United States Department of Agriculture

Office of International Cooperation and Development in Cooperation with U.S. Agency for International Development

Agricultural Economic Report Number 455

Development and Spread of Semi-Dwarf Varieties of Wheat and Rice in the United States

An International Perspective

Dana G. Dalrymple

Abstract

Semi-dwarf, high-yielding varieties of wheat and rice, along with associated inputs, have formed the basis of what has popularly been known as the "green revolution" in many developing nations. This report traces the development and use of comparable semi-dwarf varieties in the United States. It is the first general publication on the subject.

Particular attention is given to the important role played by foreign varieties, especially those generated by international agricultural research centers, in the improvement of wheat and rice in the United States. Neither crop is indigenous to the United States so that all the ancestors of present varieties have been "immigrants." The genetic source of semi-dwarfism is usually the same for both the U.S. varieties and those in developing nations.

The report covers the following main subjects: history of production and varietal improvement, development and use of semi-dwarf wheat, development and use of semi-dwarf rice, associated technological factors, changes in yields, evaluating economic impact, and institutional linkages.

By late 1979, 147 semi-dwarf varieties of wheat and 6 of rice had been released. Many of these included varieties developed in the international centers in their ancestry. Semi-dwarf wheat was planted on about 22 percent of the U.S. wheat area in 1974 and roughly 29 percent in 1979. Semi-dwarf rice varieties represented about 9 percent of the U.S. rice area in 1979. The semi-dwarfs have represented an evolutionary rather than revolutionary change. Their use is likely to expand.

KEY WORDS: Wheat, rice, high-yielding varieties, short straw, plant breeding, agricultural research, United States.

Development and Spread of Semi-Dwarf Varieties of Wheat and Rice in the United States

An International Perspective

By
Dana G. Dalrymple
Agricultural Economist

June 1980

United States Department of Agriculture
Office of International Cooperation and Development in Cooperation with U.S. Agency for International Development
Washington, D.C. 20250

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402

Abbreviations

AID, USAID–U.S. Agency for International Development

AES–(State) Agricultural Experiment Station (usually located at State college of agriculture)
AR/SEA (or SEA/AR)–Agricultural Research, Science and Education Administration, USDA
ARS–Agricultural Research Service (now AR/SEA), USDA
ERS–Economic Research Service (now a part of ESCS), USDA
ESCS–Economics, Statistics, and Cooperatives Services, USDA
OICD–Office of International Cooperation and Development, USDA
SRS–Statistical Reporting Service (now a part of ESCS), USDA
USDA–U.S. Department of Agriculture

CIMMYT–International Maize and Wheat Improvement Center (Mexico)
IRRI–International Rice Research Institute (Philippines)
INIA–Instituto Nacional de Investigaciones Agricolas (Mexico)

LDC–Less developed country

Style Notes

Usage of several terms in this report may differ from common practice in other quarters. "Semi-dwarf" is hyphenated rather than being spelled as one word. And "variety" is used in place of "cultivar."

Disclaimer

The views expressed in this report are those of the author and are not necessarily those of USDA or USAID. Mention of commercial firms and/or their products does not constitute or imply endorsement.

Preface

This study was suggested by Dr. Floyd Williams, Associate Director for Research (Acting), Office of Agriculture, Development Support Bureau, AID. Dr. Williams wondered about the degree to which semi-dwarf varieties of wheat and rice were being used in the United States. AID has provided considerable support for the development and dissemination of these varieties in less developed countries (LDC's). What degree of relationship, if any, exists between these international activities and developments in the United States? How transferable is this type of technology?

At the outset it was assumed that a considerable body of general literature existed on the semi-dwarfs in the United States. It was soon found that this was not the case. The raw materials were there (the most critical of which are periodic varietal surveys) but they had not been put together recently. The main reasons were, I suspect, the incremental nature of the varietal improvement process and the difficulty of identifying and documenting specific semi-dwarf varieties.

The resulting report, therefore, took on a broader and more extended nature than originally intended. International aspects are indeed covered, but there is also considerable information of a definitional and domestic character. This should broaden the potential U.S. (and perhaps foreign) audience, but it may be a bit of a burden to readers concerned only with international aspects (and who may wish to skip most of Chapters V, VI, and VII). In any case, more is said about wheat than about rice.

The disciplinary treatment of the subject matches its rather broad nature. The report is, to use an overworked term, interdisciplinary; it draws from history, economics, plant breeding, and agronomy. None of these disciplines, however, are presented in great depth. Nor are they given equal weight (economists have not, for example, heretofore taken up the subject).

Several other characteristics should be noted. First, the report is essentially a review of literature, supplemented by extensive correspondence and many telephone calls. Second, the report tends to emphasize increased yields; other goals, particularly those relating to grain quality, are of considerable importance but relatively little is said about them (except for rice in Appendix B). Third, despite a rather extended review process, some errors undoubtedly remain. I bear the responsibility.

The report may be regarded as a companion to a study I did several years ago on high-yielding varieties of wheat and rice in developing nations.[1] It is based on data and information available through December 1979.

I hope that the subject will be of as much interest to others as it has been to me. I would be pleased if the report stimulated further study.

---

[1] *Development and Spread of High-Yielding Varieties of Wheat and Rice in the Less Developed Nations*, USDA (in cooperation with AID), Office of International Cooperation and Development, Foreign Agricultural Economic Report No. 95, September 1978 (6th edition), 134 pp.

Acknowledgements

This report was made possible only by the generous cooperation and assistance of a large number of individuals, both in the public and private sectors. Virtually all of the principal breeders of semi-dwarf wheat and rice in the United States have been contacted at one point or another. Other biological and social scientists have also been of assistance.

It would be difficult, in this brief space, to identify all who contributed by providing information and/or reviewing portions of the manuscript. Many are cited in the footnotes. I would, however, like to give special recognition to three USDA colleagues: L. W. Briggle, Larry Dosier, and T. H. Johnston. I would also like to acknowledge the assistance of and/or review comments of: C. Roy Adair, Henry Beachell, Charles Bollich, J. J. Bond, D. Marlin Brandon, R. H. Busch, Howard Carnahan, T. T. Chang, Byrd Curtis, Dewayne Hamilton, Walter Heid, Warren E. Kronstad, Marco Marchetti, C. O. Qualset, Wayne Rasmussen, L. P. Reitz, Bob Romig, J. Neil Rutger, Henry Shands, Mark Sorrells, Dwaine Umberger, Orville Vogel, and James R. Welsh. Aubrey Robinson served as editor.

But in mentioning these individuals, I find that, as did a well-known historian in a different context, "The faces and voices of all that I have left out crowd about me as I reach the end." (Barbara W. Tuchman, *The Proud Tower*, 1966, Foreword)

Contents

Summary

Semi-dwarf wheat and rice varieties, together with a package of improved production inputs, have formed the basis for what is popularly known as the "green revolution" in many developing nations. Semi-dwarfs are considered high-yielding varieties in these countries because of their ability to respond to higher levels of fertilization without lodging or falling over. They also have some other improved plant characteristics.

To what extent have semi-dwarf varieties of wheat and rice been developed and adopted in the United States? Have the varietal improvements in the developing nations had any relationship to those in the United States? Wheat and rice are not indigenous to the United States and improvement in varieties grown here has long depended on introductions from abroad. (While the United States is largely a nation of immigrants with respect to its population, it is entirely so with respect to the ancestors of present wheat and rice varieties.) Has the same pattern been involved for semi-dwarfs? Despite the importance of the subject, surprisingly little of a general nature has been written about it. This report is intended to correct that situation.

The United States has had a close and early involvement with the development of semi-dwarf varieties of wheat and rice. Virtually all semi-dwarf wheat varieties are descendants of a cross originally made in the United States in the late 1940's. The first modern semi-dwarf wheat variety was released in the United States in 1961. It was followed by several more varieties in the United States and by a host of varieties developed under the direction of an American, Dr. Norman E. Borlaug, at the International Maize and Wheat Improvement Center (CIMMYT) in Mexico (in cooperation with the Mexican national agricultural research program, INIA). Similarly, two United States rice breeders helped develop the semi-dwarf rice varieties first released by the International Rice Research Institute (IRRI) in the Philippines in the 1960's.

Despite this involvement, the United States may seem to have developed and used semi-dwarf varieties, with a few notable exceptions, at a relatively slow pace. To some extent this is true, but for good reasons. First, the United States has had a longstanding program of varietal improvement for wheat and rice. Short varieties have been developed which have met the needs of many regions. Semi-dwarf varieties have emerged and been adopted as the demand for them has grown. Secondly, even where such a demand exists, it takes time to develop and test semi-dwarf varieties which are: (1) an improvement over existing varieties, (2) well adapted to local growing conditions, and (3) up to United States grain quality standards. But it is also true that a great deal more has been accomplished in terms of the development and use of semi-dwarf varieties in the United States than has generally been recognized.

The lack of general information on this subject may be partly due to the difficulty of identifying or distinguishing the semi-dwarf varieties. While semi-dwarfs are generally somewhat shorter than traditional varieties, the difference may be slight or nonexistent in certain cases. Little or nothing is said about the semi-dwarf nature in advertising or promoting these varieties; as a result, many farmers only know that they are relatively short-strawed. Yet there is usually a significant genetic difference, and this difference is used to identify the varieties discussed in this report.

The difference is the presence of distinct dwarfing genes: two, and possibly a third, in the case of wheat and usually one in the case of rice. Essentially all semi-dwarf wheats used in the United States trace their dwarfing gene back to a Japanese variety, Daruma; in most cases this gene was transmitted through another Japanese variety, Norin 10. In the case of semi-dwarf rice, the gene is derived from the Chinese variety Dee-gee-woo-gen; it is usually transmitted through the IRRI varieties (except IR-5) or through the Taiwanese variety, Taichung Native 1. A "similar" (allelic) dwarfing gene has also been produced by induced mutation in California and is present in several commercial varieties.

Use of a genetic definition of semi-dwarfs, while fairly precise, entails some operational problems. It necessitates a knowledge of the genealogy of each variety, which in some cases is difficult to obtain. It involves imposing some other height criteria because the dwarfing genes are recessive and their presence does not necessarily mean semi-dwarf height. Some other classification problems are also involved. Even so, it appears to be the most systematic procedure presently available.

Altogether, 147 semi-dwarf varieties of wheat and 6 semi-dwarf varieties of rice were identified through late 1979. All are the result of hybridization, but they are not hybrids since they do not represent the F_1 generation. The semi-dwarf varieties may be divided into three categories: (1) introductions from abroad, (2) selections from crosses made abroad, and (3) selections from crosses made in the United States. Several rice varieties have also been developed through irradiation. Of the 147 wheat varieties, 18 were introductions from Mexico, 34 were selections from Mexican crosses, and 95 were selections from United States crosses (14 of which had Mexican varieties in their genealogy). Of the 6 rice varieties, 1 was an introduction, 4 were a result of hybridization, and 1 was a product of irradiation.

Once the semi-dwarf varieties have been sorted out, it is a relatively easy task to go through the existing national varietal surveys (one every 5 years for wheat and every year for rice) and to determine the area planted to the semi-dwarfs.

In the case of wheat, this process revealed that 69 semi-dwarf varieties were commercially planted in 1974. The area planted to semi-dwarf wheat varieties has increased as follows in the United States (starting from a figure of 0 in 1959):

Year	Semi-Dwarf Area	Semi-Dwarf as Proportion of Total Area
	Acres	*Percent*
1964	1,609,000	2.92
1969	3,806,000	7.01
1974	15,756,000	22.14

Similar national data are not yet available for 1979, but preliminary and partial data suggest that the semi-dwarf proportion may have risen to about 29 percent of total wheat area—or slightly over 20 million acres.

The semi-dwarf wheat area may also be summarized in several other ways. In terms of origins, the breakdown, on a percentage basis, was:

Category	1964	1969	1974
Introductions	0.3	7.3	5.4
Selections	0	4.5	20.3
Crosses	99.7	88.2	74.3
Total	100.0	100.0	100.0

The introductions, with one exception, came from the CIMMYT/INIA program in Mexico, and the selections were made from CIMMYT/INIA crosses. Thus, in 1974, 25.7 percent of the semi-dwarf area in the United States (or 5.7 percent of the total U.S. wheat area) had a Mexican base.

In terms of market type, the largest proportion of the semi-dwarf wheat area in 1974 was of the Hard Red Spring type (42.1 percent), followed by White (25.4 percent), and Hard Red Winter (24.5 percent). Soft Red Winter, Club, and Durum accounted for the remaining 8 percent. The semi-dwarfs represented particularly large proportions of the area planted to White wheat (63.6 percent), Club (48.1 percent), and Hard Red Spring (45.0 percent).

In terms of States, the 1974 leaders in total semi-dwarf area were (in descending order): Minnesota, North Dakota, Washington, Texas, Oklahoma, Kansas, Idaho, and Oregon. States with the highest proportions of their total area planted to semi-dwarfs were (also in descending order): Arizona, California, Nevada, Minnesota, New York, Oregon, Washington, and Idaho. On the other hand, the semi-dwarf area was smallest in the Midwest (Ohio, Indiana, Illinois, and Missouri).

Semi-dwarf rice varieties have only recently come into use, and then in one State, California. Semi-dwarf rice area in California was unofficially estimated at about 50,000 acres in 1978 and about 265,000 acres in 1979—or roughly 1.6 percent of the total U.S. rice area in 1978 and 8.8 percent in 1979. In terms of origins, one variety with an IRRI parent occupied about 45 percent of total semi-dwarf area in 1978 and about 60 percent in 1979— or about 0.76 percent of the total U.S. rice area in 1978 and 5.27 percent in 1979.

Use of semi-dwarfs is generally associated with relatively high degrees of soil fertility and good water supply. Although specific data are not available for semi-dwarfs, several parameters can be identified for wheat and rice as a whole. In 1974, according to the U.S. Census of Agriculture, about 62 percent of the total wheat area and nearly all (99.6 percent) of the rice area was fertilized; irrigated area was 5.2 percent for wheat and 100 percent for rice. Wheat is grown under relatively extensive conditions; rice under intensive conditions. This means that the proportion of area potentially suitable for semi-dwarfs is considerably less for wheat than for rice. Current breeding work may lead to further improvements in tolerance of environmental conditions.

