative Approaches to Rice Breeding* (Los Baños, Philippines: IRRI, 1980), pp. 135-152. *Also see* R.F. Chandler, Jr., *Rice in the Tropics: A Guide to the Development of National Programs* (Boulder, Colo.: Westview Press, 1979), pp. 113-122.

[60] T.T. Chang, "Conservation of Rice Genetic Resources: Luxury or Necessity?" *Science* 224 (April 1984):254-255; letter from Chang, January 1985.

[61] Based on US. Agricultural Attaché Reports KS-3013 (March 30, 1983, pp. 12-13) and KS-3053 (December 22,1983, pp. 7-8) from Seoul.

[62] A recent article suggests that yields of the Tongil-type varieties have to be 15% to 25% higher than traditional varieties if farmers are to find it more profitable to grow them ("The Rice Production Policy of the Republic of Korea," *International Rice Commission Newsletter* [December 1982]:17). Tongil-type yields from 1978 to 1983 averaged only 9.4% higher.

[63] "Rice Activities in the Republic of Laos," *International Rice Commission Newsletter* (December 1982):44; R.B. Singh, "Rice Production in Lao People's Democratic Republic," *International Rice Commission Newsletter* (December 1984):11-18; and letter from T. Ton That, agriculture officer (rice agronomy), Plant Production and Protection Division, FAO, Rome, April 1984.

[64] N. Parthasarathy, op. cit. *(see* footnote 10), p. 21; B.H. Chew and M. Sivanaser, "Progress of Rice Varietal Improvement in West Malaysia," in International Rice Research Institute, *Rice Breeding* (Los Baños, Philippines: IRRI, 1972), pp.147-149.

[65] Chew and Sivanaser, op. cit. *(see* footnote 64), pp. 148-149; Dalrymple, op. cit. *(see* footnote S), p. 79, footnote 5b; C.Y. Hwa, J. Varughese, M.B. Osman, and L.K. Hup, "Varietal Evaluation in the Double Cropping Areas," in Malaysian Agricultural Research and Development Institute, *Research for the Rice Farmer; Proceedings of the National Rice Conference* (Kuala Lumpur, Malaysia: the Institute, 1980), pp. 72-88; letters from M.Y.B. Hashim, director general, Malaysian Agricultural Research and Development Institute, Kuala Lumpur, March and May 1985; "Characteristics of Released Padi Varieties," paper provided by O. Othman, Malaysian Agricultural Research and Development Institute, Kuala Lumpur.

[66] The data for 1981-82 come from a publication *(Paddy Statistics, Peninsular Malaysia, 1982)* that is evidently issued annually by the Ministry of Agriculture but is little known outside the country. The HYRV category as defined here includes all of the individual varieties listed in the bulletin for the main and off-seasons, with the exception

of Serendah Kuning and Mandu Tiga, which occupied small areas. (They may also be HYRVs, but I have no information on them.) The total rice area in Sabah and Sarawak in 1980 was 186.000 ha, compared to 519,000 ha harvested in West Malaysia (B. Rose, *Appendix to the Rice Economy of Asia* [Washington, D.C.: Resources for the Future, 1985], pp. 216, 228, 237).

[67]Based on letters from Hashim, op. cit. (*see* footnote 65) (including unpublished attachment titled, "Percentages of Main Padi Areas Planted With High Yielding Varieties"); and G.S. Khush, plant breeder, IRRI, 1985 (based on conversation with O. Othman of the Malaysian Agricultural Research and Development Institute). Grain quality is a particularly important consideration in Malaysia *(see* L.J. Fredericks and R.J.G. Wells, *Rice Processing in Peninsular Malaysia* (New York: Oxford University Press, 1983).

[68]Herdt and Capule, op. cit. *(see* footnote 9), p. 13.

[69]Dalrymple, op. cit. *(see* footnote S), p. 80.

[70]Letter from C.T. Hash, USAID, Kathmandu, Nepal, September 1984.

[71]K.P. Shrestha, B.R. Akhikary, B.B. Shahi, and S. Samoto, "Three New Rice Varieties for Nepal," *International Rice Research Newsletter* (August 1982):3-4.

[72]R.P. Sharma and J.R. Anderson, *Nepal and the CGIAR Centers; A Study of Their Collaboration; in Agricultural Research,* Study Paper No. 7 (Washington, D.C.: Consultative Group on International Agricultural Research, October 1985), pp. 7, 33, 34. This judgment is in part based on the result of some farm household surveys.

[73]Parthasarathy, op. cit. *(see* footnote 10), pp. 17-18; A. Majid, "Rice Production in Palastan," *International Rice Commission Newsletter* (June 1979):9-11; M.A. Khan and M. Akbar, "Rice Research Institute, Dorki (Sind), Palustan," *International Rice Commission Newsletter* (December 1981):15, 17; and A. Majid, "Rice Research Institute; Kala Shah Kaku (Punjab-Palistan)," *International Rice Commission Newsletter* (June 1985):38-43.

[74]A.A. Soomro and G.W. McLean, "High Yielding Rice Varieties in West Palastan" in International Rice Research Institute, *Rice Breeding* (Los Baños, Philippines: IRRI, 1972), pp. 157-159; Herdt and Capule, op. cit. *(see* footnote 9), pp. 13-14. Details on procurement prices are provided in the annual *Agricultural Statistics of Pakistan,* Pakistan, Ministry of Food, Agriculture, and Cooperatives, and in *Statistical Bulletin on Rice Production in Pakistan* (Islamabad: Pakistan Agricultural Research Council, 1983). In recent years, exports of IRRI varieties, especially from Sind, have increased (letters from P. Amir, Department of Agricultural Economics, Michigan State University, East Lansing, October and November 1984). *Also see* R.A. Azhar and F. Mahmud, "Social Profitability of Alternative Rice Varieties in Pakistan: Basmati vs. IRRI," *Pakistan Journal of Applied Economics* III(2)(1984):139-156.

[75]Dalrymple, op. cit. *(see* footnote 8), p. 81. Some background on this process is provided in Chandler, op. cit. *(see* footnote ll), p. 142.

[76]Dalrymple, op. cit. *(see* footnote 8), p. 81; Majid, op. cit. *(see* footnote 73), p. 10; Khan and Ahbar, op. cit. *(see* footnote 73), p. 17.

[77]"Pakistan Names Two IRTP Entries as Varieties," *International Rice Research Newsletter* (August 1984):23; "IRTP Entries Lead to New Varieties," *The IRRI Reporter* (3) (September 1984):l.

[78]J. N. Rutger, "Applications of Induced and Spontaneous Mutation in Rice Breeding and Genetics," *Advances in Agronomy* 36 (1983):394. *Also see* A. Muhammed, "Collaborative Research: Pakistan's Experience," in International Rice Research Institute, *Impact of Science on Rice* (Los Baños, Philippines, IRRI, 1985), p. 203.

[79] *See* P. Amir, "Increasing the Productivity of Rice Based Farming Systems of the Pakistan Punjab" (Ph.D. dissertation, Michigan State University, 1985).

[80] A.J. Bueno, "Rice Varietal Improvement in the Philippines," *International Rice Commission Newsletter* (June 1983):15-16; Jones, op. cit. *(see* footnote 43), pp. 437-438.

[81]Bueno, op. cit. *(see* footnote 80), p. 16; E.C. Cada and P.B. Escuro, "Rice Varietal Improvement in the Philippines," International Rice Research Institute, *Rice Breeding* (Los Baños, Philippines: IRRI, 1972). pp. 161-166.

[82]The initial distribution and spread of IR8 in the Philippines is discussed in detail by Chandler, op. cit. *(see* footnote ll), pp. 109-112. Some statistics on early seed distribution are provided in Dalrymple, op. cit. *(see* footnote 8), p. 82.

[83]In 1972 a program named Masagana 99 was established to encourage adoption of new rice

technology. *See* Chandler, op. cit. (footnote 11), pp. 124-129; and R. Barker, *The Philippines Rice Program—Lessons for Agricultural Development,* Cornell International Mimeograph 104, September 1984, 24 pp.

[84]Data from Bureau of Agricultural Economics, Manila, Philippines.

[85]Dalrymple, op. cit. (*see* footnote 8), p. 82, footnote 6; letter from C.G. David, agricultural economist, IRRI, June 1984; "Technology Transfer Workshop," report of the director general, IRRI, Los Baños, Philippines, March 1984, p. 1; and letter from A.J. Bueno, Maligaya Rice Research and Training Center, Monoz, Nueva Ecija, Philippines, April 1984.

[86]Chandler, op. cit. (*see* footnote 11), p. 143; Dalrymple, op. cit (*see* footnote 8), p. 84; and Herdt and Capule, op. cit. (*see* footnote 9), p. 52.

[87]This section is based on the following references: N. Parthasarathy, "Rice Breeding in Tropical Asia Up to 1960," in International Rice Research Institute, *Rice Breeding* (Los Baños, Philippines: IRRI, 1972), p. 20; H. Weeraratne, "Progress of Rice Breeding in Ceylon Since 1960," in International Rice Research Institute, *Rice Breeding* (Los Baños Philippines: IRRI, 1972), pp. 137-140; "Sri Lanka Releases Three New Rice Varieties," *International Rice Research Newsletter* (December 1980):3-4; D. Senadhira, "New Rice Varieties of Sri Lanka," *International Rice Commission Newsletter* (December 1981):19-20; D. Senadhira, "Central Rice Breeding Station—Batalagoda, Sri Lanka," *International Rice Commission Newsletter* (June 1982), pp. 25-26; and G.W.E. Fernando, "The Impact of Short-Aged Cultivars on Rice Production in Sri Lanka," *International Rice Commission Newsletter* (June 1984): 9-14. An extremely helpful review was provided by S. Senadhira, then at the International Rice Research Institute.