The proof of the value of semi-dwarfs and their associated technology lies in their effect on yields. Unfortunately, it is difficult to judge the effect of the semi-dwarfs with the data at hand. During the period when the use of semi-dwarf wheat expanded most sharply, there was a tapering off in the rate of yield increases of all crops. Also, while yield increases can be fairly well documented at the experimental level (where most semi-dwarfs appeared to have a yield advantage of 5 to 25 percent), the same cannot presently be done at the farm level. Moreover, yield levels are influenced by the use of associated inputs which must share some of the credit. And in the case of wheat, at the time that the area planted to semi-dwarfs was expanding most rapidly—1969 to 1974—there also was an increase in the total area planted (particularly during 1972-1974), which undoubtedly brought less productive land into cultivation. After 1974, however, yields rose steadily, reaching record levels in 1979; some, but as yet undetermined part, of this increase probably was due to increased use of semi-dwarfs. The situation for rice is uncertain, but the current release and development of semi-dwarf rice varieties may soon further stimulate yields. This apparently has already happened in California where record yields were achieved in 1979. In the South, some of the standard varieties are already short-statured and capable of high yields.

Just as it is difficult to assess precisely the impact of semi-dwarfs on yield levels, it is even more difficult to assess the more general economic impact of semi-dwarfs. The cost of production per *acre* may well increase because of the use of additional fertilizer, but the cost per unit of *product* should decrease. The latter reduction, to the extent it is realized, could benefit both producer and consumer. However, because of the tendency for overproduction of both crops and the inelastic domestic demand for each, the benefits may fall much more to consumers than producers—depending, in part, on the extent to which the crop is exported. In any case, the overall benefits to society should be substantial and should mean a substantial return to investment in research. Some of this return can be traced to work done by the international agricultural research centers partly supported by the U.S. Agency for International Development (AID).

If the United States is to share more fully in the benefits of the work of these centers, and in the increasing work done by other national programs, it might do well to give more attention to improving its institutional arrangements for acquiring this technology. Considerable liaison and contact exists, but these could well be strengthened. At present, the United States is better organized at the public level to provide technology to developing nations than it is to obtain it from developed or developing nations. Relatively modest efforts in assisting the acquisition of international technology could pay substantial benefits in the future.

Conversion Factors

1 acre = 0.4047 hectare (ha.)
1 hectare (ha.) = 2.471 acres
1 inch = 2.54 centimeters (cm.)
1 centimeter (cm.) = 0.3937 inch
1 ton (short) = 2,000 pounds
1 metric ton (mt) = 2,204.6 pounds
1 bushel (bu.), wheat = 60 pounds
= 27.22 kilograms
1 hundredweight (cwt.), rice = 100 pounds
= 45.36 kilograms
1 pound (lb.) = 0.4536 kilograms (kg.)
1 kilogram (kg.) = 2.2046 pounds
10 bu. (wheat)/acre = 672.5 kg./ha. = 0.6725 mt/ha.
1,000 lbs. (rice)/acre = 1,120.8 kg./ha. = 1.1208 mt/ha.
1 mt (wheat)/ha. = 14.87 bu./acre
1 mt (rice)/ha. = 892.2 lbs./acre

Picture Credits

Plate *Source*

1. *Harper's Weekly*, July 30, 1887, p. 541.
2. U.S. Dept. of Agriculture (Neg. Cen-31). Photographed by Underwood and Underwood; original in Library of Congress (LOC LC USZ 62 16180).
3. *Harper's Weekly*, January 5, 1867, p. 8.
4. Texas A & M University, Agricultural Research and Extension Center, Beaumont.
5. Oregon State University, Dept. of Crop Science, Corvallis.
6. B. Rodney Bertramson, Pullman, Wash.
7. Cornell University, Dept. of Plant Breeding and Biometry, Ithaca, N.Y.
8. University of California, Dept. of Agronomy and Range Science, Davis.
9. University of California, Dept. of Agronomy and Range Science, Davis.
10. U.S. Dept. of Agriculture (Neg. BN-46191).
11. U.S. Dept. of Agriculture (Neg. BN-43651).
12. Oregon State University, Agricultural Experiment Station, Corvallis.

I. INTRODUCTION

The greatest service which can be rendered any country is to add an useful plant to its culture; especially, a bread grain . . .

—Thomas Jefferson, 1821*

Semi-dwarf varieties of wheat and rice, along with fertilizer and irrigation, have helped bring about a much-heralded "green revolution" in many less developed nations. While the term "green revolution" is an unfortunate one that leads to inflated expectations, grain production has undergone profound changes in numerous countries.

If the semi-dwarf varieties have played a vital role in this process in developing nations, what has been their role in the United States where varietal improvement has been carried out for over a century and where improved cultural practices such as fertilization have long been thought to be the norm? Surprisingly little appears to have been written about this potentially important matter.

Possibly this is because an on-going process of varietal improvement has brought about shorter strawed varieties that have lessened the potential importance of semi-dwarfs. It might also be suggested that food supplies are in much shorter supply in developing nations than in the United States, where, in fact, the problem is often one of surpluses of these two crops. To some extent both propositions are true.

But it is also true that the United States is the world's leading generator and user of improved agricultural technology. If semi-dwarf varieties held promise of increasing output at reasonable cost, then it would seem that they must have been considered and utilized. As it turns out, this is indeed the case, but the story is not well known.

It is the purpose of this report—as suggested by the title—to examine the development and spread of semi-dwarf varieties of wheat and rice in the United States. For good reason, special attention is devoted to the international dimensions of this process.

Given this orientation, the report is relatively broad. But the focus on plant height means that many other important aspects of plant improvement are not covered (general goals for rice breeding in the South, for example, are summarized in Appendix B).

International and Historical Dimensions

Wheat and rice are not native to the United States. All varieties used throughout the history of this nation have at some point in their ancestry been imported from other countries. These foreign roots are now obscure in many cases. In respect to these crops, as well as others, the United States is truly a nation of "immigrants."[1]

Thus, any improvement in wheat or rice varieties must necessarily involve varieties which have already been imported, new varieties from abroad, or—more recently—induced mutations. For much of early U.S. history, the main path lay in the import of new varieties. During the late 1800's and early 1900's, greater attention was given to selection and crossbreeding to achieve varietal improvement.

One of the many desired characters in varietal improvement is a stiff stem—one which will not easily fall down or bend (lodge) before the grain is harvested. Lodging reduces both grain yields and quality and makes mechanized harvesting more difficult. Lodging resistance is needed in fertile areas and is particularly important with increased use of fertilizer. Heavy rains and wind can intensify lodging problems.

Compared with many other nations, wheat was at first grown under relatively extensive conditions in the United States. Land was plentiful and if more grain was desired, more could be planted. With the closing of the frontier, however, production gradually became more intensive. More emphasis was placed on improving yields. Fertilizer was one key way to improve yields. Rice was nearly always raised under relatively intensive conditions.

For many years, wheat and rice varietal improvement that simply emphasized stronger straw was sufficient to limit lodging at the levels of fertilizer then utilized. In fact, aside from lodging, it was thought that taller plants were more productive. But as the need for higher yields increased, and as fertilizer became relatively less expensive and was more widely and more heavily applied, lodging became more of a problem. Increased mechanization also reduced the use of livestock for draft and, hence, lessened the demand for straw.

Gradually, the importance of shorter height was realized. It was possible to select from crosses between existing varieties for this characteristic. The height of wheat and rice plants gradually declined. But there was a concurrent need for better methods of grass and weed control because short-strawed varieties are poor competitors. Also, there were limits to how far this process could go with the existing germplasm resources. One potential was to be found, as in the past, overseas. Semi-dwarf varieties of wheat and rice had, in fact, long been in commercial use in certain other nations, particularly where these crops had been raised under relatively intensive conditions.

In 1873, Horace Capron, former U.S. Commissioner of Agriculture who headed an agricultural advisory group to Japan, wrote that "the Japanese farmers have brought the art of dwarfing to perfection." Capron noted that "on the richest soils and with the heaviest yields, the wheat stalks never fall down and lodge."[2] Crossbreeding was undertaken in Japan in the 1920's and 1930's to further develop short-strawed varieties. The same was true in Italy.[3]

In the case of rice, increased use of commercial fertilizer (fishmeal and soybean cakes) in Japan in the late 1800's led to an interest in the development of varieties with short stems. One of the first was selected in 1877 and more intensive improvement work was undertaken with the introduction of chemical fertilizer in the early 1900's. Similar work was initiated by the Japanese on Taiwan in the early 1920's.[4]

But aside from Japan and Italy, relatively little was done elsewhere to develop short varieties until the mid-1950's and early 1960's. In the case of wheat, semi-dwarf varieties were imported into the United States in 1946 and a useful cross with a U.S. variety was obtained in the early 1950's. The first semi-dwarf wheat variety was released in the United States in 1961. It was shortly followed by a host of semi-dwarf varieties jointly developed by the International Maize and Wheat Improvement Center (CIMMYT) and released by the Mexican national agricultural research program (INIA). The early Mexican semi-dwarf varieties obtained their short stature from the Japanese-American cross developed in the early 1950's.

Semi-dwarf rice originated in Southeast Asia and was first grown in mainland China. The first modern variety (Taichung Native 1) was developed on Taiwan in the mid-1950's. With the establishment of the International Rice Research Institute (IRRI) in the Philippines in 1962, development of semi-dwarf varieties moved into high gear; the first tropical variety (IR-8) was released in 1966 and was quickly followed by many others.

The semi-dwarf varieties developed by CIMMYT and IRRI not only had shorter stems than traditional varieties, but they also had several other complementary plant features. They were generally early maturing and had high tillering capacity (the plants send out many shoots—which include roots, stem, and leaves—more fully utilizing the ground area available). Other features include larger grain number per spikelet in wheat, and improved structure of the leaf canopy in rice.[5]

The CIMMYT and IRRI varieties provided the basis for the "green revolution" that began in Asia in the mid-1960's. I have calculated elsewhere that by 1976/77 roughly 135 million acres of high-yielding varieties, principally semi-dwarfs, of wheat and rice were planted in the less developed nations—more than one-third of their total wheat and rice area.[6]

Has anything of comparable magnitude occurred in the United States following the release of the first semi-dwarf wheat cross in 1961? This report is devoted to this question.

In order to better set the stage for the reader who is not familiar with wheat and rice production in the United States or with semi-dwarfism in these plants, the next two sections of the Introduction provide background information and definitions. Those who are familiar with these matters may wish to move directly to Chapter II.

Background Information on Production and Varieties

There are three somewhat different types of background information which may be useful for the general reader: the importance and nature of wheat and rice production in the United States; the registration system for new varieties of wheat and rice; and the definition and development of semi-dwarf varieties. The latter section also may be of broader interest.

Wheat and Rice Production in the United States[7]

The importance of wheat production in the United States is well known; the significance of rice may be less generally recognized.[8] In 1977, the United States produced 77.2 million metric tons of **wheat**, more than any other nation in the world, except the Soviet Union. This output was valued at $4.7 billion, down from the value of the 1976 and 1975 crops. Cash receipts from wheat in 1977 ranked sixth among all agricultural commodities in the United States in 1977. Similarly, in 1977, **rice** production totaled 4.5 million metric tons, which put the United States in twelfth place in the world. This output was valued at nearly $940 million, less than that of 1975 but above 1976's level. Cash receipts from rice ranked fifteenth among all agricultural commodity groups in 1977. Thus, wheat is easily the more important crop, but rice is of substantial importance.

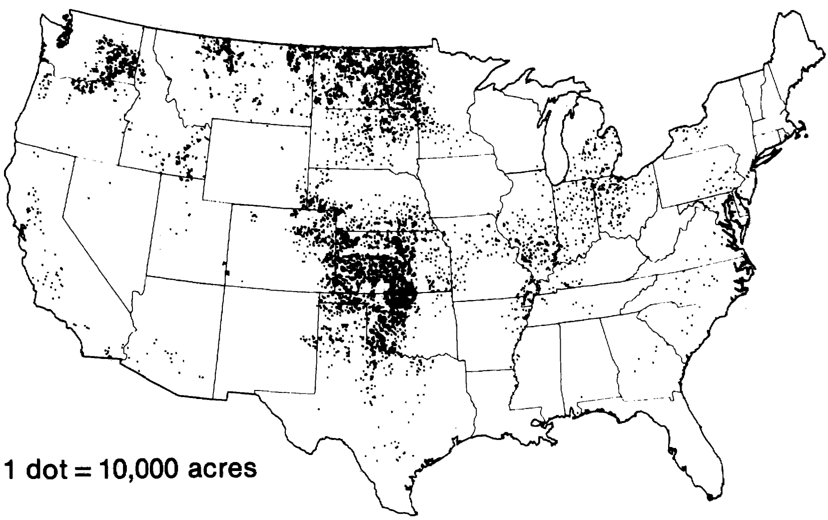
The location of production varies considerably between the two crops. **Wheat** is widely spread over the continental United States and commercial production is found in every State, except in New England. However, production is heavily concentrated in the Great Plains States and to a lesser extent in the Midwest and the Pacific Northwest (see figure 1). Rice production is much more concentrated—and is almost entirely found in four South Central States and in California (see figure 2).

A comparison of the utilization of the two crops in 1976 follows:[9]

Category	Wheat	Rice
	Percent	
Domestic use		
Food	32.6	27.0
Seed	5.4	9.5
Feed	6.1	2.9
Subtotal	44.1	39.4
Exports	55.9	60.6
Total	100.0	100.0

Figure 1

Location of Harvested Wheat Area, United States, 1974
All Farms—County Unit Basis



Source: *1974 Census of Agriculture,* Vol. IV, Part 1, April 1978, p. 148.

Clearly, export markets are very important for both crops. In fact, the United States is usually the world's leading exporter of both crops. In 1976, Government programs accounted for 18.7 percent of U.S. wheat exports and 23.0 percent of the rice exports.