[88]C.S. Ying, "Bg90-2 Released in China," *International Rice Research Newsletter* (February 1985):6-7.

[89]This section is based on S. Awaul, "Progress in Rice Breeding in Thailand," in International Rice Research Institute, *Rice Breeding* (Los Baños, Philippines, 1972), pp. 167-170; S. Awaul, "Rice Research and IRTP Involvement in Thailand," in International Rice Research Institute, *Rice Improvement in China and Other Asian Countries* (Los Baños, Philippines: IRRI, 1980), pp. 281-282; letters from B. Jackson, Department of Agronomy, University of Arkansas, Fayetteville, October 1984, January 1984; [B. Jackson] *The RD Rice Varieties in Thailand* (Bangkok: Rice Research Institute, Department of Agriculture, Ministry of Agriculture and Cooperatives, 1985), 12 pp.; and P. Weerapat and N. Kengseree, "Rice Varieties of Thailand," Rice Research Institute, Department of Agriculture, Ministry of Agriculture and Cooperatives, Bangkok, Thailand, 1985, 11 pp. (Also discussion with Weerapat, Washington, D.C., October 1985.)

[90]For details on the Thai breeding program, *see* D. Welsch and S. Tongpan, "Background to the Introduction of High-Yielding Varieties of Rice in Thailand," in Shand, op. cit. (*see* footnote 15),pp. 124-143.

[91]This section is a condensation of material provided in Dalrymple, op. cit. (*see* footnote 8), pp.91-92.

[92]Based on an FAO project report for 1982-83 enclosed in a letter from Ton That (*see* footnote 63), November 1984.

[93]International Rice Research Institute, *IR36* (Los Baños, Philippines, 1982), p. 8.

[94]Nguyen van Luat, Bui Ba Bong, Nguyen Minh Chau, and J. Chandra Mohan, "Performance of IR42 and IR48 in Cuu Long Delta, Vietnam," *International Rice Research Newsletter* (February 1983):4.

[95]FAO, op. cit. (*see* footnote 92).

[96]Nguyen van Luat et al., loc. cit. *(see* footnote 94).

[97]Letter from R. Huke, professor of geography, Dartmouth College, Hanover, New Hampshire, November 1984.

[98]International Rice Research Institute, loc. cit. (*see* footnote 93).

[99]Letter from Chang *(see* footnote 23), January 1985.

[100]Calculated from data in *Taiwan Agricultural Yearbook* (Taipei: Department of Agriculture and Forestry, 1984), pp. 22-23.

[101]Dalrymple, op. cit. *(see* footnote 8), p. 71.

[102]C.S. Huang, "A Breakthrough in the Ceiling Grain Yield of Ponlai Rice," *International Rice Research Newsletter* (December 1979):4.

[103]W.L. Chang, "Tainung 68, the first BPH-Resistant Japonica Cultivar Developed in Taiwan," *International Rice Research Newsletter,* (August 1982):8; letter from W.L. Chang, Hwalien District Agricultural Improvement Sta-

tion, Chian Village, Taiwan, July 1984.

[104]C.H. Huang, "Development of High-Yielding Indica Rice of Long-Grained Form From IRRI's Cultigens in Taiwan," Council for Agricultural Planning and Development, Taipei, n.d.

[105]*See* D.N. Ahmet, "Rice Agriculture in Turkey," *International Rice Commission Newsletter* (June 1981):13-15.

[106]Based on articles by S.S. Saini in the *International Rice Research Newsletter:* "Breeding High-Quality and High-Yielding Varieties of Rice in Afghanistan" (December 1981):5,6; and "Performance of Indian Rice Varieties in Afghanistan" (April 1982):3-4.

[107]Letter from G.S. Khush, plant breeder, IRRI, June 6, 1985 (based on discussions with R.N. Mishra, rice expert with the India AID mission in Kabul).

[108]M.S. El-Harrawi, "Rice Production in Egypt," *International Rice Commission Newsletter* (December 1980):16-17; A.F. El-Azizi, "Egypt," in *Rice in Africa,* ed. I.W. Buddenhagen and G.J. Persley (New York: Academic Press, 1978), pp. 319-321.

[109]"Breeding Program," in Egypt, Ministry of Agriculture, *Proceedings, Third National Rice Institute Conference, February 1983, Cairo, Egypt,* Rice Research and Training Project (Cairo: Ministry of Agriculture), pp. 129-138.

[110]Based on estimates provided by C. Price, Rice Research and Training Project, Ministry of Agriculture, Giza, Egypt, January 1984 (derived from the annual *Bulletin of Agricultural Economics,* ed. M.F. Sharaf (Cairo: Ministry of Agriculture, 1982).

[111]U.S. Department of Agriculture, op. cit. *(see* footnote 2). When the annual data are plotted for the period, the trend line is almost flat.

[112]M.S. Balal, "The Role of Short Duration Varieties of Rice in Cropping Intensification in Egypt," in Egypt, Ministry of Agriculture *(see* footnote 109), pp. 75-84.

[113]Egypt, Ministry of Agriculture, op. cit. *(see* footnote 109); "Egypt, IRRI Cooperate on Rice Project," *The IRRI Reporter* (3) (September 1984):2-3.

[114] Telephone conversations with D.S. Mikkelsen and J.N. Rutger, Department of Agronomy and Range Science, University of California, Davis, January and December 1985; U.S. Department of State telegrams from Cairo 04567, 19 February 1985 and 32310, 24 December 1985; "Why the Countdown for Reiho Production Has Begun," *Al Akhbar,* (Cairo) 13 December 1984, p. 3, trans. from Arabic; Price, op. cit. *(see* footnote 110). Indica rices typically have more genes for resistance to blast than japonica rices. Reiho did not suffer from blast in 1985 and even though it is not recommended, the area planted may increase somewhat in 1986.

[115]Ibid. IR28 and some other IRRI lines were originally sponsored by a member of the Egyptian National Academy of Science who was a member of the IRRI board.

[116]Price, op. cit. *(see* footnote 110); letter from D.J. Greenland, IRRI, March 1984; M.S. Balal, "Rice Production in Egypt," and "Breeding Rice Varieties for Higher Productivity," FAO/SIDA Seminar, Cairo, Egypt, September 1973, pp. 73, 215.

[117]Dalrymple, op. cit. *(see* footnote 8), p. 95; M.S. Chaudry, M. Moafizad, and M.S.M. Salehi, "Evolution of High-Yielding Varieties in Iran," *International Rice Commission Newsletter* (June 1979):22-23; letter from M.A. Vahabian, Seed and Plant Improvement Institute, Ministry of Agriculture and Rural Development, Karadj, Iran, April 1984; letter from Khush *(see* footnote 107), May 1985; and A.A. Zali, "Rice Production in Iran," in International Rice Research Institute, *Impact of Science on Rice* (Los Baños, Philippines: IRRI, 1985), p. 89.

[118]This section is largely based on Dalrymple, op. cit. *(see* footnote 8), p. 96; unpublished information provided by G.S. Khush *(see* footnote 107): May 1985 letter, "Report of Trip to Iraq (September 1978)," 11 pp.; and letter from R.S. Marouf, director general of field crops, Abu Ghraib Farm, Baghdad, December 1977. An earlier estimate of the quantity of IR26 seed expected to be available in 1978 —1,800 tons, which would have planted 15,000 ha —was considerably less.

[119]The section on Africa draws extensively from several sources. Three key published references were Dalrymple, op. cit. *(see* footnote s), pp. 97-102, I.W. Buddenhagen and G.J. Persley, eds., *Rice in Afnca* (New York: Academic Press, 1978), 360 pp.; and the *International Rice Commission Newsletter* (published by FAO twice a year). Two recent unpublished papers were of great help: "Impact of IITA's Rice Program,"

IITA, September 1984, 26 pp.; and "WARDA: Program Achievement, Contribution to and Impact on Rice Development in West Asia," WARDA, October 1984, 98 pp. To reduce repetition, the references to Dalrymple and the two unpublished papers are generally not included in the following citations. Rather, the emphasis is on other published references and recent communications. Considerable background information is provided in S.R. Pearson, J.D. Stryker, and C.P. Humphreys, *Rice in West Africa: Policy and Economics* (Stanford, Calif.: Stanford University Press, 1981), 482 pp., and International Rice Research Institute, *Rice Improvement in Eastern, Central, and Southern Africa,* Proceedings of the International Rice Workshop at Lusaka, Zambia, April 9-19, 1984 (Los Baños, Philippines: IRRI, 1985), 159 pp.

[120]For background on the cultigens, see T.T. Chang, "The Origin, Solution, Cultivation, Dissemination and Diversification of Asian and African Rices," *Euphytica* 25 (1976):425-441; and A.J. Carpenter, "The History of Rice in Africa," in Buddenhagen and Persley, eds., op. cit. *(see* footnote 119), pp. 3-10.

[121]In contrast to the data presented in table 3.24, WARDA reports slightly different proportions for West Africa: upland, 65%; lowland, 35% (including 2% irrigated), "External Program Review of WARDA," Technical Advisory Committee, Consultative Group on International Agricultural Research, Rome, 1983, p. 9.

[122]Carpenter, op. cit. *(see* footnote 120), pp. 8-9.

[123]S.S. Virmani, J.O. Olufowote, and A.O. Abifarin, "Rice Improvement in Tropical Anglophone Africa," in Buddenhagen and Persley, eds., op. cit. *(see* footnote 119), pp. 101-106; M. Jacquot, "Varietal Improvement Programme for Pluvial Rice in Francophone Africa, " in Buddenhagen and Persley, eds., op. cit. (see footnote 119), pp. 117-129. *Also see* R. Chabrolin, "Rice in West Africa," in *Food Crops of the Lowland Tropics,* ed. C.L.A. Leakey and J.B. Wills (New York: Oxford University Press, 1977), pp. 12-20; and A.O. Abifarin, "Upland Rice Improvement in West Africa," in International Rice Research Institute, Rice Breeding (Los Baños, Philippines: IRRI, 1972), pp. 627-628.