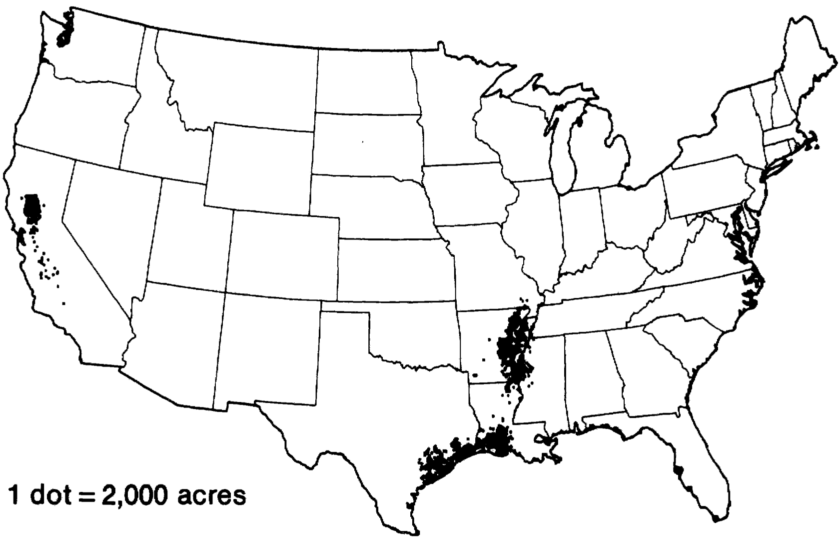
Registration System for Varieties

Hundreds of wheat varieties and about two dozen rice varieties are grown in the United States, with more being introduced every year. How can one keep up with the current and new varieties? And how can one identify semi-dwarf varieties? These are important questions and probably help explain why little has been written about semi-dwarfs in the United States.

Varieties in common use are reported in different ways for wheat and rice. Since 1919, the U.S. Department of Agriculture and the States have conducted a wheat varietal survey every 5 years. The last published report is for 1974;[10] the 1979 survey is now being summarized. A few States also conduct annual varietal surveys on their own. Rice varieties are reported yearly by the Rice Millers' Association (Arlington, Va.); both acreage and production by variety are included.[11]

Figure 2

Location of Harvested Rice Area, United States, 1974
Farms With Sales of $2,500 and Over— County Unit Basis



Source: *1974 Census of Agriculture*, Vol. IV, Part 1, April 1978, p. 155.

Nearly all varieties of wheat and rice introduced, selected, or developed in the United States are made a part of the World Collection, maintained by the Germplasm Resources Laboratory, Science and Education Administration, USDA, Beltsville, Md. Foreign introductions are given a plant introduction number (the actual numbers are preceded by P.I.) All others are given a cereal investigation number (preceded by C.I.). These numbers are often used in identifying varieties. The Germplasm Resources Laboratory maintains an information card and a small stock of seed of each accession in the collection. This process has been going on for decades and is remarkably complete.

Concise and authoritative background information on new wheat and rice varieties (as well as other crops) is published as "Registration of Crop Cultivars" in *Crop Science*, issued every other month by the Crop Science Society of America. *Crop Science* has been issued since 1960 (before that some registrations were carried in the *Agronomy Journal*). The only problems are an inevitable delay in registering new varieties and a lack of complete coverage due to the voluntary nature of the process. Varieties developed by private firms are less likely to be entered for publication than those developed at public institutions.

Information on most of the new varieties developed by private firms, however, is now on file with the Agricultural Marketing Service of USDA at Beltsville. As a result of the Plant Variety Protection Act, enacted December 24, 1970, breeders may in effect patent their new varieties.[12] As with patents, a detailed application must be filed. This is then examined and if the variety is found to be new and novel, a Certificate of Protection is issued. Once the certificate is issued, the application is open to public inspection in the Plant Variety Protection Office at the National Agricultural Library in Beltsville. An *Official Journal of the Plant Variety Protection Office* is published every 3 months, listing the applications and certificates issued.

Defining and Developing Semi-Dwarfs

Semi-dwarfism is at once both easy and difficult to define. At one level, it is simply a plant which has a distinctly shorter stalk than traditional varieties. This shortness is brought about by a specific gene or set of genes (generally two or possibly three genes in wheat; usually one gene in rice) that can be identified in genetic tests. In the case of wheat, semi-dwarfs are insensitive to the growth hormone gibberellin. Visually, however, it is sometimes difficult to draw the line between short-strawed varieties (without dwarfing genes) and semi-dwarf varieties (with dwarfing genes). The semi-dwarf gene—or genes—generally used is recessive in nature and the resulting plants can show a gradation in height. Thus, in some instances, certain short-strawed varieties can be shorter than some semi-dwarf varieties.[13]

Moreover, each variety varies in height from location to location and from year to year. For example, from 1973 to 1976 in five locations in the United States, Blueboy wheat (one of the first semi-dwarfs) averaged 9 percent shorter than Atlas (normal height), but the range was from 19 percent shorter to 16 percent taller.[14] Height fluctuations in rice may be considerably less, due in large part to more uniform growing conditions, but still may differ appreciably according to nitrogen fertilization levels and timing. Obviously, these variations lead to difficulties in drawing the line between short stature and semi-dwarf varieties. The problems will be discussed more thoroughly in Chapters III and IV.

All widely used semi-dwarf varieties developed in the United States, or elsewhere in the world, are the result of crossbreeding. This process is commonly known as hybridization. The first generation product of this cross (F_1) is a hybrid. The subsequent generations (F_2, etc.) are not generally known as hybrids. All semi-dwarf varieties in commercial use in the United States are selections from subsequent generations. Thus, although the result of hybridization, the present semi-dwarf varieties themselves are not considered true hybrids. Development of true hybrids (F_1) for commercial use is a complex process which has been undergoing research development for a number of years. It is discussed more fully in Chapter V.

Varietal Classes, Production, and Use

Wheat and rice varieties in the United States are often discussed in terms of their market characteristics. Some of these terms will be used in the following chapters. The systems are quite different in the case of wheat and rice.

Wheat

Wheat may be viewed in terms of botanical species or commercial characteristics. The former can be treated quite briefly; the latter requires more extended discussion. Market classes are then related to areas of production and types of use.

BOTANICAL SPECIES. There are three species of Triticum wheat grown in the United States: (1) Common, *Triticum aestivum*; (2) Club, *Triticum compactum;* and (3) Durum, *Triticum durum*. Most wheat in the United States is of the Common type. In 1974, the planted area was divided as follows among the three species (in percent): Common 93.0, Durum 5.6, and Club 1.4.[15]

COMMERCIAL CHARACTERISTICS.[16] Commercial characteristics relate to hardness or softness of the grain, whether the crop is winter or spring in growth character, and the color of the grain.

Hardness and softness are of significance both in terms of production and marketing. Hard wheats, which include Durum, are generally grown in dryland areas with relatively low rainfall; wheat is usually grown every other year with a year of fallow in between. Soft wheats, which include Club, are raised in areas of relatively abundant rainfall, and they are usually grown in rotation with other crops. Hard wheats, other than Durum, are used primarily for making bread; Durum wheats are used for macaroni, spaghetti, and noodles. Soft wheats are used for making cookies, crackers, pastries, cake mixes, and other similar items. Over the 3-year period from 1976 to 1978, hard wheats, including Durum, accounted for an average of 72.7 percent of the total production (of which 5.9 percent was Durum), while soft wheat accounted for 27.3 percent.

Wheat may be of winter or spring growth habit. Winter wheat is planted in the fall and harvested in the spring or early summer; spring wheat is planted in the spring and harvested in late summer or early fall.[17] Winter crops are generally preferred by farmers because of higher yields. Spring wheats, because they mature later in the season, are more susceptible to hot weather, drought, rusts, and other hazards. They are usually planted only where severe winter weather is apt to kill off part or all of the fall seeding, or in regions with cooler summers where spring wheat can outperform winter varieties. In the

3 years from 1976 to 1978, the winter crop accounted for 70.5 percent of the harvested area and the spring crop (including Durum) represented 29.5 percent. In terms of production in the same period, winter wheat accounted for 72.6 percent and spring wheat for 27.4 percent. Yields for the winter crop averaged 31.7 bushels per acre, while those for the spring crop were: Durum, 29.6; and other spring, 28.4.

The color of wheat grain is often used in classification. Over the same 3-year period, 81.6 percent of U.S. production was red and 18.4 percent was white. Club wheats are white while Durum is amber.

In general use, the above characteristics are combined into six market classes. These classes, and their relative proportion of production from 1976 to 1978, are:

Class	*Percent*
Hard Red Winter	46.9
Soft Red Winter	14.9
White Winter	10.9
Hard Red Spring	19.9
Durum (Spring)	5.8
White Spring	1.6
Total	100.0

In the varietal surveys, White Winter and White Spring are combined and reported simply as white.

MARKET CLASSES AND LOCATION OF PRODUCTION.[18] As noted in the previous section, some market characteristics are related to rainfall and temperature. Thus, in geographic terms, the "east" (east of the Great Plains) produces soft wheat, the Plains States produce hard wheats, and the Western States produce both. Winter wheat production predominates in the "eastern" States and in the central and southern plains, while spring wheat production is found in the northern plains; the Western States produce both spring and winter wheat.

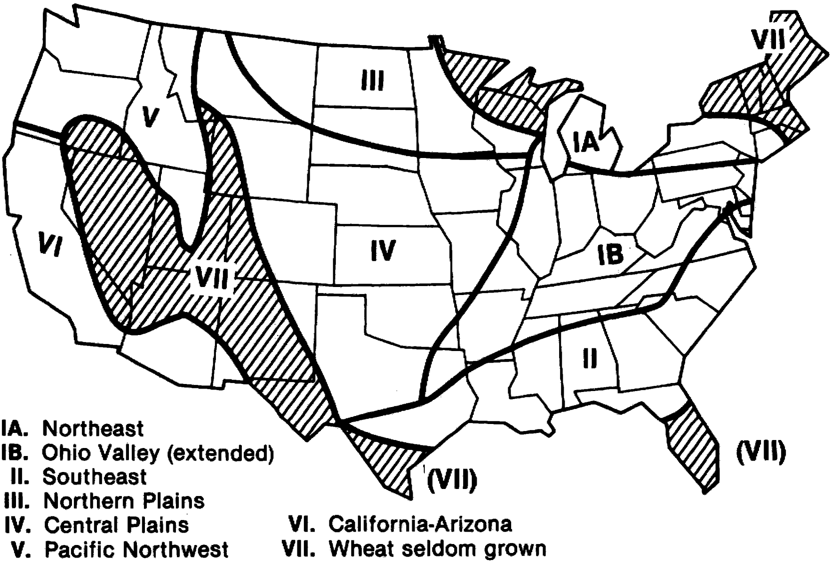
This distribution may be pictured more precisely by consulting figure 3. The "eastern" States refer to regions IA, IB, and II; Plains States to regions III and IV; and the Western States to regions V and VI. On this basis, some States (Minnesota, Montana, and Texas) represent as many as three regions.

In terms of the individual regions, the dominant (but not exclusive) market types are:

IA, Northeast. White Winter.
IB, Ohio Valley (extended). Soft Red Winter.
II, Southeast. Soft Red Winter.
III, Northern Plains. Hard Red Spring, Durum.
IV, Central Plains. Hard Red Winter (some Hard Red Spring).

Figure 3

Adaptation Regions for Wheat, United States



Source: Adapted from L. P. Reitz, *Wheat in the United States*, USDA, Agricultural Research Service, Agriculture Information Bulletin No. 386, February 1976, p. 3.

V, Pacific Northwest. Soft White (including Club); Hard Red Winter, Hard Red Spring.

VI, California-Arizona. Hard Red Spring,[a] White (including Club), Durum.

[a]Planted in the fall and grown like winter wheat; sometimes classified as Hard Red Winter (as in table 13, p. 122).

MARKET CLASSES, PROTEIN LEVELS, AND USE.[19] The use of wheat varieties is largely dictated by their protein level. For the production of yeast-leavened bread and rolls, flour with a protein content of at least 11 percent is usually preferred. To produce such flour, the wheat must have a protein level of at least 12 percent. The hard U.S. wheats usually meet such levels and are used for this purpose (one exception is Durum wheat, which is used for macaroni and similar products).

Flours for purposes other than yeast-leavened bread are generally made from wheats of lower protein content—in the 8 to 11 percent range. In some cases, the optimum protein content range is quite narrow. Approximate levels for some products are (in percent): cookies 8-9, pie crust 8-10, cake 9-9.5, biscuits 8.5-10.5, and crackers 10-11. The soft wheats—Soft Red Winter and White—have protein levels in this range.

In the case of hard winter wheats, there is concern that protein levels have been declining for some time and that this now may be a limiting factor in meeting domestic and export requirements.[20] The hard winter varieties have been bred for increased yields but often do not receive adequate nitrogen fertilization to keep protein levels up (this point will be discussed in Chapter V).

Rice

As in the case of wheat, rice may be considered in terms of botanical species and market characteristics.

BOTANICAL SPECIES. Asian or common rice (*Oryza sativa L.*) is the only species of cultivated rice in the United States.[21] The two major eco-geographic races within this species found in the United States are indica and japonica. The tropical varieties largely belong to the indica race and most of the temperate varieties to the japonica race. Both races, however, have been extensively crossed in the South Central United States and the distinction is relatively minor there.[22] Japonica varieties have predominated in California, but crosses with indica varieties are coming into use. Virtually all of the work of IRRI has centered on semi-dwarf indica varieties, while the japonica varieties have been emphasized in Japan. There can be difficulties in transferring the dwarfing gene from indica to japonica varieties in the United States because of sterility in early generations and the possible transfer of unacceptable grain quality and cold susceptibility.[23]

MARKET CHARACTERISTICS. Rice in the United States is classified and marketed under three market categories: short-grain, medium-grain, and long-grain. In 1978, 8.9 percent of U.S. production was short-grain, 27.2 percent medium-grain, and 63.9 percent long-grain. Traditional indica rice tends to be long-grain, and japonica short- to medium-grain. Most of the short-grain rice was produced in California, and essentially all of the long-grain rice in the Southern States; medium-grain rice was produced in all the main rice States.[24]

Short- and medium-grain rice varieties are quite distinct from long-grain rice in cooking and processing characteristics.[25]

- Short- and medium-grain types are sometimes referred to as soft rice. When cooked, they are more moist than the long-grain varieties and the grains tend to stick together. They are preferred for manufacture into such products as dry breakfast cereals or baby foods, and for brewing uses.
- Long-grain rice is frequently called hard rice. It usually cooks dry and flaky with a minimum of splitting, and the cooked grains tend to remain separate. It is generally preferred for use in prepared products, such as

parboiled rice, quick-cooking rice, canned rice, canned soups, dry soup mixes, frozen dishes, and other convenience-type foods.

The physical difference between short- and medium-grain rice is largely one of length and length/width ratio; in the case of brown rice the kernel length of short-grain rice is up to 5.5 millimeters, while medium-grain rice is 5.51 to 6.6 millimeters. (Long-grain rice is 6.61 to 7.5 millimeters.) Short- and medium-grain rice differ considerably from long-grain rice in amysose content which primarily determines dryness of cooked rice.

* * *

With these terms and definitions in mind, we now turn to a brief historical review of wheat and rice production and varietal improvement in the United States.

References and Notes

**The Jeffersonian Cyclopedia*, ed. by John P. Foley, Funk and Wagnalls Co., 1900, p. 697, item 6677.

[1] The extent of U.S. dependence on plants introduced from other nations is reviewed in popular terms by Claire Shaver Haughton in *Green Immigrants: The Plants that Transformed America*, Harcourt, Brace, Jovanovich, New York, 1978, 450 pp.

[2] Horace Capron, "Agriculture in Japan," *Report of the Commissioner of Agriculture for the Year 1873*, Washington, 1874, p. 369.

[3] These developments are described in Dana G. Dalrymple, *Development and Spread of High-Yielding Varieties of Wheat and Rice in the Less Developed Nations*, USDA (in cooperation with AID), Office of International Cooperation and Development (OICD), Foreign Agricultural Economic Report (FAER) No. 95, September 1978 (6th edition), pp. 10-14.

[4] *Ibid*., pp. 1, 24, 25.

[5] D. S. Athwal, "Semidwarf Rice and Wheat in Global Food Needs," *The Quarterly Review of Biology*, March 1971 (Vol. 46, No. 1), pp. 24-26. Dr. T. T. Chang of IRRI adds that in the case of rice:

> Shortening the culms has generally led to more erect and shorter leaves, more uniform distribution and increased light penetration of the canopy, and a greater photosynethetic capacity with heavy nitrogen application. Semi-dwarfism in rice is also associated with vigorous tillering, faster leaf development, and adaptability to spacing and planting methods, with consistently higher grain-to-straw ratio.

(Memo from Dr. Chang, May 7, 1979; also summarized by Chang, et al., "Crop Adaptation," in *Plant Breeding Perspectives* (ed. by J. Sneep and A. J. T. Hendriksen), PUDOC, Wageningen, 1979, p. 248.)

[6] Dalrymple, *op. cit*., pp. x, xi, 113-126.

[7] Much further background information is provided in two recent Agricultural Economic Reports (AER's) issued by the Economics, Statistics, and Cooperatives Service of USDA: Walter G. Heid, Jr., *The U.S. Wheat Industry*, AER No. 432, August 1979, 117 pp.; and S. H. Holder, Jr., and W. R. Grant, *The U.S. Rice Industry*, AER N 433, August 1979, 141 pp.

[8] Data reported in this paragraph were obtained from: *Agricultural Statistics, 1978*, USDA, pp. 1, 4, 9, 10, 19, 20, 25; *Fact Book of U.S. Agriculture*, USDA, Miscellaneous Publication No. 1063, November 1978, pp. 83, 84.

[9] Calculated from data reported in *Agricultural Statistics, 1978*, USDA, pp. 4, 11, 20, 23.

[10] L. P. Reitz and W. G. Hamlin, *Distribution of the Varieties and Classes of Wheat in the United States in 1974*, USDA, Science and Education Administration, Statistical Bulletin No. 604, June 1978, 98 pp.

[11] See, for example, "Rice Acreage in the United States, 1978," 6 pp. and "Rice Production in the United States, 1978," 6 pp. One limitation of the rice data is that the statistics for California do not provide a detailed breakdown by variety. Prior to 1979 the data were grouped under what amounted to three generic classes; the 1979 data provide a breakdown only by length of grain.

[12] Details may be obtained from the following publications issued by the Agricultural Marketing Service of USDA: "Plant Variety Protection; How It Works for You," PA-1191 June 1977, 8 pp. (leaflet); *United States Plant Variety Protection Act . . . Regulations and Rules of Practice*, 1973, 44 pp.

[13] Several other characteristics might also be noted. Although dwarf varieties usually exhibit stunting of height or deformation of grains, this is not the case with semi-dwarfs. Also, the semi-dwarf genes have high heritability in that once the recessive state is attained, the short stature becomes stabilized in the subsequent generations. (Comments attached to letter from T. T. Chang, IRRI, Dec. 14, 1979. Also see T. T. Chang and B. S. Vergara, "Ecological and Genetic Information on Adaptability and Yielding Ability in Tropical Rice Varieties," in *Rice Breeding*, IRRI, 1972, pp. 431-452.)

[14] Derived from reports of the 5th to 8th International Winter Wheat Performance Nursery, Nebraska Agricultural Experiment Station (in cooperation with USDA and AID), Research Bulletins 276 (April, 1976), 279 (December 1976), 281 (October 1977), and 285 (July 1978).

[15] Reitz and Hamlin, *op. cit.*, p. 8.

[16] The statistics reported in this section were calculated from *Crop Production, 1978 Annual Summary, Acreage, Yield, Production*, USDA, Economics, Statistics and Cooperatives Service, Crop Reporting Board, Jan. 16, 1979, pp. B-22 to B-24.

[17] In California, Arizona, and South Texas, "spring" wheat is planted in the fall and in that sense could be considered "winter" wheat.

[18] Based on L. P. Reitz, *Wheat in the United States*, USDA, Agricultural Research Service, Agriculture Information Bulletin No. 386, February 1976, pp. 6-14.

[19] Based on: L. P. Reitz, "World Distribution and Importance of Wheat," in *Wheat and Wheat Improvement* (ed. by K. S. Quisenberry and L. P. Reitz), American Society of Agronomy, Madison, 1967, pp. 1, 3; and Lawrence Zeleny, "Criteria of Wheat Quality" in *Wheat Chemistry and Technology* (ed. by Y. Pomeranz), American Association of Cereal Chemists, Inc., St. Paul, 1971, p. 30.

[20] *Summary Progress Report—1978, U.S. Grain Marketing Research Laboratory*, USDA, Science and Education Administration, ARM-NC-1, February 1979, p. 7.

[21] American wild rice belongs to *Zizania aquatica*.

[22] Telephone conversation with Dr. T. H. Johnston, AR/SEA, USDA, Stuttgart, Arkansas, May 3, 1979.

[23] J. N. Rutger and M. L. Peterson, "Improved Short Stature Rice," *California Agriculture*, June 1976 (Vol. 30, No. 6), p. 6.

[24] Calculated from *Crop Production, op. cit.*, p. B-25. The Rice Millers' Association reported a small area (1,657 acres) of long-grain rice in California in 1978. A detailed breakdown is reported in table 8 on p. 78.

[25] Information taken from D. F. Houston (ed.), *Rice Chemistry and Technology*, American Association of Cereal Chemists, St. Paul, 1972, pp. 5-6 and 104-106.

II. BRIEF HISTORY OF PRODUCTION AND VARIETAL IMPROVEMENT

. . . I feel that there is a latent feeling among nearly all farmers—sophisticated or traditional—that the seed (variety) is the elixir upon which his crop production is based.

—**Norman E. Borlaug, 1969***

Semi-dwarf varieties of wheat and rice are, despite a fairly extended history in Asia, relatively new to U.S. agriculture. Their reception and adoption have been conditioned by long-evolving patterns of production and varietal improvement. The patterns will be briefly outlined in this chapter. Wheat and rice have followed quite different paths, especially in terms of production, and will be treated separately.

Wheat[1]

Wheat is one of the traditional crops of U.S. agriculture. Yet certain historical aspects of its production and improvement—particularly the use of foreign varieties—may not be well recognized.

Production[2]

Wheat production in the United States began along the Atlantic Coast early in the 1600's and moved westward with the settlement of the country. It was reportedly grown in the Jamestown Colony as early as 1611 and at Plymouth, Mass., soon after 1621. The first great westward shift in wheat production took place during the period from 1783 to 1840 with the settlement of western New York, the eastern Lake Region, and the Ohio Valley. As of 1839, about 60 percent of the nation's wheat was produced (in decreasing order of importance) in Ohio, Pennsylvania, New York, and Virginia. Wheat growing began around 1838 in the Willamette Valley of western Oregon.

Changes taking place from 1840 to 1920 may be summarized as follows:

- 1840's. Start of production in Utah and New Mexico.
- 1850's. Second great shift in production: Illinois, Indiana, and Wisconsin

become the leading wheat producers. Texas, Arizona, California, and Idaho begin wheat production.

- 1860's. Initiation of production in Colorado, Montana, and eastern Washington (dryland).
- 1870's. Wheat Belt moves westward across the prairies with substantial production in the Red River Valley, Kansas, and Nebraska. Dryland production in West Coast States increases greatly. Overall area and production nearly double.
- 1880's. Sharp increases in area in the northern Great Plains, central Kansas, and the West Coast States.
- 1890's. Production intensifies in Red River Valley, Kansas, Nebraska, Oklahoma, and eastern Washington, but starts to decline in California. Concentration and intense specialization is evident.
- 1900's. Wheat belt shifts farther west on Great Plains. Large increase in Montana, Idaho, and eastern Oregon and Washington. After 1900, much of the expansion was on to drier and more hazardous areas.
- 1910-20. Due to stimulus of World War I, sharp increase in area and production; both set new records in 1915. Area increases sharply again in 1919.
- 1920-40. Both area harvested and production drops to a low point in the Depression drought year of 1934.

Many factors influenced the changes that took place in the century between 1840 and 1940, and in the decades since.[3] Mechanization, weather, and changes in transportation and demography are certainly to be included among them. In the remainder of this section, however, we will focus on only one—changes and improvements in varieties.

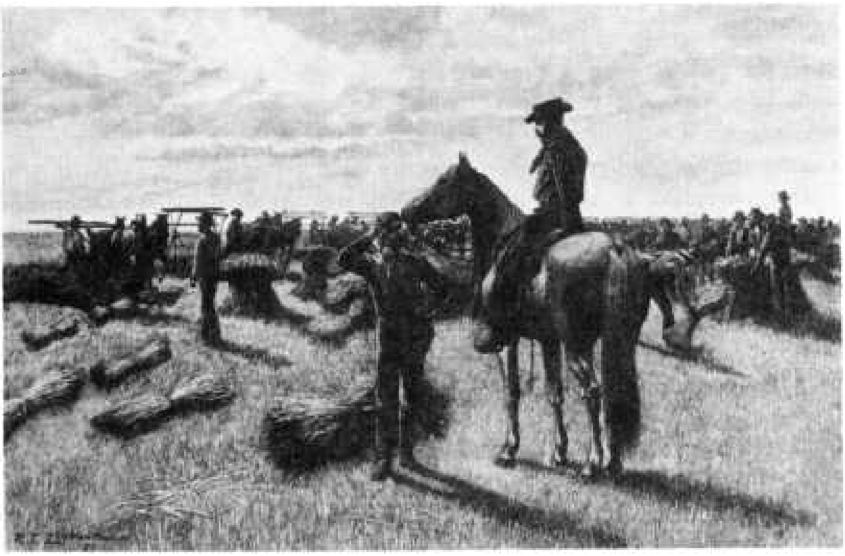


Plate 1. "Wheat harvesting in Dakota " as depicted in *Harper's Weekly*, 1887.

Varietal Improvement

Varietal improvement in wheat has typically followed three stages: introduction, selection, and hybridization. These steps involve:

- Introduction of varieties from foreign countries;
- Isolation of selections from (a) mixtures and natural hybrids in fields, and (b) pure line or single-line varieties; and
- Hybridization, the selection from progeny of artificial crosses.

A fourth stage, irradiation breeding, also has been utilized recently.

Several improved wheat varieties developed in the United States form part of the ancestry of three Asian varieties, which in turn provided the dwarfing characteristic now used in nearly all American varieties.

INSTITUTIONAL SETTING. The period of wheat improvement until the late 1800's, or possibly even 1900, might be regarded as the pre-research period. Varietal improvement was largely a matter of trial and error. The U.S. Government helped import new varieties, but otherwise improvement was largely in private hands. The development of State agricultural experiment stations was spurred by the passage of the Hatch Act in 1877, but the stations needed more time to get organized and to get work underway. Wheat research was begun or at least first reported in some of the States as follows: Kansas, 1874; Nebraska, 1890; Colorado, 1893; Texas, 1894. Wheat research done by USDA from 1895 to 1897 was summarized in 1900.[4]

A cooperative Federal-State wheat investigations program was developed in the late 1920's and grew to include three regional programs: Hard Spring wheat, 1928; Hard Red Winter wheat, 1930; and White wheat, 1930.

VARIETAL INTRODUCTION. All wheat varieties grown in the United States have been derived from imported varieties.

In the earliest days, settlers had relatively little choice: they had only the seeds they happened to bring with them from a foreign nation. These seeds were often not well-suited to local conditions. Thus, during the 1600's, corn—a native crop grown by the Indians—usually fared better.

One exception in terms of adaptability was the introduction of Spanish wheats into Texas as early as 1582[5] and into California in 1770. These seeds were brought by Columbus to the West Indies, from whence they were taken to Mexico. By the time they reached California, they had gone through a selection process that sorted out the most adaptable. Sonora was one such variety.