[124]Based on data on seed exports from the Philippines reported in Dalrymple, op. cit. (*see* footnote 8), p. 97.

[125]Jacquot, op. cit. *(see* footnote 123), pp. 122-123, 126; R. Chambrolin, "Contribution de l'IRAT à l'Amélioration des Variétes de Riz Pluvial," *L'Agronomie Tropical* (October 1974):1016-1018.

[126]A brief report on Rwanda is provided in "Rice Development Strategy for Rwanda in the 1980's," *International Rice Commission Newsletter* (June 1983):47-48.

[127]Information provided in a letter and attachment from Ton That *(see* footnote 63), November 1984.

[128]Articles in the *International Rice Commission Newsletter* as follows: C. Poisson and I. Nebie, "Rice Production Program in Upper Volta" (December 1982):44-45; and J.A. Sawadogo, "Situation and Prospects of Rice Development in Upper Volta" (June 1984):15-17. Also, D.V. Tran, "Riziculture: Rapport Technique Final," Centre d'Experimentation du Riz et des Cultures Irrigués, March 1984, pp. 2-3; and letter from J. Becker, USAID, Ouagadougou, Burkina Faso, March 1984.

[129]Letter from K. Alluri, rice breeder, IITA, November 1984; S.N. Gwei, "Rice Production in the Republic of Cameroon," in International Rice Research Institute, *Impact of Science on Rice* (Los Baños, Philippines: IRRI, 1985), pp.142-143.

[130]M. N'Douba, "Chad," in Buddenhagen and Persley, eds., op. cit. *(see* footnote 119), pp. 317-318.

[131]P.D. Manser, "Rice Pests in The Gabon," *International Rice Commission Newsletter* (June 1984):43-47.

[132]T. Ton That, op. cit. *(see* footnote 127). Background on I-Kong-Pao is provided in the section on Senegal.

[133]Letter from Greenland *(see* footnote 116), January 1985 (based on discussion with N. Quarshie, officer-in-charge, Nyankpala Agricultural Research Station, Tamale, Ghana); J.O. Olufowote, D.C. Pakani, and D.K. Das Gupta, "Spread of IR42 and IR3273-P339-2 in Irrigated Areas of Ghana," *International Rice Research Newsletter* (June 1985):3.

[134]C.S. Da Silva, "Guinea-Bissau," in Buddenhagen and Persley, eds., op. cit. *(see* footnote 119), pp. 324-325.

[135]"Rice Policies and National Production Programme; The Case of the Ivory Coast," International Rice Commission Newsletter (June

1984):5-7; C. Poisson, "La Recherche Rizicole en Côte d'Ivoire, Hier et Aujourd'hui," Institut des Savanes, April 1980; and Ton That, loc. cit. (*see* footnote 127).

[136]J.M. Munyua, "Kenya," in Buddenhagen and Persley, eds., op. cit. (*see* footnote 119), pp. 326-327; Department of State telegram 06742 from Nairobi, Kenya, February 27, 1985; J.J. Njokah and M.M. Okhoba, "Key Research Areas in Irrigated Rice in Kenya," in International Rice Research Institute, op. cit. (*see* footnote 119), pp. 91-96.

[137]Virmani et al., op. cit. (*see* footnote 123), pp. 107, 109, 328-330; S.S. Virmani, F. Tubman, F. Sumo, and P.M. Worzi, "Suakoko 8," *International Rice Commission Newsletter* (February 1971;):3-4; S.S. Virmani, "Rice Research Priorities in Liberia for the 1980's," *International Rice Commission Newsletter* (December 1980):42-43 *(also see* pp. 12-13); and comments by A. Carpenter (forwarded by T.T. Chang, IRRI, January 1985).

[138]International Rice Research Institute, "Rice in Malagasy Republic: Current Research and Production and Recommendations for Acceleration," Los Baños, Philippines, IRRI, October 1982, pp. 11-13, 15-16; M. Arraudeau, "Rice Breeding in Malagasy Republic," in Buddenhagen and Persley, eds., op. cit. (*see* footnote 1191, pp. 131-135; RJ. Rakotonirainy, "Malagasy," in Buddenhagen and Persley, eds., op. cit. (*see* footnote 119), pp. 331-333. Chianan 8 is a ponlai variety developed between 1931 and 1943 from the cross (O-luan-chu x Shinriki Aikoku) x Taichung 65; it became the leading variety in Taiwan in 1959 (International Rice Research Institute, *Rice Breeding* [Los Baños, Philippines: IRRI, 19721, p. 34). Background is provided by R.Z. Antoine in "Rice Production in Madagascar," in International Rice Research Institute, *Impact of Science on Rice* (Los Baños, Philippines: IRRI, 1985), pp.127-135.

[139]Letter from Alluri (*see* footnote 129) (based on information from A. Kumwenda and W. H. Mabwe of the Lifuwu Rice Research Station:); A.S. Kumwenda, "Malawi," in Buddenhagen and Persley, eds., op. cit. (*see* footnote 119), pp. 334-335 *(also see* pp. 110-111); P.A.C. Mtenje, "Rice Production in Malawi," in International Rice Research Institute, *Impact of Science on Rice* (Los Baños, Philippines: IRRI, 1985), p. 138.

[140]M.F. Traore, "Mali," in Buddenhagen and Persley, eds., op. cit. *(see* footnote 119), pp. 336-337; Ton That, op. cit. *(see* footnote 127).

[141]T. Ton That, "Rice Cultivation in Mauritania," *International Rice Commission Newsletter* (June 1980):14-15.

[142]F. Macapuguay, "Rice in the Semi-Arid Region of the Limpopo, Mozambique," *International Rice Commission Newsletter* (June 1984):60-63.

[143]Ton That, op. cit. *(see* footnote 127).

[144]O.A. Atanda, "Nigeria," in Buddenhagen and Persley, eds., op. cit. (*see* footnote 119), pp. 338-339; Virmani et al., op. cit. (*see* footnote 123), pp. 102, 106-107; J.O. Olufowote and A. Joshua, "Popular Rice Varieties in Production Programs in Some States of Nigeria," *International Rice Commission Newsletter* (June 1981):27-30; and J.O. Olufowote and K. Alurri, "Performance of Promising Irrigated Rice Varieties in Nigeria," *International Rice Commission Newsletter* (June 1981):46-48.

[145]M. Toure, "Senegal," in Buddenhagen and Persley, eds., op. cit. (*see* footnote 119), pp. 341-342; K. Le, HYV Rice in Senegal," March 1984 (provided by J. Balis, Dakar, Senegal, March 1984); A. Faye and M. Gning, "New Upland Rice Varieties for Senegal," *International Rice Research Newsletter* (December 1985):3; "DJ.12.519, A Promising Rice Cultivar for Rainfed, Shallow, Drought-Prone Areas in Senegal," *International Rice Research Newsletter* (December 1985): 15. I-Kong-Pao is noted in International Rice Research Institute, *Rice Breeding* (Los Baños, Philippines: IRRI, 1972), p. 39.

[146]A.D. Jones, I.C. Mahapstra, and S.A. Raymundo, "Rice Research in Sierra Leone," in Buddenhagen and Persley, eds., op. cit. (*see* footnote 119), pp. 223-224; Virmani et al., op. cit. (*see* footnote 123), pp. 107-108; "Sierra Leone's Eight New Rice Varieties," *International Rice Commission Newsletter* (December 1979):38; S.A. Raymundo, "New Blast Resistant Rice Varieties for Sierra Leone," *International Rice Commission Newsletter* (June 1980):54.

[147]G.I. Ghobrial, "Sudan," in Buddenhagen and Persley, eds., op. cit. (*see* footnote 119), pp. 343-344.

[148]Letter from H.M. Chng'ang'a, rice research coordinator, Tanzania Agricultural Research Institute, Katarin, Ifakara, December

1984; H.M. Ching'ang'a, "Rice in Tanzania," [country report], in International Rice Research Institute, op. cit. *(see* footnote 119), pp. 97-105; J.H. Monyo, "Rice Production on State Farms in Tanzania," *International Rice Commission Newsletter,* (June 1979):4-5; and "IRRI Trustees Visit Africa," *The IRRI Reporter* (4) (December 1983):1.

[149] Information provided by T. Hargrove, editor, IRRI (based on a visit to Zanzibar in February 1984.) Background is provided in A.N. Carpenter, "Increase of Rice Production in Zanzibar," *International Rice Commission Newsletter* (December 1979):53-56.

[150] Ton That, op. cit. *(see* footnote 127). *Also see* "Rice Production in Togo," *International Rice Commission Newsletter* (June 1985):18-21.

[151] Letter from Greenland *(see* footnote 116), December 1984.

[152] B. Rutebuka, "Zaire," in Buddenhagen and Persley, eds., op. cit. *(see* footnote 119), pp. 349-350.

[153] Letter from Alluri, op. cit. *(see* footnote 129); S.C. Prasad, "A Review of Rice Research in Zambia —Past, Present, and Future," in International Rice Research Institute, op. cit. *(see* footnote 119), pp. 135-146. For background, *see* R. Crawford and R.M. Lembeta, "Zambia," in Buddenhagen and Persley, eds., op. cit. *(see* footnote 119), pp. 351-352. *Also see* C.C.H. Hill, J.B. Siakant, and M.A. Qasem, "Preliminary Yield Responses and Other Characteristics of Irrigated HYV Rice," *International Rice Commission Newsletter* (December 1983):56-57.

[154] Letter from Alluri, op. cit. *(see* footnote 129); I.M. Mharapara and N.R. Mugabe, "Rice Research in Zimbabwe," in International Rice Research Institute, op. cit. *(see* footnote 119), pp. 113-118.

[155] Area data from U.S. Department of Agriculture, op. cit. *(see* footnote 2).

[156] E.M. de Rubinstein, "The Diffusion and Economic Impact of High-Yielding Semi-Dwarf Rice Varieties in Latin America," CIAT Working Paper, July 1984, p. 26. Cited in International Center for Tropical Agriculture, *CIAT 1984* (Cali, Colombia: CIAT, 1984), p. 3.

[157] International Center for Tropical Agriculture, *CIAT Report, 1983* (Cali, Colombia: CIAT, 1983), p. 55.

[158] de Rubinstein, op. cit. *(see* footnote 156), pp. 36-37.

[159] Two CIAT reports were of particular importance: de Rubinstein, op. cit. (see footnote 156), pp. 36-37; and International Center for Tropical Agriculture, *Report on the Fifth Conference of the IRTP for Latin America, 9-13, August 1983* (Cali, Colombia: CIAT, 1984), pp. 160-165. The first report presents estimates for irrigated and upland rice for 1981-82 and is the major source of data attributed to CIAT in the text in the remainder of this section. The *CIAT Report, 1983* provides HYRV estimates for irrigated rice in 1980-81. In some cases the country estimates are not entirely consistent between the seasons; on the other hand, the overall irrigated totals are not much different, especially when the same countries are included. Where country figures derived from other sources differ from those reported by CIAT, this is noted in the text.

[160] Much of the background information provided for Latin-American countries up to 1977 was previously reported in the earlier edition of this report —Dalrymple, op. cit. (see footnote 8), pp. 103-112. In order to reduce the volume of the references and notes, neither this report nor the references cited therein are cited in the following country sections. CIAT sources are also not normally repeated. *(See* footnote 159.)

[161] Data from CIAT for 1980 suggest that the irrigated HYRV areas for these countries were–Belize, 4,000 ha; Chile, 41,000 ha; Jamaica, 1,000 ha; and Uruguay, 60,000 ha.

[162] Letter from G.E. Joandet, national research coordinator, INTA, Buenos Aires, Argentina, February 1984.

[163] A recent summary is provided by P. Carmona in "Evolucion del Cultivo de Arroz con Riego en Rio Grande do Sul, Brasil," in International Center for Tropical Agriculture, *Arroz en las Américas* (Cali, Colombia: CIAT) (December 1984):l-4.

[164] F.H. de Melo, *Brazil and the CGIAR Centers: A Study of Their Collaboration in Agricultural Research,* Study Paper 9 (Washington, D.C.: Consultative Group on International Agricultural Research, 1986), p. 87-88.

[165] Letter from A. Blumenschein, director, Centro Nacional de Pesquisa-Arroz, Feijao, EMBRAPA, Goiania, Goias, Brazil, August 1984.

[166] Further information on rice varietal development in Colombia is provided in P.R. Jennings, "The Amplification of Agricultural Production," *Scientific American* 235(3) (September 1976):194;

G.M. Scobie and R. Posada T., *The Impact of High-Yielding Rice Varieties in Latin America, With Special Emphasis on Colombia,* Series JE-01 (Cali, Colombia: International Center for Tropical Agriculture, 1977), pp. 13-18; R. Hertford, J. Ardilla, A. Rocha, and C. Trujillo, "Productivity of Agricultural Research in Colombia," in *Resource Allocation and Productivity in National and International Agricultural Research,* ed. T.M. Arndt, D.G. Dalrymple, and V.W. Ruttan (Minneapolis: University of Minnesota Press, 1977), pp. 88-95. Two recent accounts are provided by D. Munoz in the *International Rice Commission Newsletter:* "Rice Breeding in Colombia" (June 1983):11-12; and "Oryzica-1 and Metica-1. New Resistant Varieties to Hoja Blanca Virus" (December 1983):28-29.

[167]Letter from P. Jennings, rice breeder, CIAT, March 1984; M.J. Rosero, *Report of the Monitoring Tour to Venezuela, Colombia, Ecuador, Panama, and Costa Rica, August 1984* (Cali, Colombia: International Center for Tropical Agriculture, March 1985), p. 30.

[168] Iowa State University, "Analysis of Cooperation and Coordination Between the International Research Centers (CIMMYT, CIAT, CIP) and the National Centers of Latin America," report prepared for the InterAmerican Development Bank, Ames, Iowa, 1981, p. 65; information from the Oficina Nacional Semillas provided by T.C. Ivers, USAID, San José, Costa Rica, March 1984; Rosero, op. cit. *(see* footnote 167), pp. 69, 74.

[169]International Center for Tropical Agriculture, "Summary Report, Visit of the CIAT-IRRI Rice Team to the Republic of Cuba, May 27 to June 4, 1978," Cali, Colombia, 1978, pp. 3-4.

[170]Personal communication from a review team member, February 1984; letter from Jennings, op. cit. *(see* footnote 167).

[171]For details on several of these varieties, *see* L. Johnson, "Rice Cultivation in the Tidal Swamps of Samborondon, Ecuador," in International Rice Research Institute, *Workshop on Research Priorities in Tidal Swamp Rice* (Los Baños, Philippines: IRRI, 1984), pp. 100-101.

[172]Letter from J. Goodwin, USAID, Quito, Ecuador, February 1984; Rosero, op. cit. *(see* footnote 167), pp. 46,47.

[173] Letter from C. McFarland, USAID, Guatemala City, February 1984.

[174] L.G. Small, "Rice Research in Guyana," *International Rice Commission Newsletter* (June 1983):13. Background information is provided in A.B. Shaw, "Impact of New Technology on the Guyanese Rice Industry: Efficiency and Equity Questions," *The Journal of Developing Areas* 18(2) (January 1984):191-218.

[175]Letter from A.H. Wahab, USAID, Port-au-Prince, Haiti, February 1984.

[176]Letter from S.C. Wingert, USAID, Tegucigalpa, Honduras, April 1984.

[177] The section on Mexico is based largely on information provided by L.H. Aragon, plant breeder and coordinator, INIA-South Area Rice Program, Instituto Nacional de Investigaciónes Agricolas, Zacatepec, Morelos, Mexico, December 1984. Morelos A70 and Zapata A70 are considered improved tall varieties and are excluded.

[178]Iowa State University, op. cit. *(see* footnote 168), p. 66.

[179] Data from J.E. Mojica P., "Evaluación y Recomendaciónes Sobre el Cultivo y Comercialización de Arroz en Panama," National Directorate for Sector Planning, Ministry of Agriculture, Cuadro No. 5, Panama, n.d. Background information is provided in B. Senauer, "A Protectionist Foodgrain Price Policy; The Case of Rice in Panama," *Food Policy* 10(4) (November 1985): 352-364.

[180]Iowa State University, op. cit. *(see* footnote 168), p. 149.

[181]Letter from D. Bathrick, USAID, Quito, Ecuador, May 1984; "A Turnaround in Peruvian Rice Production," *CIAT International* (October 1985): 3-7.

[182] A.D. van Dijk, "The Operation of Irrigation Schemes and the Organization of Rice Units in Suriname," *International Rice Commission Newsletter* (June 1983):4-6; Department of State telegram 00352 from Paramaribo, Suriname, February 7, 1985.

[183] Rosero, op. cit. (*see* footnote 167), p. 12.

4. SUMMARY OF AREA ESTIMATES

There is scarcely time to congratulate ourselves on the achievements of today because we have to hustle to produce something better for tomorrow. The task of the breeder and geneticist has become never-ending.

—Gove Hambridge and E.N. Bressman, 1936[1]

This chapter summarizes HYRV area data, first by region, and then for the developing world as a whole. Similar data for wheat are included for comparison.

DATA LIMITATIONS

The data summarized in this chapter are labeled "estimates" for good reason. They are not exact because of problems in definition and reporting, as already noted. Although HYRVs can be defined in general terms, they can be difficult to differentiate from some improved local varieties, and this may not be done in national surveys. Where HYRV data are gathered, the procedures may be questionable and results not very accurate. Where HYRV data are not available, it becomes necessary to turn to perhaps even more inexact sources—estimates by breeders or information on seed sales.

The problem of inexact national estimates is compounded when they are used to produce regional totals. Definitions of HYRVs, moreover, may vary from country to country. The resulting classification may not be consistent. In some cases, improved varieties may be included in the HYRV category; in other cases, varieties that appear to be in the HYRV category on the basis of national yield levels may be left out. Gaps in reporting and differences in reporting periods provide additional difficulties.

Altogether, the data for noncommunist Asia are relatively good and data for the other regions, with a few exceptions, are relatively weak. This variability creates some difficulties in arriving at a total for the developing countries—and has in part been approached by using conservative estimates.

Data on the area planted with leading individual varieties are not included because data of this nature are even less often reported at the country level than HYRV data as a whole. One rice variety, IR36, has been planted on an exceptionally wide area. IRRI estimates that in 1981, IR36 was planted on more than 10.7 million ha in Asia.[2] It would be desirable to have more area data for at least the leading varieties.

In analyzing the data, it should be recognized that we are dealing with a joint product—the result of both national and international agricultural research programs. The varieties used by IARC (international agricultural research center) breeders usually have many linkages to earlier national breeding programs, and the varieties developed by the IARCs usually are tested and further selected and developed in national programs. The interaction between IARCs and national centers is synergistic. Hence, it is difficult and probably not useful—possibly even divisive—to try to use these and other data to determine which party contributed what proportion of the final product.