With the passage of time and greater shipments of seeds from other countries, it was inevitable that better adapted varieties were identified. Many of these varieties have long since passed out of cultivation, but several were grown for 100 years or more. Most of these early varieties appear to have been soft winter wheats; white grains were preferred to red because the latter discolored the flour.

As wheat production spread west into the prairies, the soft eastern varieties did not prove to be well adapted to the increasingly dry lands. There was an expanded need for drought-resisting varieties. These were initially provided through the introduction of several hard types of wheat.

In 1860, a Hard Red Spring wheat from Canada known as Red Fife was first raised by a farmer in Wisconsin. Red Fife was later one of the parents of another Canadian variety, Marquis, which was introduced in the United States in 1912.[6] For 20 years, Marquis was the king of wheat varieties in the United States, and has subsequently been used as a parent in breeding many improved varieties.

In the early 1870's, a Hard Red Winter wheat known as Turkey was introduced in Kansas by Mennonite settlers from Russia. Whereas other settlers had had difficulty in raising wheat, the Mennonites succeeded. They came from a similar region, and brought a variety well adapted to the environment.[7] M. A. Carleton of USDA was so impressed with the performance of Turkey that he went to Russia in 1898 to secure additional strains of Turkey (including Crimean) and other drought-resistant varieties.[8] For many years, Turkey wheat was the most important variety grown in the United States. One strain, Turkey Red, later became one of the parents of Norin 10—the source of dwarfism for most of the semi-dwarfs now raised in the United States.

A Russian Durum variety, Arnautka, was introduced by USDA in 1864 but it did not find wide use. In 1900, Carleton brought back a number of other Russian Durum varieties including Kubanka. Seed of Kubanka, along with some Arnautka seed from North Dakota, was distributed to farmers in 1902.[9] They outyielded the standard spring varieties in the dry areas in the northern plains.

While the original white wheats raised in the United States were soft, the situation changed with the introduction of Baart wheat in 1900 and Federation wheat in 1914, both hard varieties from Australia. Baart wheat was initially utilized in Arizona and then spread to other Pacific Coast States and to Idaho.

The hard varieties, while well accepted by growers, were at first resisted by millers who used stones for grinding. Steel roller mills and purifying machinery came into use in Minneapolis in 1878 and facilitated the grinding of hard wheats. While the millers seem to have taken up the hard spring types, they were slower to accept the hard winter varieties. And they were quite reluctant to accept Durums. Hard winter and Durum varieties were discounted at first, but eventually were accepted.[10]

SELECTIONS. The improvement of wheat by selection has gone through two stages. The first began in the late 1700's and early 1800's when farmers and seedsmen began to make selections from the mixtures and natural hybrids in their fields. The second stage started around 1900 when scientists began to make pure line or single-line selections (the progeny of a single self-fertilized individual of homozygous or nearly homozygous composition).

It is not certain when the first stage started in the United States. In another publication, I have noted the emergence of an improved new variety known as Forward in 1794; it had been selected 7 years earlier. The variety is notable in the context of this publication because it reportedly produced one-third less straw on a short stem.[11]

Better-known early selections include:

- Red May, selected by General Harmon in 1830 from the white-kerneled May of English origin and grown in Virginia before the Revolutionary War.
- Fultz, a descendant of a mixture or hybrid found in a field of Lancaster (Mediterranean), was selected by Abraham Fultz, a farmer in Mifflin, Pa., in 1862. Fultz later became one of the parents of Norin 10, and, in turn, of most of the semi-dwarfs grown in the United States.

Perhaps the first and best-known example of single-line selection is Kanred. It was selected from a single head of Crimean, imported by Carleton in 1900 (Crimean can be considered a strain of Turkey). Kanred was one of a group of seeds first selected at the Kansas State Agricultural Experiment Station in 1911. Field testing started in 1914 and it was named and released in 1917. By 1925, nearly 5 million acres were planted in Kanred.[12] Kanred later became an ancestor of two Korean semi-dwarf varieties (Suweon 92 and Seu Seun 27), which are included in the parentage of several semi-dwarf varieties now grown in the United States.

HYBRIDIZATION. The use of artificial crosses as a means of varietal improvement in the United States dates from about 1870. C. R. Ball notes,

> The making of wheat hybrids in this country apparently began with Cyrus G. Pringle . . . His work with wheat was done at Charlotte, Vt., where he released at least four varieties, of good quality, between 1870 and 1877. His first variety, Champlain, was brought out in 1870; his second, Defiance in 1871; and a fourth, Surprise, in 1877.[13]

The three varieties became rather widely grown in the Western States.

Two farmers next played a major role. In 1886, D. M. Schindel of Hagerstown, Md., crossed Fultz and Lancaster (Mediterranean) and named one of the selections Fulcaster. It was high-yielding and widely grown. A. N. Jones of New York State (Newark and Leroy) produced at least 15 varieties from hybrids between 1886 and 1906. Two of these were still grown in the mid-1930's.

Starting around 1890, much of the hybridization work was taken up by Federal and State agricultural research institutions. A. F. Blont of the Colorado Agricultural Experiment Station was one of the first. W. J. Spillman developed four club wheats which were released in 1907 and 1908. One of these, Ceres, was developed at the North Dakota Agricultural Experiment Station and was one of the most successful early examples. The original cross (Kota x Marquis) was made in 1918 and distributed in 1926. By 1933, about 5 million acres of Ceres were grown in the United States and Canada.

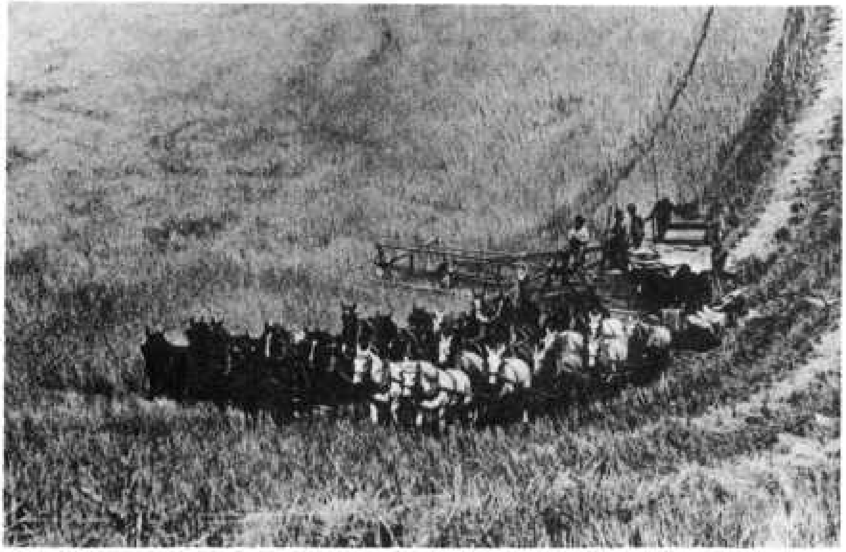


Plate 2. Combining wheat in Walla Walla, Washington, with a 33-horse team, 1902.

STATISTICAL SUMMARY. Altogether, from 1900 to 1950, 284 new varieties were grown in the United States. Of these, 55 (or 19 percent) were introductions, 88 (31 percent) were selections from existing varieties, 127 (45 percent) originated from hybridization of two or more varieties, and the origin of 14 (5 percent) is undetermined.

From 1931 to 1950, nearly 80 percent of the varieties were of hybrid origin. Of these, State and Federal experiment stations were responsible for the distribution of 197 (69 percent), farmers, seedsmen and other commercial interests for 79 (28 percent), and the record is not clear for 8 (3 percent).[14]

A further comparison is available for the 51-year period from 1924 to 1974. Reitz has calculated that changes in the U.S. wheat area seeded to varieties of different origin were as follows:[15]

Year	Introduction	Selections	Crosses	Unidentified Varieties	Total
			Percent		
1924	57.0	25.8	7.2	10.0	100
1934	50.0	32.2	13.5	4.3	100
1944	25.1	27.1	45.8	2.0	100
1954	5.5	11.2	81.8	1.5	100
1964	6.1	8.2	84.1	1.6	100
1974	4.6	7.2	86.3	1.9	100

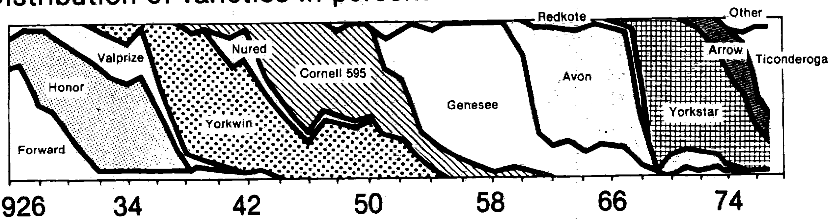
Over time, it was increasingly likely that the introductions and selections also originated from crosses. Clearly the overall variety picture is now one almost entirely of hybrid crosses.

As a result of these activities, growers have been provided a succession of improved varieties. A particularly vivid example is provided in graphic form for New York State (fig. 4). While single varieties tend to predominate more in New York than in other States, the succession of varieties is typical of other areas.

Figure 4

Succession of Cornell Wheat Varieties Used by New York State Farmers from 1926 to 1977

Distribution of varieties in percent



Note: Distribution based on sales of certified seed.

Source: W. D. Pardee, Department of Plant Breeding and Biometry, Cornell University, Ithaca, N.Y.

Rice

Rice has deep roots in American agricultural history. Production practices have rapidly modernized and foreign varieties have played an essential role in varietal improvement.

Production[16]

Rice production in the United States may be divided into two major stages. The first–termed the early period–was represented by rice production in tidal delta areas in the Southeastern States and extended from about 1685 to the mid-1880's, or roughly 200 years. The second stage–termed the "modern" period–began in the mid-1880's and was represented by mechanized cultivation under irrigation in prairie areas in the South Central States (at first in Louisiana) and in the Sacramento Valley in California.

THE EARLY PERIOD. A trial planting of rice is thought to have been made in Jamestown, Va., in 1622. Some rainfed (upland) rice for domestic use was raised in North Carolina and South Carolina before 1680. Continuous culture of rice in the tidal areas is considered to have been started about 1685 (the date is sometimes given as 1694) near present-day Charleston, S.C., utilizing imported seed. The practice became well established within the next few years and soon moved into similar areas in North Carolina and Georgia, and later into Alabama, Mississippi, and Florida.

The Civil War severely weakened the rice industry in these States and recovery was difficult. Fields and irrigation systems were neglected. Slave labor was no longer available. Capital was short and plantations were being broken up. There also was increased competition from Louisiana. "The aftermath of the Civil War actually stimulated the Louisiana rice industry, for along the Mississippi flood plain many an impoverished and carved-up sugar plantation was converted to the cheaper cultivation of rice."[17]

The South Atlantic region, moreover, was not in a strong competitive position. "Clinging to the old fields along the tidal rivers, it was unable to employ mechanized methods of cultivation because of its soft soil, small fields, and unskilled labor."[18] Production was expensive. A series of violent hurricanes after 1880 caused further difficulties.

THE "MODERN" PERIOD. The "modern" period arrived in the mid-1880's. It was marked by a shift from tidal areas to prairie regions where rice was "grown in essentially the same manner as wheat, oats, and barley, except that the crop is irrigated."[19] Crop rotations were utilized.

The switch began with the establishment of a land development scheme in southwestern *Louisiana* in the early 1880's. The area to be developed included both marshes that were to be used for rice, and prairie areas that were to be used for general farming. Seaman A. Knapp, president of Iowa State College, was induced to resign and take charge of the prairie portion. By a curious turn of events, rice culture ended up dominating the prairie development while the marsh portion of the project was eventually dropped.[20]

The prairie development attracted thousands of farmers from the North Central States and the Midwest. The first arrivals in 1884 had no intention of raising rice, but they noticed that the Cajun natives were doing so by catching water in pockets and then allowing it to drain down over the lower rice lands (this was known of as the "Providence" system).

> The Westerners copied the Cajuns' methods of irrigation and found that their own mechanized farm equipment was admirably adaptable to rice cultivation, since the prairie lands were hard and easily drained and thus able to bear the teams and heavy equipment.[21]

Some equipment adjustments were necessary, especially to the binders.[22] According to Knapp, the principal difficulties were overcome by the end of 1886.[23] By 1889, Louisiana became the leading rice-producing State.

The Providence method of irrigation worked well until 1893 when a series of dry years set in.

> But this new industry . . . had considerable ingenuity, and by 1896, an entirely new and dependable system of irrigation had been devised, consisting of a network of large irrigation canals with steam pumps to lift the water into the canals from the nearby streams, lakes and bayous. Almost at once a further system was introduced: the digging of irrigation wells, which made dependence upon surface water unnecessary and thus unlocked new rice areas away from the lakes and streams.[24]

As of 1895, the rice area in the State totaled 170,000 acres; by 1905 it had grown to 250,000 acres, and by 1910 to 360,000.[25]

From Louisiana, prairie rice production extended into similar areas in neighboring States. Production first moved to southeast *Texas*. In 1891, a small pumping station for irrigation was constructed in Jefferson County. This venture expanded in 1898 into the Beaumont Irrigation Company which initially irrigated 3,000 acres of rice. The State rice area expanded from 175 acres in 1892 (all on the Beaumont prairie) to 8,700 acres in 1899 (8,500 in the Beaumont district and 200 acres in Colorado County). By 1909 the State's rice area had grown to 238,000 acres.[26]

Rice was first grown on an experimental basis on prairie land in *Arkansas* in 1902, near the town of Lonoke, as a cooperative effort of a local farmer and the Arkansas Experiment Station. In 1903, with USDA technical help, a well was sunk and levees constructed. An experimental crop of 10 acres was planted in the spring of 1904, and in 1905 that area was expanded to about 30 acres (in the same year a total of about 450 acres were planted in Lonoke County). The statewide rice area in 1906 was estimated at 5,000 acres in 1906 and 60,000 acres in 1910.[27]

Rice variety tests were begun by the USDA near Biggs in the Sacramento Valley in *California* in the spring of 1909 and were continued for the next 2 years. In 1912, the first commercial crop of 1,400 acres was grown near Biggs. The area expanded quickly, reaching 162,000 acres by 1920.[28]

Elsewhere, rice was first grown in the Elsberry district of *Missouri* in 1923 (though evidently not in the prairie-type areas noted above)[29] and has been raised in *Mississippi* since about 1948.