HYRV AREA: REGIONAL AND TOTAL

In this section, the HYRV area for each country listed in chapter 3 is summarized by region and then totaled for the developing world as a whole. The focus is on the 1982-83 crop year. Complete crop-year data, however, are not available for every country. Where gaps exist, data for an earlier period—and some guesses—are used. In some cases, official data may be subject to revision. Moreover, some data are reported for calendar years and had to be aligned with a crop year; this process entailed some difficulties.[3]

Relatively complete time series data from the mid-1960s to the early 1980s are available only in Asia. Data for other regions are fragmentary. While the general regional trends are up, there are several exceptions at the country level. The area planted in a given country in a given year also may be influenced by a number of factors, including weather, seed supplies, insect and disease problems, government price policies, and market conditions.

Asia

The HYRV statistics situation for South and East Asia is mixed. Time series data are available on HYRVs since the mid-1960s for several South and Southeast Asia countries, but only limited data are available for the communist nations in the region.

Selected Asian Nations

Time series data for HYRVs in nine Asian nations for the 18-year period from 1965-66 to 1982-83 are summarized in table 4.1 and figure 4.1. The area of rice and wheat expanded at a rather steady rate throughout the period. Rice, however, expanded more rapidly than wheat, whose rate of growth slowed somewhat in the mid-1970s. The drop in rice area in 1982-83 was due largely to a decline in area in India, which is expected to be more than made up for by increases in India and Indonesia in 1983-84 (tables 3.7 and 3.9). India accounted for the largest share by far of the high-yielding variety (HYV) area of both crops in the region; in the case of rice, it was followed by Indonesia, the Philippines, Burma, and Bangladesh.

Other Asian Nations

The statistical situation for HYRVs in two other Asian nations—Malaysia and South Korea—aswell as Taiwan is mixed. Malaysia issued variety data through 1977-78, but no further data were obtained until the 1981-82 season. Complete time series data are available for South Korea (table 3.11). Taiwan provides statistics on various types of rice but none were found on specific varieties.

South Korea and Taiwan have rice cultures that set them apart: (1) japonica types predominate in both, and japonica × indica types are found in South Korea; (2) both were formerly under Japanese rule and have a particularly long history of rice improvement; (3) both have long high average yield levels; and (4) both are in relatively temperate climate zones.

For 1982-83, it was decided to carry Malaysia at the 1981-82 level (261,900 ha) and include the japonica × indica data for South Korea (386,400 ha). Taiwan was not included because of insufficient varietal data.

Communist Nations

Several communist nations in Asia grow HYRVs. The largest by far, and the largest in the world, is China. A rough guess is that 95% of the total rice area was planted with HYRVs in the early 1980s. Given a total area of about 33.1 million ha, this would mean that the HYRV area was about 31.4 million ha. Vietnam also has a significant area planted with HYRVs-estimated at 1.88 million ha in 1983. About 10,000 ha were estimated to have been planted in Laos in 1981-1982. Little is known about Cambodia, but if about 5% of its area was planted with HYRVs, it would total roughly 88,000 ha. In North Korea, it appears that a large area is planted with HYRVs, but no estimates are available. The HYRV area in communist Asia in 1982, excluding North Korea, might have been about 33.38 million ha.

One striking difference in the communist nations is the extent to which IRRI rice varieties are grown. It appears that IRRI varieties, which are widely and directly planted in the Southeast Asian communist nations, are essentially used only as parents in China (not an unimportant role, especially in the case of hybrid rice), and are probably not used at all in North Korea, where the climate is such that only japonica varieties are grown.

Total HYRV Area in Asia

Assembling a regional total area for HYRVs in Asia is not a precise process. The several

Table 4.1. Estimated area planted with high-yielding varieties of rice and wheat, South and Southeast Asia nations, 1965-66 to 1982-83

Crop year	Rice (ha)[a]	Wheat (ha)[b]	Total (ha)
1965-66	13,800	12,300	26,100
1966-67	984,500	653,500	1,638,000
1967-68	2,584,000	3,928,000	6,512,000
1968-69	5,198,400	7,243,500	12,441,900
1969-70	7,487,300	7,677,200	15,164,500
1970-71	9,631,300	9,720,000	19,351,300
1971-72	12,953,300	11,278,100	24,231,400
1972-73	14,753,300	13,744,300	28,497,600
1973-74	18,895,600	14,726,500	33,633,100
1974-75	20,290,400	15,196,400	35,486,800
1975-76	22,374,100	17,795,000	40,169,100
1976-77	24,031,600	19,491,400	43,523,000
1977-78	28,124,400	20,931,800	49,056,200
1978-79	30,216,400	21,534,600	51,750,700
1979-80	30,261,400	21,339,000	51,600,400
1980-81	33,909,500	22,781,200	56,690,400
1981-82	36,025,300	23,778,400	59,803,700
1982-83[c]	35,725,400	25,341,200	61,066,600

[a] Bangladesh, Burma, India, Indonesia, Nepal, Pakistan, Philippines, Sri Lanka, and Thailand.
[b] Bangladesh, India, Nepal, and Pakistan.
[c] Includes Thailand and West Malaysia at 1981-82 level.

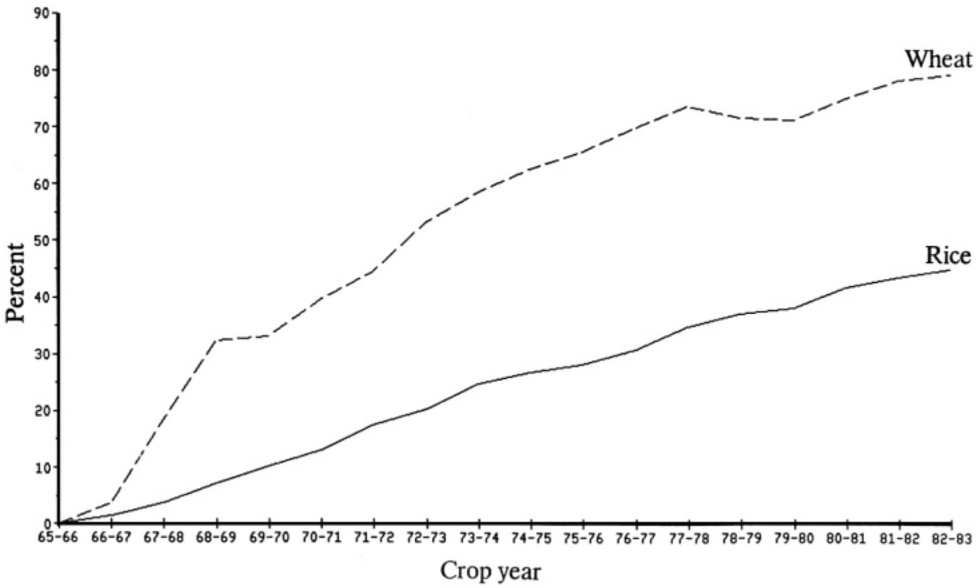


Figure 4.1. Estimated area planted with high-yielding varieties of rice and wheat, South and Southeast Asian nations, 1965-66 to 1982-83. Source: table 4.1.

Table 4.2. Total high-yielding varieties of wheat and rice area, Asia, 1982-83

Region	Rice (ha)	Wheat (ha)	Total (ha)
Selected Asian nations	35,725,400	25,341,200	61,066,600
Other Asian nations	648,300[a]	26,000[b]	674,300
Total noncommunist Asia	36,373,700	25,367,200	61,740,900
Communist Asian nations[c]	33,380,000	8,920,000[d]	42,300,000
Total Asia	69,753,700	34,287,200	104,040,900

[a]South Korea, West Malaysia.
[b]South Korea.
[c]Excludes North Korea.
[d]China; incomplete estimate of short high-yielding varieties.

pieces can be put together as shown in table 4.2 for 1982-83. A total of 69.75 million ha of HYRVs are estimated to have been grown in Asia during this crop year. The HYRV area in the noncommunist nations—36.37 million ha—exceeded that in the communist nations, excluding North Korea, by about 9%.

The estimates for the communist nations should be considered rough. The rice area in China is so large that a 1% variation in the HYRV proportion increases or lowers the HYRV area by more than 300,000 ha. On the other hand, the data for HYRVs in the noncommunist nations in Asia generally are as good as we have for developing countries.

Near East

Available data on the HYRV area are confined to Egypt and Iran. The area in Egypt in 1983 was only about 20,700 ha. The HYRV area rose sharply in 1984, but the crop had a severe disease problem. The area in Iran was about 60,000 ha. It appears that the HYRV area in Afghanistan is limited but could be fairly extensive in Iraq. A total HYRV area of about 100,000 ha for the region in 1982-83 seems a reasonable estimate, but it may be low.

Africa

Rice is grown in many African nations, generally as an upland crop. HYRVs, subject to variation in definition, tend to be found in relatively small, irrigated, or more favored rainfed lowland areas, but it is extremely difficult to find reliable statistics.

A review of information reported earlier for individual African countries indicates HYRV areas ranging from 1,000 ha to 100,000 ha. The latter figure is for Ghana in 1977. In 1982-83 the overall rice area was down by half. The largest recent figures are for Senegal (70,000 ha) and Nigeria (60,000 ha). Piecing the African areas together produces an estimated total of 225,000-250,000 ha.

Latin America and the Caribbean

HYRVs are grown in many Latin American and Caribbean nations. CIAT conducts periodic meetings of rice researchers in the region to provide an opportunity to gather data on HYRV use. The most recent meeting, in August 1983, provided data for the 1981-82 crop year. In some cases, country statistics were higher than those from other sources. It is not known which statistics are more accurate, but the CIAT estimates, because of their comprehensive nature, are used in compiling a regional total.

For the 1981-82 season, a review of 24 countries showed that 22 used HYRVs with a total acreage of 2.29 million ha—71.1% irrigated and 28.9% upland. Brazil was the leading country with 755,500 ha, followed by Colombia with

410,300 ha. Estimates for other countries were: Argentina, 27,500 ha; Belize, 2,900 ha; Bolivia, 29,600 ha; Costa Rica, 72,300 ha; Cuba 130,000 ha; Dominican Republic, 83,000 ha; Ecuador, 85,000 ha; El Salvador, 13,900 ha; Guatemala, 3,100 ha; Guyana, 24,300 ha; Haiti, 3,700 ha; Honduras, 23,000 ha; Jamaica, 1,400 ha; Mexico, 166,400 ha; Nicaragua, 31,900 ha; Panama, 55,200 ha; Paraguay, 20,700 ha; Peru, 111,400 ha; Suriname, 35,700 ha; Venezuela, 200,000 ha.

CIAT has used the data from several rice conferences to prepare estimates of the areas planted with HYRVs during the intervening years. (See table 4.3.) The resulting pattern shows a steady increase in adoption. Unfortunately, the last year reported is 1981-82. Based on other data in the CIAT report, including some projections of rate of adoption, a 12% increase in the area planted with HYRVs in 1982-83 can be estimated, for a total HYRV figure of about 2.5 million ha.

Total HYRV Area

Total regional estimates for 1982-83 are summarized in table 4.4. The data, with the exception of Latin America, were selected from the lower variants cited throughout this bulletin with the hectare figures generally rounded down to the nearest hundred thousand. The data in some cases, such as Egypt, exclude varieties that might be considered HYRVs.

Total estimated HYRV area for the four regions, excluding communist Asia, was roughly 39.2 million ha in 1982-83. The HYRV area was slightly smaller for rice than for wheat, which is included for comparison. In each case, the HYRV area was concentrated in Asia. For rice, Asia was followed by Latin America, then Africa and the Near East. The HYRV area in communist Asia, where estimates are less reliable, was very large and represented 74% of the four-region total.

Table 4.3. Estimated area planted with high-yielding (semidwarf) varieties of rice, Latin American nations, 1969-70 to 1981-82[a]

		HYRV area (%)	
Year	HYRV area (ha)	All Latin America	All Latin America except Brazil
1969-70	53,000	0.8	3.3
1970-71	133,000	2.0	8.0
1971-72	250,000	4.0	16.3
1972-73	345,000	5.7	21.7
1973-74	482,000	7.6	30.4
1974-75	613,000	9.5	34.4
1975-76	935,000	12.7	43.3
1976-77	938,000	11.0	46.7
1977-78	1,120,000	14.1	51.4
1978-79	1,206,000	16.1	58.0
1979-80	1,533,000	20.4	64.2
1980-81	1,862,000	22.7	68.1
1981-82	2,286,000	26.0	70.2

[a] Chile and Uruguay not included in HYRV total (no HYRVs) but are included in overall area total for rice.

Source: E.M. de Rubenstein, "The Diffusion and Economic Impact of High-Yielding Semi-dwarf Rice Varieties in Latin America," CIAT Working Paper, Cali, Colombia, July 1984, p. 34.

Table 4.4. Estimated area planted with high-yielding varieties of wheat and rice in developing countries, 1982-83

Region	Rice (ha)	Wheat (ha)	Total (ha)
Asia	36,400,000[a]	25,400,000	61,800,000
Near East	100,000	7,600,000	7,700,000
Africa	200,000	500,000	700,000
Latin America	2.500.000	8,300,000	10,800,000
Total	39,200,000	41,800,000	81,000,000
Communist Asia	33,400,000[b]	8,900,000[c]	42,300,000
Total	72,600,000	50,700,000	123,300,000

[a] Excludes Taiwan.
[b] Excludes North Korea.
[c] China; incomplete estimate of short high-yielding varieties.

When the data, excluding communist Asia, are converted to percentages, regional concentrations are even more evident (table 4.5). The total rice area is almost all in Asia, where the HYRV area is principally located. Within Asia, much of the HYRV area was in India (47.6% of the total HYRV area in the four regions). The HYRV proportions by region mirrored, to some extent, the overall distribution of the two crops except in the case of wheat in Asia and the Near East.

Perspective on changes in total HYRV area over time may be obtained from two sources. First, a comparison of the 1982-83 totals for non-communist nations with roughly comparable figures for 1976-77, reported in a previous edition of this report, reveals that the HYRV area increased from 25.3 to 39.2 million ha, a growth of 55.7%. Secondly, calculations made for the CGIAR impact study suggest the following growth in the total area of modern varieties, including China (in million hectares): 1970, 37.0; 1975, 57.3; 1980, 70.3; and 1983, 76.3.[4] The figures are largely derived from, but are not directly comparable to, data reported in this study. The rate of growth is

Table 4.5. Distribution of high-yielding varieties (HYVs) of rice and wheat among the developing regions of the world,[a] 1982-83

Region	Rice (%)		Wheat (%)		Total (%)	
	HYV	All	HYV	All	HYV	All
Asia	92.9	86.2	60.8	46.5	76.3	69.9
Near East	0.3	1.2	18.2	36.6	9.5	15.7
Africa	0.5	4.4	1.2	1.4	0.9	3.2
Latin America	6.3	8.2	19.9	15.5	13.3	11.2
Total	100.0	100.0	100.1[b]	100.0	100.0	100.0

[a]Excludes communist Asia.
[b]Total does not equal 100% due to rounding.

Table: 4.6. Estimated area of high-yielding varieties of rice and wheat as a proportion of total area planted with those crops in developing countries, 1982-83[a]

Region	Rice (%)	Wheat (%)	Total (%)
Asia	44.9[b]	79.2	54.6
Near East	8.4	30.6	29.6
Africa	4.7	50.6	13.3
Latin America	32.9	77.6	59.0
Total	41.6	60.9	49.5
Communist Asia [c]	81.0	30.6[d]	58.0
Total	53.6	51.9	52.9

[a]See text footnote for discussion of basic data used in making the calculations reported here.
[b] Excludes Taiwan.
[c] Excludes North Korea.
[d] China; incomplete estimate of short high-yielding varieties.

similar to that reported for selected Asian nations in figure 4.1.

HYV AREA: PROPORTIONS

Interpretation of the regional HYV area statistics can be facilitated by comparing them against total rice and wheat areas. This section examines cross-sectional data for 1982-83 for the four regions, and time series data for wheat and rice in Asia and for rice in Latin America. Due to methodological problems in matching reporting periods for the HYVs with those for total area at the regional level, the results should not be considered precise.[5] The HYVs would be expected to represent a larger proportion of production than of area.

Regional Totals

The HYV proportions for rice and wheat in 1982-83 are summarized for each of the four regions and for the developing world as a whole in table 4.6. The proportions for HYRVs were re1atively low in Africa and the Near East, and substantially higher in Latin America and Asia; in each case, the proportions were considerably lower than for wheat. The rice total for the four regions (41.6%) was considerably below the proportion for wheat (60.9%). When, however, communist Asia, for which the data are particularly uncertain, is added, the total rice proportion rises substantially (to 53.6%) and slightly exceeds the total for wheat (51.9%).

By way of comparison, the CGIAR impact study, noted earlier, calculated that the proportion of modern rice varieties in developing countries, including China, increased as follows over time: 1965, 8.4%; 1970, 30.1%; 1975, 44.5%; 1980, 53.0%; and 1983, 57.6%.[6] The figures are not fully comparable to those reported here but do underline the expanding significance of the new varieties.

Time Series Data

The adoption rate for HYRVs in nine Asian nations increased steadily from 1966-67 to 1982-83 (table 4.7 and figure 4.2). By comparison the rate for HYV wheat in four Asian nations was faster at first and then somewhat more variable. The rice proportion, however, may hold a greater prospect for further increase if it is possible to develop varieties for the wide range of growing conditions that are not now well suited for HYRV cultivation.

Two levels of adoption rates for rice in Latin America are shown in figure 4.3: one for Latin America as a whole, and one excluding Brazil because it has a large area of upland rice where

Table 4.7. Estimated proportion of total area planted with high-yielding varieties of rice and wheat, 9 South and Southeast Asian countries, 1965-66 to 1982-83[a]

Crop year	Rice (%) [b]	Wheat (%) [c]
1965-66	-	-
1966-67	1.4	3.6
1967-68	3.6	18.4
1968-69	7.1	32.3
1969-70	10.1	33.1
1970-71	13.0	39.6
1971-72	17.5	44.6
1972-73	20.3	53.3
1973-74	24.8	58.6
1974-75	26.8	62.7
1975-76	28.4	65.8
1976-77	31.0	70.1
1977-78	35.1	73.8
1978-79	37.3	71.9
1979-80	38.3	71.4
1980-81	42.0	75.3
1981-82	43.8	78.5
1982-83	45.1[d]	79.5

Key: —=Negligible.

[a] See text footnote 5 for discussion of basic data used in making the calculations reported here.

[b] Bangladesh, Burma, India, Indonesia, Nepal, Pakistan, Philippines, Sri Lanka, and Thailand.

[c] Bangladesh, India, Nepal, and Pakistan.

[d] HYRV total includes Thailand and West Malaysia at 1981-82 levels.