While these developments were taking place, planting of rice declined in the Southeastern States and rice crop reports were discontinued in 1910 in North Carolina, and in 1920 in South Carolina, Georgia, and Florida. Upland rice, however, continued to be grown as a subsistence crop in several of the Southeastern States until the early 1940's.[30]

Thus in the course of a few decades, the traditional system of rice culture was largely swept away and replaced by a highly mechanized one in new areas. An article written in 1914 stated that "the production of rice has probably undergone greater changes than that of any other crop grown in the United States."[31]

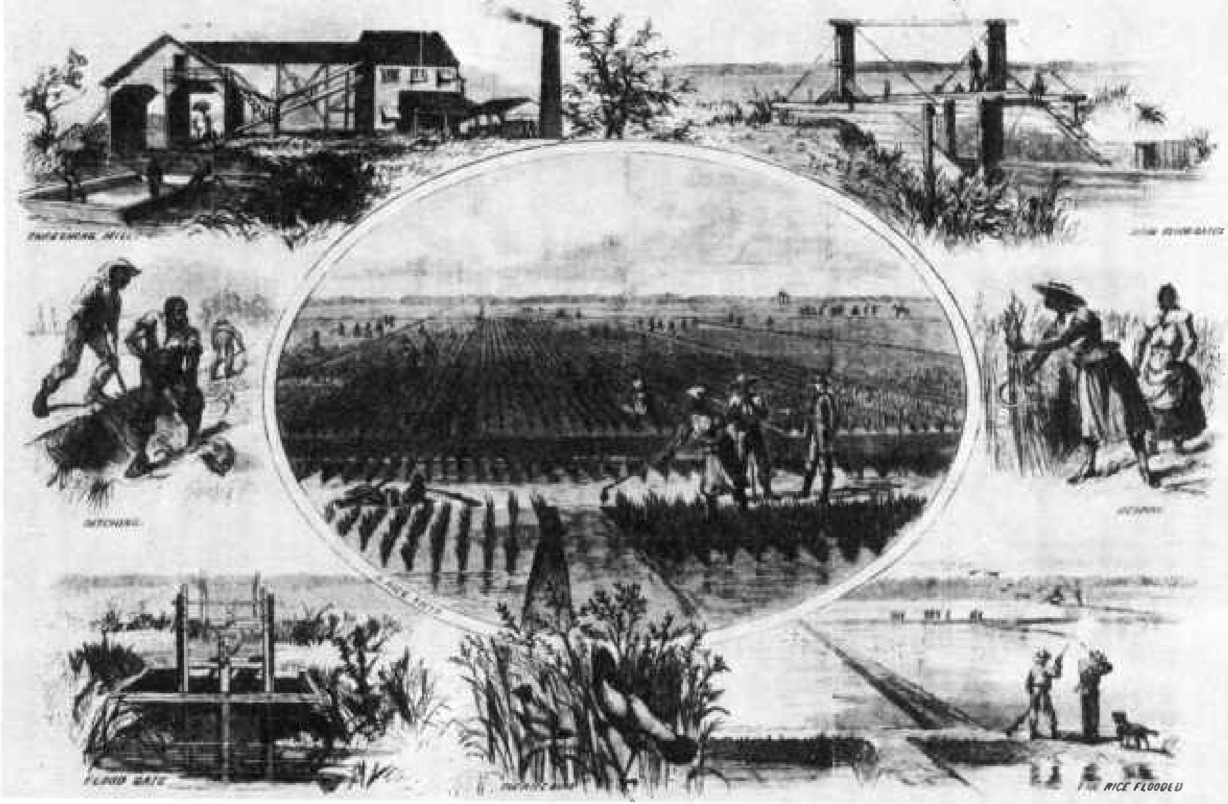


Plate 3. "Rice Culture on the Ogeechef, near Savannah, Georgia," as depicted in *Harper's Weekly*, 1867.

Varietal Improvement[32]

As with wheat, rice improvement usually has consisted of three stages: introduction, selection, and hybridization. These steps involve:

- Introduction of varieties from foreign countries;
- Isolation of pure-line selections from introduced varieties; and
- Creation of new varieties by crossing (hybridization), followed by selection.

A fourth stage, mutation breeding, also has been utilized.

INSTITUTIONAL SETTING. Virtually all of the rice improvement work (with one notable exception to be discussed) has been done by publicly sponsored research stations. The more technical work has usually involved USDA employees at State agricultural experiment stations. Farm groups are also sometimes involved in the sponsorship of this work.

USDA involvement in rice improvement might be said to have begun in 1898 with the appointment of Knapp as plant explorer. He brought back rice varieties from Asia in 1899 and 1901 (to be discussed in further detail in the next section) and arranged farm demonstrations of varieties and cultural methods in Louisiana and Texas. In 1906, studies of varieties, irrigation, cultural methods and fertilizer were begun, mainly near Crowley, La. Experiments or demonstrations with rice were started in 1909 in Arkansas, South Carolina, and California, and in 1910 in Texas.[33]

Specialized rice research stations were organized by the States, and USDA cooperation was obtained at an early date. As noted, USDA first became involved in Arkansas in 1903. USDA work on rice was moved to Crowley, La., in 1905, where it was conducted in cooperation with the State prior to the establishment of a State Rice Research Station in 1909.[34] A Rice Experiment Station was also established at Beaumont, Tex., in 1909; USDA cooperation was obtained in 1912 and it became known as the Cooperative Rice Experiment Station. The first observation and seed increase plots were grown in 1912 and formal experiments were initiated in 1913. In California, the Biggs Rice Field Station was established in 1912 by a group of ranchers (organized as the Sacramento Valley Grain Association) so that the USDA work might be expanded and conducted under conditions more favorable for experimental work.[35] A Rice Branch Experiment Station was established near Stuttgart, Ark., in 1927.[36] And the Elsberry Rice Experiment Field Station was established in Missouri in 1928.[37]

Although the stations have been established as a result of State initiative, the research programs have traditionally been carried on in cooperation with the U.S. Department of Agriculture. USDA scientists are located in each principal State, and a coordinated rice improvement program was begun in 1931.[38]

VARIETAL INTRODUCTION. The first known introduction was Carolina White. The accounts of its introduction vary, but it is thought to have originally come from Madagascar and was put ashore at Charleston about 1685 (or possibly 1694).[39] The second variety was Carolina Gold, which probably came in as a mixture in Carolina White and was later isolated and grown as a separate variety (alternatively, it may have been a later introduction).

Between 1685 and 1889, few or no other rice varieties appear to have been introduced. As Jones notes, "the growers seem to have been satisfied with the yields and quality of Carolina White and Carolina Gold."[40] But late in the period it became evident that these varieties were not as productive as those grown elsewhere.

In 1890, a variety known as Honduras was introduced from that country through commercial channels and was widely grown on the new ricelands. In 1899, Knapp traveled to Japan to obtain varieties of better milling quality. He returned with 10 tons of Kiushu rice, which reduced the milling breakage by as much as one-half. Another 1,000 tons was imported in 1900 and it soon became the most common variety. Fifteen other varieties were introduced following a second trip by Knapp in 1901.[41] Carleton of USDA obtained a collection of rice varieties from foreign exhibitors at the Louisiana Purchase Exposition in St. Louis, Mo., in 1904.[42]

During the next 30 years, several thousand varieties were introduced, mainly through USDA. Between 1909 and 1929, the Rice Experiment Station at Crowley alone grew 8,000 samples of 3,000 varieties of rice from 40 countries, including 2,000 from the Philippines alone.[43] However, only a few were found to be well adapted.

Plate 4. Cutting and binding rice near Spindletop, Jefferson County, Tex., 1915. Note oil tanks in background.

SELECTIONS. Selections from introduced varieties have been an important source of varieties in the United States. Practically all varieties grown here from 1920 to about 1945 were developed by this method.

Selection work was begun in 1907 by S. L. Wright of Louisiana and many of the important varieties subsequently grown in the Southern States were selected by him.[44] A number of USDA and State scientists also took up selection in the next several years.

Varieties developed through selection which are still well known—but no longer widely grown—include Bluebonnet 50, Blue Rose, Caloro, Colusa, Fortuna, Nira, Rexoro, Sunbonnet, and Zenith.[45] Fortuna was selected from a variety selected from Taiwan; Nira and Rexoro from hill rices introduced from the Philippines. Fortuna was widely grown in the late 1920's and 1930's, but was replaced by Bluebonnet, a cross between Fortuna and Rexoro. Rexoro also was used as a parent for several other crosses. Thus, Fortuna and Rexoro had a substantial impact on present varieties.[46]

HYBRIDIZATION. While selection represented an important step in varietal improvement, it did not provide all the improved characteristics. In 1922, improvement through hybridization was begun by J. W. Jones in California. The first variety developed was Calady, selected from a cross made by Jones in 1924 between Caloro and Lady Wright. By 1935, it was in commercial production in California. Crossing was begun in Arkansas and Texas in 1931 by C. Roy Adair and H. M. Beachell. Early hybrid-derived varieties included Arkrose (Arkansas, 1942, Jones and Adair), and Texas Patna and Bluebonnet (Texas, 1944, Beachell). All varieties released since 1942, except for mutations, are progeny of hybrids (crosses).

The development of a new rice variety through hybridization is normally a time-consuming process. According to one Arkansas publication, "About 12 years are required from the time carefully selected parents are crossed until an offspring with the desired combination of characteristics can be released."[47] In California, the process has been speeded up by raising two generations per year.

* * *

Further details on the development of semi-dwarf wheat and rice varieties will be provided in the next two chapters.

References and Notes

*Norman E. Borlaug, "Improving Plants . . . Seed for the Future," *International Conference on Mechanized Dryland Farming*, Deere & Company, Moline, Illinois, 1970, p. 70 (proceedings of conference held in August 1969).

[1] This section is based, except as noted, on: J. Allen Clark "Improvement in Wheat," *Yearbook of Agriculture, 1936*, USDA, pp. 209-227; and Carleton R. Ball, "The History of American Wheat Improvement," *Agricultural History*, April 1930 (Vol. 4, No. 2), pp. 48-71. Further detail prior to 1900 is provided by Mark Alfred Carlton, *The Basis for the Improvement of American Wheats*, USDA, Division of Vegetable Physiology and Pathology, Bulletin No. 24, 1900, 87 pp. Further detail on the subsequent period is found in S. C. Salmon, O. R. Mathews, and R. W. Leukel, "A Half Century of Wheat Improvement in the United States," *Advances in Agronomy*, Vol. 5, Academic Press, New York, 1953, pp. 1-151. Also see John W. Schmidt, "Wheat–Its Role in America's Heritage," *Agronomists and Food: Contributions and Challenges*, American Society of Agronomy, Special Publication No. 30, 1977, pp. 45-52.

[2] The material in this section is largely taken from C. R. Ball, C. E. Leighty, O. C. Stine, and O. E. Baker, "Wheat Production and Marketing," *United States Department of Agriculture Yearbook, 1921*, USDA, 1922, pp. 87-96. (Contains dot charts showing location of U.S. wheat production every tenth year from 1839 to 1919.) Dates cited do not necessarily signify first date of any production.

[3] Changes over the period from 1920 to 1955 are discussed in C. W. Nauheim, W. R. Bailey, and D. E. Merrick, *Wheat Production: Trends, Problems, Programs, Opportunities for Adjustment*, USDA, Agricultural Research Service, Agricultural Information Bulletin No. 179, March 1958, pp. 12-21.

[4] Partly based on K. S. Quisenberry and L. P. Reitz, "Turkey Wheat: The Cornerstone of an Empire." *Agricultural History*, January 1974 (Vol. 48, No. 1), pp. 106-107. The report referred to was Carleton, *op. cit.*., pp. 40-63.

[5] Letter from I. M. Atkins, Denton, Texas, August 1, 1979. Further details will be provided by Atkins in *A History of Small Grain Crops in Texas . . . 1582-1976*, Texas Agricultural Experiment Station, B-1301, in press.

[6] For further background on the development of Marquis, see J. W. Morrison, "Marquis Wheat–A Triumph of Scientific Endeavor," *Agricultural History*, October 1960 (Vol. 34, No. 4), pp. 182-188.

[7] For further details on Turkey, see Quisenberry and Reitz, *op. cit.*, pp. 94-114.

[8] See Mark Alfred Carleton, *Russian Cereals Adapted for Cultivation in the United States*, USDA, Division of Botany, Bulletin 23, 1900, 42 pp.

[9] Mark Alfred Carleton, *Macaroni Wheats*, USDA, Bureau of Plant Industry, Bulletin 3, 1901, pp. 28-48; Mary W. M. Hargreaves, "The Durum Wheat Controversy," *Agricultural History*, July 1968 (Vol. 42, No. 2), pp. 212-213. The account of the introduction of Arnautka presented here differs from Clark, *op. cit.*, p. 217.

[10] Ball, *op. cit.* (1930), p. 58; Hargreaves, *op. cit.*, pp. 211-229; Quisenberry and Reitz, *op. cit.*, p. 108.

[11] Dana G. Dalrymple, *Development and Spread of High-Yielding Varieties of Wheat and Rice in the Less Developed Nations*, USDA/OICD, FAER 95, September 1978 (6th edition), p. 10.

[12] Quisenberry and Reitz, *op. cit.*, pp. 94-114; Robert J. Dunbar, "Turkey Wheat: A Comment," *Agricultural History*, January 1974 (Vol. 48, No. 1), p. 113; B. B. Bayles and J. Allen Clark, *Classification of Wheat Varieties Grown in the United States in 1949*, USDA, Technical Bulletin No. 1083, March 1954, pp. 130-131.

[13] Ball, *op. cit.*, p. 60 (the third variety is not noted). The parentage of the varieties and other information about them is provided by J. A. Clark, J. H. Martin, and C. R. Ball,

Classification of American Wheat Varieties, USDA, Bulletin 1074, November 1922 (rev. August 1923), pp. 63, 67-68, and 139-140. A detailed listing of varieties released by State and Federal Stations, including introductions and selections, through the mid-1930's is provided by Clark, *op. cit.* (1936), pp. 271-293.

[14] Salmon, et al., *op. cit.* (1953), p. 109.

[15] Louis P. Reitz, "60 Years of Wheat Cultivar History in the United States," *Annual Wheat Newsletter*, Kansas State University (Dept. of Agronomy) and Canada Department of Agriculture, June 1979 (Vol. 25), pp. 12-17.

[16] Based, except as noted, on: Jenkin W. Jones, "Improvement in Rice," in *Yearbook of Agriculture, 1936*, USDA, pp. 418-419; C. Roy Adair, M. D. Miller, and H. M. Beachell, "Rice Improvement and Culture in the United States," in *Advances in Agronomy*, Academic Press, Vol. 14, 1962, pp. 63, 66; C. Roy Adair, "Introduction," in *Rice in the United States: Varieties and Production*, USDA Agriculture Handbook No. 289, June 1973, pp. 2-22; S. A. Knapp, *The Present Status of Rice Culture in the United States*, USDA, Division of Botany, Bulletin No. 22, 1899, pp. 12-17; Arthur H. Cole, "The American Rice-Growing Industry: A Study of Comparative Advantage," *Quarterly Journal of Economics*, August 1927 (Vol. XLI, No. 4), pp. 565-643; and Edward Hake Phillips, "The Gulf Coast Rice Industry," *Agricultural History*, April 1951 (Vol. 25, No. 2), pp. 91-96. Further historical details may be found in *The Rice Journal* (Vol. 47, 1944, is particularly useful) and in Robert S. Anderson, "Rice Revolution in the Southern United States, 1865-1945; The Technical and Political Ingredients of Agrarian Transformation," Simon Fraser University (Burnaby, British Columbia, Canada), Dept. of Communication, unpublished manuscript, February 1979, 84 pp.

[17] Phillips, *op. cit.*, p. 92.

[18] *Ibid.*

[19] Jones, *op. cit.* (1936), p. 420.

[20] Phillips, *op. cit.*, pp. 92-95; Knapp, *op. cit.*, pp. 21-25; and Joseph C. Bailey, *Seaman A. Knapp, Schoolmaster of American Agriculture*, Columbia University Press, 1945, pp. 120-122, 127-128.

[21] Phillips, *op. cit.*, p. 95.

[22] Bailey, *op. cit.*, pp. 120-121.

[23] Knapp, *op. cit.*, p. 22. Also see Cole, *op. cit.*, p. 608.

[24] Phillips, *op. cit.*, p. 95.

[25] *Rice, Popcorn, and Buckwheat; Acreage, Yield, Production, Price Value; By States, 1866-1953*, USDA, Crop Reporting Board, Statistical Bulletin No. 238, pp. 2-9. This bulletin is the source of most of the area data cited in the remainder of this section.

[26] J. P. Craigmiles, "Advances in Rice—Through Research and Application," *Six Decades of Rice Research in Texas*, Texas Agricultural Experiment Station, Research Monograph 4, June 1975, p. 1.

[27] Cole, *op. cit.*, pp. 609-610; and the following bulletins of the Arkansas Agricultural Experiment Station: W. G. Vincenheller, *Rice Growing in Arkansas*, No. 89, 1906 p. 119; R. J. Nelson, *Rice Culture*, No. 94, 1907, p. 31; R. J. Nelson, *Rice*, No. 98, 1908, p. 133; *Twentieth Annual Report*, 1907, pp. 8, 24.

[28] See Charles E. Chambliss and E. L. Adams, *The Culture of Rice in California*, USDA, Farmers Bulletin 688, September 1915, pp. 1-2. (Revised editions issued as: Chambliss, *Rice Growing in California*, F. Bulletin 1141, September 1920; and Jenkin W. Jones, *How to Grow Rice in the Sacramento Valley*, F. Bulletin 1240, March 1924, revised June 1931.) Also see: Cole, *op cit.*, pp. 611-613; and Jack H. Wilson (ed.), *Rice in California*, Butte County Rice Growers Association (P.O. Box 128 , Richvale, Calif. 95974), 1979, 254 pp.

[29] Cole, *op. cit.*, pp. 610-611.

[30] Letter from Henry M. Beachell, Cooperative CRIA-IRRI Program, Bogor, Indonesia, Aug. 13, 1979.

[31] *Census of Manufactures*, 1914, pp. ii, 424 (cited by Cole, *op. cit.*, p. 596).

[32] Based, except as noted, on: Jones, *op. cit.* (1936), pp. 428-433, 442-445; Adair et al., *op. cit.* (1962), pp. 96-98; Adair, et al., *op. cit.* (1963), p. 22; C. R. Adair, et al., "A Summary of Rice Production Investigations in the U.S. Department of Agriculture, 1898-1972," *The Rice Journal*, March 1975 (Vol. 78, No. 3), pp. 26-29, April 1975 (Vol. 78, No. 4), pp. 24-26; C. N. Bollich and J. E. Scott, "Past, Present, and Future Varieties of Rice," in *Six Decades . . . , op. cit.*, pp. 37, 38; Craigmiles, *op. cit.*, pp. 1-2; and T. H. Johnston, et al., "The Development of Early-Maturing and Nitrogen-Responsive Rice Varieties in the United States," *Rice Breeding*, IRRI, 1972, pp. 61-64.

[33] Adair, et al., *op. cit.* (March 1975), pp. 26-29. This reference is an excellent source of information on the names and dates of USDA personnel assigned to various rice research activities.

[34] *Annual Report of the Department of Agriculture for the Year Ended June 30, 1906*, USDA, 1907, pp. 38, 227. (Also noted in *1907* Report, p. 314.)

[35] Chambliss and Adams, *op. cit.*, pp. 1-2.

[36] "Rice Branch Experiment Station," University of Arkansas, undated leaflet. This date is sometimes given as 1926.

[37] Adair, et al., *op. cit.* (March 1975), p. 27.

[38] Johnston, et al., *op. cit.*, p. 61.

[39] For a review of some of the differing accounts, see Adair et al., *op. cit.* (1962), p. 63.

[40] Jones, *op. cit.*, pp. 428-429.

[41] Bailey, *op. cit.*, pp. 133-135; Knapp, *op. cit.*, p. 4; Phillips, *op. cit.*, p. 95.

[42] Adair, et al., *op. cit.* (1975), pp. 26-29.

[43] J. Mitchell Jenkins, "Twenty Years Experience in Rice Investigational Work in Louisiana," Rice Experiment Station, Crowley, Aug. 8, 1929, p. 19 (cited by Anderson, *op. cit.*, pp. 47, 71).

[44] Wright's life and work are presented in fictionalized form by Frances Parkinson Keyes in *Blue Camellia*, Julian Messner Inc., New York, 1957, 432 pp. One of Wright's best known varieties was Blue Rose (C.I. 2128). Blue Rose was selected from an unknown variety found in a field of Japanese rice; by 1934 it represented about 50 percent of the rice grown in the United States (based on registration of Blue Rose reported in fn. 45 below). It subsequently became, through Century Patna 231, one of the ancestors of IR-24, IR-26, and IR-30 (derived from T. R. Hargrove, W. R. Coffman, and V. L. Cabanilla, *Genetic Interrelationships of Improved Rice Varieties in Asia*, IRRI, Research Paper Series No. 23, January 1979, p. 10, Fig. 1).

[45] Details on these varieties are provided by T. H. Johnston in "Registration of Rice Varieties," *Agronomy Journal*, November 1958 (Vol. 50, No. 11), pp. 694-700.

[46] Letter from Beachell, *op. cit.* Beachell notes that C.I. 5094 from the Philippines was also one of the parents of Texas Patna. Also see Bollich and Scott, *op. cit.*, p. 39.

[47] Bobby A. Huey, *Rice Varieties for Arkansas*, Arkansas Cooperative Extension Service, Leaflet 518 (1977).

III. SEMI-DWARF WHEAT VARIETIES

Civilization is in part a product of wheat . . . . It is not too much to say that the improvement of wheat, by genetic or other means, is important to man in proportion to the importance of the plant itself.

–J. Allen Clark, 1936*

Semi-dwarf wheat varieties have undergone a long period of development in the United States and, with a few exceptions, have been adopted gradually. The semi-dwarf growth habit is of principal value in reducing lodging and in improving yield responsiveness to added fertilizer.

The previous chapter noted that historically varietal improvement usually has had three major components: introduction, selection, and hybridization. In discussing semi-dwarfs, use of these terms is slightly different. The reason is that all semi-dwarfs are the result of hybrid crosses. Some were made overseas, with the resulting selection *introduced* into the United States. Also, some crosses were made overseas, but the final *selections* were made in the United States. And finally, *crosses* and selections may have been made wholly in the United States (though in some cases the parents may have resulted from crosses made elsewhere).

Within this context, this chapter reviews the introduction and development of semi-dwarf varieties in the United States, delineates all the known semi-dwarf varieties released and/or in use, and provides estimates of the area planted to these varieties.

Development

Since about 1940, there has been a gradual increase of interest in the development of short (as well as early-maturing and disease resistant) wheat varieties in the United States. Prior to that time, most U.S. wheat breeders believed that only tall wheats had potential for high yield. A new stage of development was provided by the introduction of semi-dwarf germplasm in 1946 and by the introduction of the first American semi-dwarf variety, Gaines, in 1962.

Short-Strawed Varieties

The new era in varietal type began in the early 1940's with the distribution of three varieties—Triumph, Pawnee, and Wichita—that were distinctly shorter and earlier than the conventional varieties while producing as much or more grain. In the late 1940's and early 1950's, a number of additional short varieties were released which had much improved straw strength (Brevor, Ramona 50, Lemhi 53, Lee, and Knox). Others followed in the mid- to late-1950's (Burt, Dual, Vermillion, and Monon). Several of these varieties, and others, were developed in Indiana, where the well-known Arthur variety was introduced in 1968. Beginning in 1960, short straw was introduced into Durum lines (Wells, Lakota).[1]

One variety that played a particular role in pointing the way for shorter varieties in the Pacific Northwest was Elgin, a 1932 selection (from Alicel). Elgin was a short, stiff-strawed variety which was high yielding and of excellent quality in experimental trials. Salmon, et al., commented on it in these terms in 1953:

> Previous to the creation of Elgin, it was often believed that short, stiff-strawed varieties could be obtained only with some sacrifice in yield. Elgin proves conclusively that this is not true in the Pacific Northwest and for this area, at least, has done much to determine the objectives of varietal improvement for the future. Hereafter, no variety for the Pacific Northwest can be expected to be endorsed enthusiastically by farmers unless it has short, stiff straw similar to or better than that of Elgin.[2]

Elgin, however, was a Club wheat limited to the Palouse region and was susceptible to bunt. And while it soon retired from the field, the authors' comments about short straw proved to be prophetic.

Asian Sources of Dwarfism[3]

Semi-dwarf stature in wheat is due to a specific set of dwarfing genes. The Asian wheat varieties originally carrying these genes were not suitable for commercial production in the United States. The genes, therefore, had to be transferred to U.S. varieties through hybridization.

Essentially all of the present U.S. semi-dwarf varieties derive their dwarfing genes from three Asian varieties, which in turn had a common ancestor. The development of these varieties is presented in graphic form in figure 5.

The common ancestor is a Japanese variety known as Daruma.[4] A white variant of Daruma was known as Shiro-Daruma, and a red variant as Aka-Daruma. In 1917, Shiro-Daruma (or perhaps Daruma) was crossed with the

American variety Glassy Fultz at the Central Agricultural Experiment Station (Nishigahara, Tokyo) to produce Fultz-Daruma. The date and location of the cross of Aka-Daruma with Glassy Fultz are not clear. (Glassy Fultz was a selection of the American variety, Fultz, discussed in the previous chapter; Fultz was imported by the Japanese Government in 1887.)

The Fultz-Daruma progeny were then used to make two other critical crosses with two related U.S. varieties: (1) Fultz-Daruma with Turkey Red; and (2) (Aka-Daruma x Glassy Fultz) with Kanred. (Kanred was selected from Crimean, which is a strain of Turkey.)

–The first cross was made at the Ehime Prefectural Agricultural Experiment Station in 1925. Seed from the initial cross was planted at the Konosu Experimental Farm of the National Agricultural Station in 1926. Seed was subsequently sent to the Iwate Prefectural Agricultural Experiment Station. A semi-dwarf selection developed from the seventh generation in 1932, Tohoku No. 34, was particularly promising. Following further testing, it was named Norin 10 and registered and released in October 1935.

–The second cross was made at the Rikuu Branch Station (Omagari, Akita Prefecture) in Japan. The F_3 seeds were sent to Korea where Suweon 85 was developed; it was released in 1932. Suweon 85 was then crossed with Suweon 13 to produce Suweon 92 and Suweon 90, which were released to farmers in 1934. Suweon 90 was crossed with Shiroboro (from Japan) at the Seu Seun Branch Experimental Station in 1936 to produce Seu Seun 27, which was not released but used for breeding.[5]

Although Norin 10 was to become the major source of dwarfism in U.S. varieties, Seu Seun 27 also has been extensively used. Suweon 92 has received more limited use.