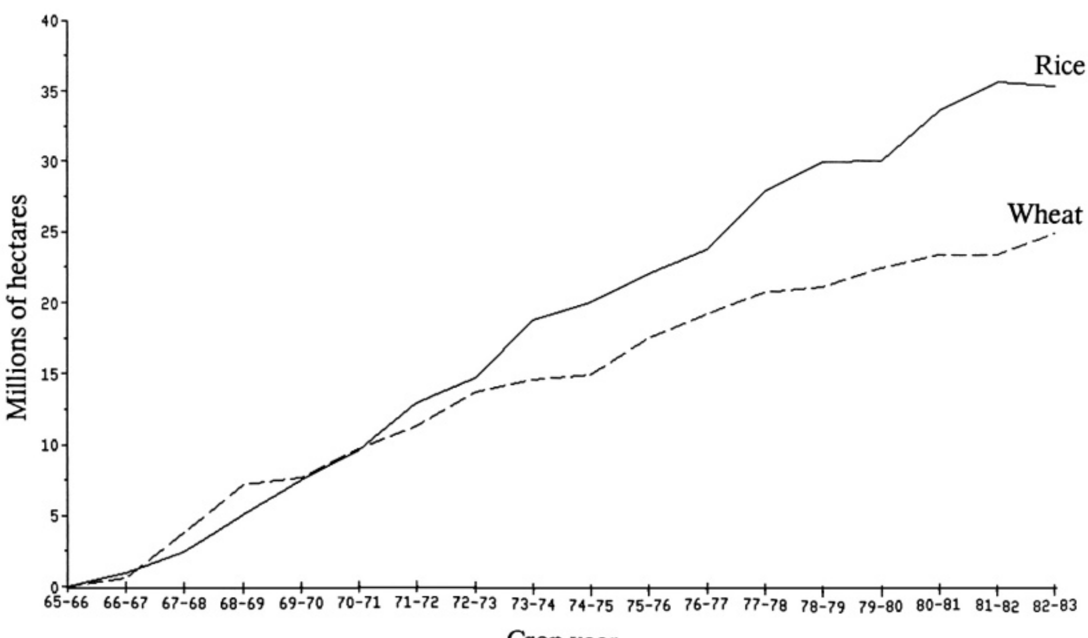


Figure 4.2. Estimated proportion of areas planted with high-yielding varieties of rice and wheat, South and Southeast Asian countries, 1965-66 to 1982-83. Source: table 4.7.

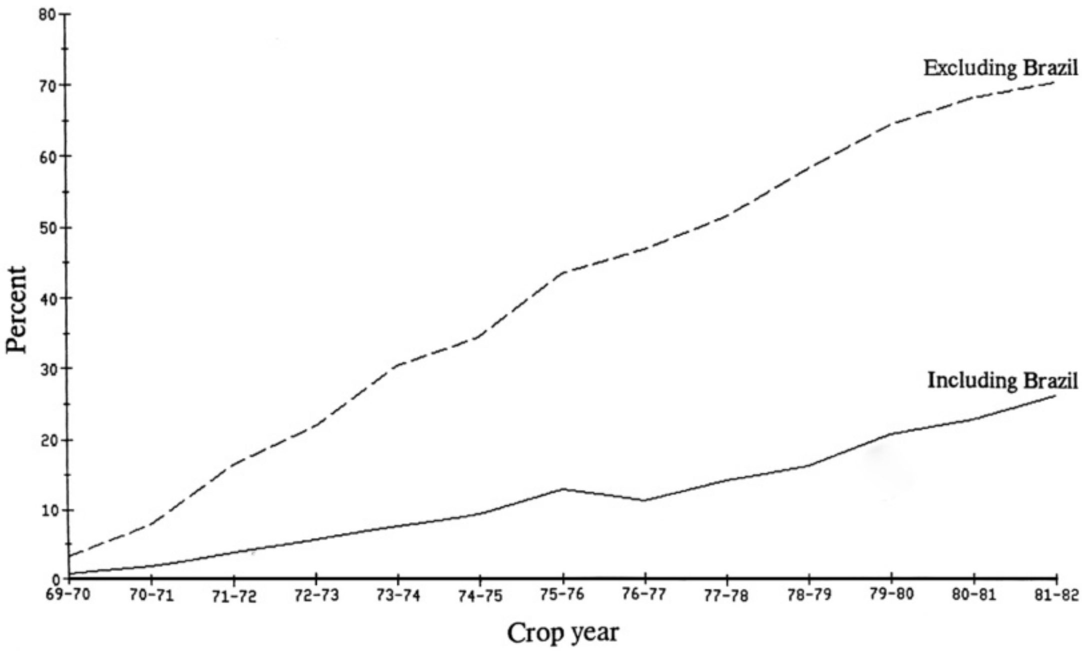


Figure 4.3. Estimated proportion of total area planted with high-yelding varieties of rice, 22 Latin American countries, 1969-70 to 1981-82. Source: table 4.3.

HYRVs are not widely planted. Thus, while both curves show increasing levels, the one excluding Brazil grew more sharply—to 70% in 1981-82. There is some question as to how much more this percentage will increase. The fate of the overall proportion for Latin America will depend heavily on whether HYRVs are developed for upland areas in Brazil.

FUTURE RATES OF HYV ADOPTION

Countries that already have achieved high levels of HYRV adoption are likely to experience reduced rates of expansion of HYRV area. Some nations probably are well along the adoption curve or approaching the peak. For most major countries, moreover, the top of the curve for HYRVs may be considerably below 100%.

Several supply and demand factors constrain HYRV adoption. On the supply side, available HYRVs are not suitable for all soils and climates, and they require seeds and inputs that either are not available or are not fully used by every farmer, seed supply being a problem in many areas. On the demand side, although increased attention has been given to developing HYRVs to meet local tastes and preferences, they still may not meet all consumer requirements. In addition, government price policies may not encourage HYRV production.

A very high rate of adoption of specific HYRV seeds is not necessarily desirable. Where vast areas are planted with the same or similar varieties, the possibility of increased insect and disease problems increases under intensive cultivation. The case of the brown planthopper in Indonesia has been the most serious. On the other hand, in Thailand, where only about 10% of the rice area is planted with HYRVs, no major insect or disease problems have been reported.[7]

Because of these and other factors, the HYRVs are unlikely to completely replace traditional varieties in most areas. But even if HYRV adoption levels taper off, it does not mean that yield levels will stagnate. New HYRVs, with greater yield potential or greater yield stability, or both, constantly are being developed. The use of other production inputs, such as fertilizer, is generally low, and considerable potential for yield increases remains even after the initial HYRV adoption curve levels off.

REFERENCES AND NOTES

[1]G. Hambidge and E.N. Bressman, "Better Plants and Animals—Forewordand Summary," in U.S. Department of Agriculture, *Yearbook of Agriculture, 1936* (Washington, D.C.: the Department, 1936), p. 121.

[2]International Rice Research Institute, *IR-36* (Los Baños, Philippines: IRRI, 1982.) Individual country estimates were (in millions of hectares): Indonesia, 5.3; Philippines, 2.3; Vietnam, 2.1; other Asia, more than 1.0. While the area reported here for IR36 is clearly very large, it is not certain whether it is a record. The other major contenders are the Russian wheat varieties Bezostaya and Mironovskaya. According to one account, Bezostaya was planted on at least 16 million ha (National Academy of Sciences, *Genetic Vulnerability of Major Crops* [Washington, D.C.,: the Academy, 19721 pp. 135-136), but other estimates are lower.

[3]Briefly, rice data reported on a calendar year basis were associated with the following crop year (i.e., 1982 with 1982-83). The problems involved with this process are discussed in footnote 5.

[4]Consultative Group on International Agricultural Research, *Summary of International Agricultural Research Centers: A Study of Achievements and Potential* (Washington, D.C.: CGIAR, 1985), p. 7. Also discussion with R. Herdt, Scientific Advisor, CGIAR Secretariat, September 1985.

[5]These calculations, with one exception for Latin America, utilize unpublished estimates of total rice and wheat area prepared by the World Analysis Branch, International Economics Division, Economic Research Service, USDA. They were obtained from a computer printout informally known as the "Grain Data Base." (The January 3, 1985 printout contained information as of November 1984). Because the data - gathering process for the HYVs provided only a partial set of information on total area, the USDA information was needed to get a complete and consistent developing-country estimate over time.

Use of the data, however, led to one perplexing situation. The USDA data are reported for calendar years, while the HYV data cited here are almost always for crop years. Matching calendar and crop years produced an unexpected result when official statistics were examined for India and Pakistan: in the case of wheat the crop year data matched the following calendar year (i.e., 1982-83 with 1983) and in the case of rice the crop year matched the previous calendar year (i.e., 1982-83 with 1982). The timing of the main harvest of the two crops varies, which may have led to the split. In any case, it provides a dilemma in trying to compute percentages. Where the focus is on South and Southeast Asia, it would seem appropriate to follow the split pattern. But it may not be appropriate for the whole developing world.

Because of the importance of the two countries (about 54% of the total HYV area in 1982-83), the split pattern was followed when matching was necessary, but the process could well be in error in some cases. The matter needs to be considered more closely. Other USDA and FAO data series merit examination.

[6]Consultative Group on International Agricultural Research, op. cit. *(see* footnote 4), p. 10. The *Summary* also provides similar estimates by major countries and regions.

[7]T.T. Chang, "Conservation of Rice Genetic Resources: Luxury or Necessity?" *Science* 224 (April 20, 1984):254-255.

Appendix A

SEMIDWARF RICE VARIETIES IN THE UNITED STATES

The HYRVs discussed in this report are principally semidwarfs. Semidwarf rice varieties are grown extensively in California and are beginning to be adopted in the southern United States. Some of the semidwarfs grown in developing countries are related to some of the semidwarfs grown in the United States.[1]

The background of semidwarf rice varieties in the United States is varied. Some varieties derive their semidwarf status from Asian ancestors. Use has been made of TN-1 (introduced in 1961), IR8 (introduced in 1966), and IRRI lines IR 659-10-8-3 (known as PI 331581; contains TN-1) and IR 1318 (also contains TN-1). Other semidwarfs in California derive their short stature from an induced mutation. The principal parent is Calrose 76, derived from an induced mutation of Calrose in California (released in 1976). All but one of the varieties noted in this report were developed in the public sector. There may be others grown under contract on relatively limited areas. California varieties are usually japonicas; varieties raised in the southern states are usually indicas.

VARIETIES

The first U.S. semidwarf variety released was LA 110. It was developed at the Rice Experiment Station at Crowley, Louisiana, from a cross between TN-1 and H4 (from Sri Lanka) and was released in 1974 for industrial use.

The next, and by far the largest group of varieties, was developed and released in California as a cooperative effort between the California Cooperative Rice Research Foundation, the California Agricultural Experiment Station, and the Agricultural Research Service of the U.S. Department of Agriculture (ARS/USDA). One semidwarf, Calpearl, was developed in the private sector.[2] Varieties released in California through 1984, along with relevant technical information, are listed in table A.1.

Two semidwarfs, Bellemont (1981) and Lemont (1983), were released in Texas. They were developed at Beaumont, Texas, as a cooperative effort between Texas A&M University, ARS/USDA, and the Texas Rice Improvement Association. Both are long-grain varieties derived from a cross involving IR659-10-8-3. Bellemont is the shorter of the two, averaging 76 to 79 cm compared to 79 to 54 cm for Lemont.[3]

Two other long-grain varieties, Leah (1982) and Toro-2 (1984), thought to be semidwarfs, were released by the Rice Research Station in Crowley, Louisiana, in the 1980s, the result of a cooperative effort between Louisiana State University and ARS/USDA. Both varieties derive their short stature from CI9902, a short-stature, lodging-resistant selection developed at Crowley. Leah has averaged 89 cm in height; Toro-2, 94 cm. Compared to Lemont, both would be considered tall semidwarfs—ifthat is what they are. One of their breeders believes they have a

Table A-1. Semidwarf rice varieties developed and released in California: technical characteristics and area planted

Grain length and variety	Year of release	Source of dwarfism	Trial averages[a] Height (cm)	Lodging (%)	Yield (kg/ha)	Estimated proportions of total area[b] 1981	1984
Short							
S-201	1980	Calrose 76	88	27	9,050	22.0	20.5
Calpearl[c]	1981	IR1318	85	26	9,980	-	7.0[d]
Medium							
Calrose 76	1976	Radiation of Calrose	95	17	9,070	7.0	-
M-7	1977	Calrose 76	96	11	9,080	15.0	1.1
M-9	1977	IR8	93	51	8,570	32.2	10.9
M-101	1979	M7	88	48	8,960	5.0	3.3
M-201	1982	IR8	87	5	9,310	-	46.4
M-301	1980	M7	(97)	(42)	-	5.0	-
M-302	1981	M7	94	22	9,090	0.1	5.6
M-401	1981	Radiation of Terso	93	52	9,340	0.1	1.8
Long							
L-202	1984	IR or TN-1[e]	80	1	8,980	-	0.1
Sweet							
Calmochi-202	1981	Radiation of Calrose	94	28	8,310	0.1[f]	-
Non-semidwarfs						13.5[g]	3.3[h]
Total						100	100

Key: –=Negligible.

[a]Average of various country trials, generally over 1980-83 period.

[b]Based on rice seed production estimates, California Crop Improvement Association.

[c]Sometimes classified as medium. Developed in the private sector.

[d]Rough estimate of proportion of area; deducted from proprietary total of 10.3%.

[e]Not certain due to "accidental mixing of F_2 populations." Another parent (tall) is IR456-3-2-1.

[f]For registered seed production.

[g]Includes proprietary varieties (6.7%).

[h]Proprietary varieties.

Sources: Columns 1 to 6 "Rice Genetics and Physiology," *Fifeenth Annual Report to the California Rice Growers* (Yuba City, California: Rice Research Board, May 1984), p. 8; *California Rice Varieties; Description, Performance, and Management,* Special Publication 3271 (Davis, California: University of California, Division of Agricultural Sciences, August 1981). p. 4. Column 7: letters from M. L. Peterson, Dept. of Agronomy and Range Science, University of California, Davis, January 1985, and Chao-Hwa-Hu, Chief Agronomist, N. F. Davis Drier and Elevator, Inc., Firebaugh, California, December 1984.

dwarfing gene but that it may be different from the one in Lemont. Further study of this matter would be useful.[4]

Several other short-statured U.S. varieties, which are not semidwarfs, have also been released in the southern states: Bond and Newbonnet in Arkansas; Skybonnet and Pecos in Texas.[5]

The trend in the United States is generally toward using shorter varieties, largely because of their ability to respond to increased levels of fertilizer. In California, the earlier semidwarfs, Calrose 76 and M7, are being replaced by shorter varieties. The most recent, M-201 and L-202, are the shortest of the group and have excellent resistance to lodging (table A.1). The latter varieties have IR8 (or TN-1) ancestry rather than Calrose 76. On the other hand, the process can go too far if seedling emergence is slowed, as was the case with Bellemont.

AREA

No official government estimates of the U.S. area planted with individual varieties are available, but estimates can be obtained from other sources to provide an idea of the changes taking place.

California

Estimates are based on seed production (table A.l). In 1981 M-9 was the leading variety, followed by S-201 and M7. Similar seed production estimates suggest a drop-off in the use of M-9 in 1982, with another, even sharper, drop in 1983. The use of M-201 increased sharply the next year, representing about 46.4% of the total seed. M-201 was followed by S-201 and M-9. Use of other public varieties evidently was limited in 1984 (11.9%). A private semidwarf variety accounted for perhaps 7% of the seed.

On the basis of this information, it would at first appear that 87.3% of the California rice area was planted with semidwarfs in 1981 and 96.7% in 1984. However, subsequent estimates of the long-grain area in 1984, almost entirely planted with a non-semidwarf variety (California Belle), suggest that the 1984 semidwarf proportion may be closer to 86.3%.[6] The total rice area in California was 222,600 ha in 1981 and 184,100 ha in 1984. The semidwarf area was probably about 194,300 in 1981 and no more than 178,100 ha in 1984.

Southern States

Estimates of area for individual varieties are prepared by the Rice Millers' Association. The first entry for a semidwarf was in 1984, when the combined area of Bellemont and Lemont was 71,400 ha. Most of this area was in Texas: 62,800 ha, of which 51,000 ha was Lemont, representing 36.7% of the state's total rice area.[7] This was about the maximum area that could have been planted with Lemont, given the availability of seed. A substantial expansion in the area of Lemont is expected. One estimate is that by 1987 Lemont will account for 121,400 ha in Texas and slightly more than 404,700 ha in other southern states.[8] Lemont seems to be well on its way to becoming the first major semidwarf in the southern states.

Total United States

The total semidwarf area in 1984 is estimated at up to 249,500 ha. The total U.S. rice area harvested in 1984 was estimated by the USDA to be 1,139,600 ha. (These estimates are subject to revision.) On this basis the semidwarfs represented up to 21.9% of total U.S. area. The proportion will very likely increase in the future.

The proportion of the total semidwarf area with IRRI varieties or lines in their ancestry can also be calculated. In California they represented 66.6% of the semidwarfs; in the south, 100% of the semidwarfs. Overall, then, IRRI ancestry was involved in 73% of the U.S. semidwarf area.

REFERENCES AND NOTES

[1]Background on semidwarf rices in the United States through 1979 is provided in D.G. Dalrymple, *Development and Spread of Semi-Dwarf Varieties of Wheat and Rice in the United States: An Intentational Perspective,* Agricultural Economics Report No. 455 (Washington, D.C.: U.S. Department of Agriculture, 1980), pp. 70-83.

[2]Technical information on this variety is provided in C. Hwa-Hu, "Breeding of California Long-Grain and Pearl Rice Varieties With High Yields and Good Grain Quality," *Japanese Journal of Breeding* 33(2) (1983):195-207. Another semidwarf, CB-801, an IR8 derivative, was released by a private firm in Texas in 1985 (per-

sonal communication with H. Beachell, Farms of Texas Co., Alvin, Texas, 1985).

[3]"Registration of Bellemont Rice," *Crop Science* 23(4) (July-August 1983):803-804; *Bellemont; A Long Grain Rice Variety: Its Characteristics and Management,* B-1462, Texas A&M University System, Texas Agricultural Experiment Station, (College Station, Texas: Texas A&M, 1984); Calvin Pigg, "Lemont Rice 1,100 Pounds Above Others," *Southwest Farm Press* 25 October 1984; "Registration of Lemont Rice" *Crop Science* 25(5) (September-October, 1985):883-884; conversations with C. Bollich, ARS/USDA, Beaumont, 1984.

[4]"Registration of Leah Rice," *Crop Science* 22(5) (September - October 1982):1086-1087; "Registration of Toro-2 Rice," *Crop Science* 22(6) (November-December 1984):1212.

[5]"Registration of Bond Rice," *Crop Science* 24(1) (January-February 1984):208; "Registration of Newbonnet Rice," *Crop Science* 24(1) (January-February 1984): 209; "Registration of Skybonnet Rice," *Crop Science* 25(5) (September-October 1985):886-887; "Registration of Pecos Rice, *Crop Science* 25(5) (September-October 1985):885-886.

[6]Based on data reported in *Weekly Rice Market News,* 20 February 1985, p. 5 (provided by J. Neil Rutger, U.S. Department of Agriculture, Agricultural Research Service).

[7]Rice Millers' Association, *Rice Acreage in the United States, 1984* (Arlington, Va.: the Association, 1985).

[8]As cited in Dalrymple, op. cit. *(see* footnote 1), p. 40. Projection by J. W. Stansel, Director, Texas Agricultural Experiment Station, Beaumont.

Bureau for Science and Technology
Agency for International Development
Washington, D.C. 20523