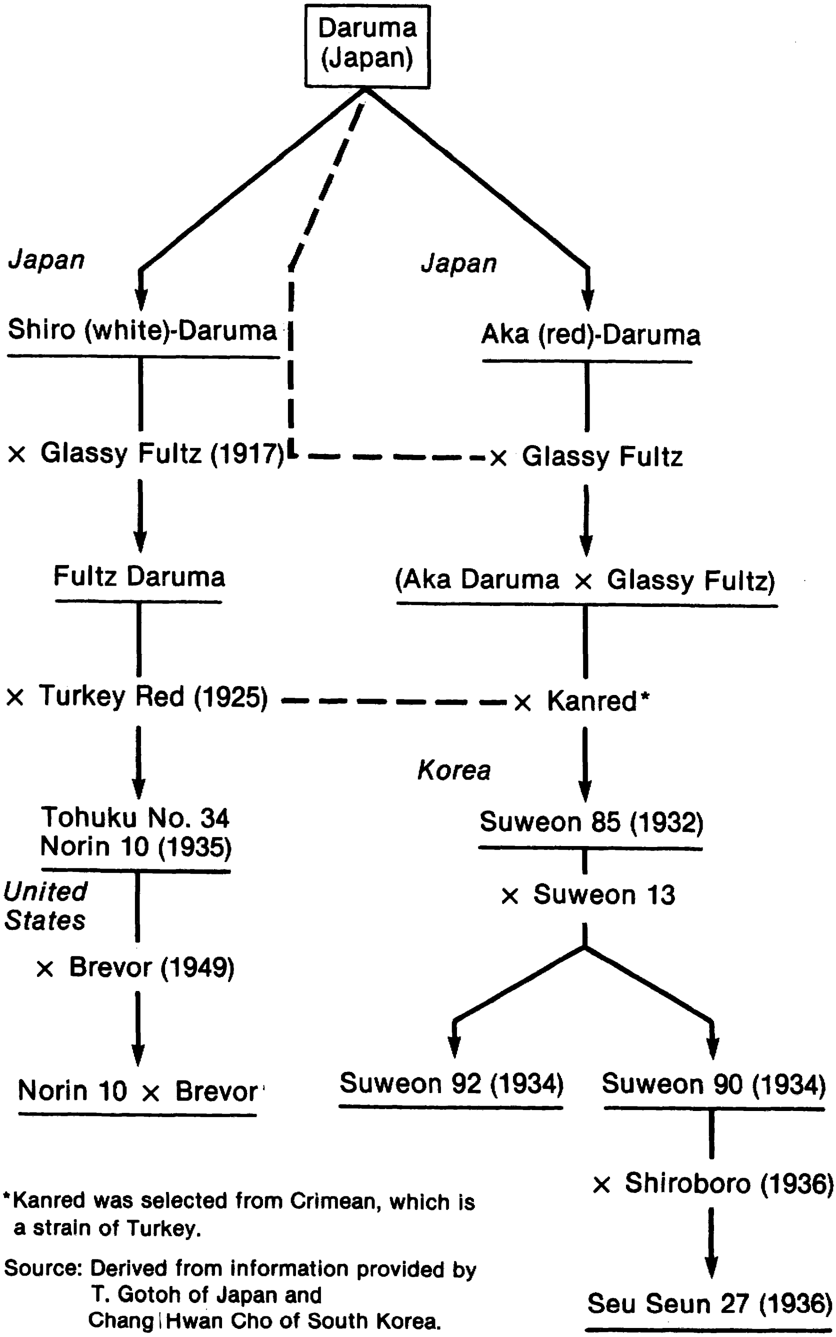
Several other Norin varieties also have been used to a limited extent. They are Norin 16, Norin 26, and Norin 33. The pedigree of these varieties is:[6]

- Norin 16 (released in 1936): F5-31/Konosu 25. F5-31 was developed from a cross of Shiro Daruma and Velvet; Konosu 25 from a cross of Florence and Igachikugo.
- Norin 26 (released in 1937): Shin Chunaga/Saitama 29. Shin Chunaga was developed by pure line selection of Chunaga; Saitama 29 from the cross California/Sojuko Akage/Haya Komugi.
- Norin 33 (developed in 1936): Hon-Iku 49/Konosu 26. Hon-Iku 49 was developed from a cross of Turkey Red and Martin's Amber; Konosu from a cross of Florence and Shiro-Chabo.

In Japan, these varieties are somewhat taller than Norin 10 (61 centimeters), growing to 80, 88, and 108 centimeters respectively. The first two are in the semi-dwarf category while the third, Norin 33, is in the medium-height category. Norin 16 probably gets its dwarfing gene from Shiro-Daruma. It is not clear what the source of dwarfism is in Norin 26 or whether it is related to Daruma (Shiro-Daruma).

Figure 5

Genealogy of Norin 10, Suweon 92, and Seu Seun 27 Semi-Dwarf Wheat Varieties



*Kanred was selected from Crimean, which is a strain of Turkey.

Source: Derived from information provided by T. Gotoh of Japan and Chang Hwan Cho of South Korea.

Introduction of Sources of Dwarfing

The story of the introduction of Norin 10 into the United States is well known. In 1946, Dr. S. C. Salmon, a U.S. Department of Agriculture scientist acting as an agricultural advisor to the occupation army in Japan, noticed that farmers were growing a number of remarkably stiff, short-stemmed wheat varieties. Salmon first saw Norin 10 at the Morioka Branch Station. He sent a number of these plant types to the USDA research facilities at Beltsville, Md., in 1946.[7]

USDA plant introduction records indicate that the first receipt of the Norin varieties cited in the previous section was as follows:[8]

–Norin 10. August 21, 1946 (P.I. 156641)
–Norin 16. June 3, 1949 (P.I. 182570)
–Norin 26. July 11, 1946 (P.I. 155266)
–Norin 33. July 11, 1946 (P.I. 155267)

Further packets of these and other Norin varieties were received in subsequent years.

Two Korean varieties, Seu Seun 27 (P.I. 157584) and Suweon 92 (P.I. 157603), were part of a larger packet presented by the Central Experiment Station in Suweon and sent by V. H. Florell. They were received by USDA on February 21, 1947.

The Norin varieties were first grown in a detention nursery in Sacaton, Ariz., for 1 year (the 1946/47 season) and then made available to U.S. wheat breeders at seven locations during the 1947/48 season.[9] The Korean varieties also would have been grown in a detention nursery and were probably distributed to the same group a year or so later (Seu Seun 27 was reportedly grown at Lincoln, Neb., in 1949).[10]

Early Crossing in the United States

The main use of the Japanese semi-dwarfs was, as noted, for breeding. However, this was not easy. With respect to Norin 10, Reitz stated:

> Crossing this dwarf with the U.S. varieties posed problems. Many of the flowers were male sterile and crossed promiscuously with adjacent plants. Timing mechanism of the wheat sprout was triggered wrong; it began unfolding before it reached the surface ... Norin 10 seemed susceptible to all of our diseases. Years of intensive selection and development were needed.[11]

One of the first groups to take up work was located at the Washington Agricultural Experiment Station at Pullman. It was composed of several USDA scientists stationed in Washington as well as State experiment station staff.

The work was headed by Dr. Orville A. Vogel of USDA.[12]

Norin 10 was one of a packet of Japanese varieties received by Vogel in 1948. Vogel gave the Norin 10 seeds and those of Brevor[13] to Dick Nagamitso, a graduate student, to cross. (Nagamitso was a student of Dr. F. C. Elliott and needed greenhouse experience in making crosses.) Nagamitso made the crosses during the winter of 1948/49 and gave the resulting F_1 seed to Vogel.[14] The cross produced a small number of semi-dwarf plants in the F_2 generation having good kernel types that appeared more productive than either parent. Three of the F_4 progeny raised in 1952 (Nos. 1, 4, and 10) were notably resistant to lodging and were advanced to cooperative varietal trials conducted in Washington and at Pendleton, Oreg.

Subsequently, it was noted that most of the plants had the same male-sterility problem as Norin 10. An intensive search for normal self-pollinating lines was undertaken, resulting in the identification of two reselections (Nos. 14 and 17), which performed satisfactorily in preliminary yield trials in 1953. These were included in the 1954 varietal trials. The selections were about two-thirds as tall as Brevor, which up until that point had been considered a very short variety.[15]

Plate 5. Drs. Orville A. Vogel and Norman E. Borlaug at the Columbia Basin Agricultural Research Center, Pendleton, Oreg., circa 1973.

Selection 14 (C.I. 13253) has since been extensively used in the breeding program in Washington and was sent to many U.S. and foreign breeders. (Borlaug in Mexico, however, had received seed of the F_2 generation of the Norin 10/Brevor cross in 1953 and started using it in his breeding program in 1954.)[16]

Norin 10 seed, as well as that of other semi-dwarf varieties, was distributed to several locations in addition to Pullman. While it is not known precisely where these locations were, one appears to have been the Kansas Agricultural Experiment Station, where a breeding program to develop semi-dwarf cultivars was established in 1949 utilizing Norin 10 and Norin 66 (P.I. 155276).[17] Another was the Nebraska Agricultural Experiment Station. Breeding of short-stature wheats was initiated in Texas in 1951 when crosses involving Norin 10, Norin 10 x Brevor, and Seu Seun 27 were made. Early generation selections from crosses made in Kansas and Nebraska were received about the same time.[18] Research involving semi-dwarfs appears to have started in New York in 1952,[19] in Arizona in 1954,[20] in Montana in 1955,[21] in South Carolina in 1957,[22] and in Wisconsin in 1960.[23] (In some cases, the research may have actually started earlier than the date indicated.) Research also was begun in California in the late 1950's.[24]

Development of First Semi-Dwarfs

The first commercial semi-dwarf to be developed and released in the United States was Gaines. The immediate history of Gaines goes back to 1954 when Dr. E. H. Everson, a USDA member of the Vogel team, crossed Norin10/Brevor 14 with a high performing selection (Orfed/Hybrid 50). Later in 1954, he crossed F_1 progeny to another high performance line (subsequently released in 1956 as Burt, C.I. 12696). In July 1956, when this cross was in the F_3 generation, Everson left Washington, but later that year the Vogel group identified Selection 9 as being superior. Following further testing and seed multiplication, this selection was released in 1961 as Gaines (C.I. 13448).[25]

The multiplication of the seed prior to release was a noteworthy process in itself. In 1958, Vogel began to think about release and, in cooperation with others, selected 1,000 representative plants (F_7 generation) which could be plant-row seeded in 1959 (plate 6). In 1960, about 75 bushels of F_8 breeder seed were obtained after rouging and cleaning. Of this, 25 bushels were allocated to Oregon and Idaho to increase as foundation seed. The 50 bushels retained in Washington were increased on three seed growers' farms to yield about 6,800 bushels of F_9 foundation seed in 1961. This seed was sold to the Washington State Crop Improvement Association and 500,000 bushels of registered F_{10} seed were produced in 1962, enough to plant about one-fourth of the wheat area in Washington.[26]

Gaines is a soft White Winter wheat. At soil fertility levels generally used for standard-height varieties, it usually yielded 5 to 20 percent more than the highest yielding commercial varieties, while on well-managed productive soils

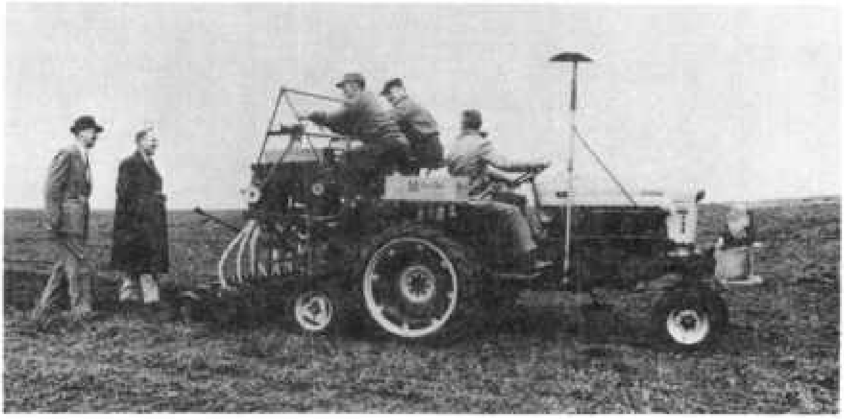


Plate 6. Planting breeder seed of Selection 9, later to be released as Gaines wheat, Pullman, Wash., fall 1959. Dr. Orville A. Vogel is driving the nursery planter, which was of his own design.

the differential increased up to 50 percent or more. One Washington farmer obtained a yield of 155 bushels/acre on an 11-acre field in 1962. The variety was quickly adopted in the Pacific Northwest.[27]

A sister selection of Gaines, Nugaines (C.I. 13968), was released in 1965. It is very similar to Gaines in most characteristics, but is superior in milling quality, test weight, and in adult plant resistance to stripe rust.[28]

Another product was Selection 101 (C.I. 13438). It was even higher yielding than Gaines, but was not suitable for commercial production because of inferior baking quality.[29] However, it has been widely used in breeding programs–particularly in Oregon.

Gaines and, to a lesser extent, Nugaines have been tested in all parts of the United States. They have limitations in many areas outside of the Pacific Northwest. They are winter wheats and may not head out unless the seedlings are subjected to a period of cool weather. They are also late in maturity and suffer attacks from some diseases, insects, and severe winter cold.

In 1963, the first Mexican semi-dwarfs were commercially planted in California. (This step followed the introduction of tall Mexican varieties the previous year in order to provide resistance to stem rust.) The varieties were not certified, however, until 1966 because extensive seed purification was needed to meet certification standards. Pitic 62 was the first to be grown extensively.[30]

The Next Round of Semi-Dwarfs

From 1966 to 1968, five more semi-dwarfs were developed and released for commercial use. All were based on work originating in the 1950's.

Three were released in 1966: Blueboy, Maricopa, and Sturdy.[31] Although the original cross for Blueboy was made in South Carolina, the selections were made at the North Carolina Agricultural Experiment Station (AES). The variety showed excellent straw strength and yield potential.[32] Maricopa, released by the Arizona AES and USDA, was adapted to the irrigated areas of Arizona.[33] Sturdy was developed by the Texas AES and USDA. Unlike the others, it obtained its dwarfing genes from Seu Seun 27; at the time of introduction it was 6 to 10 inches shorter than the other varieties in commercial production. It was recommended for dryland conditions.[34] In terms of market type, Maricopa is a semi-hard to hard White Spring wheat, Blueboy is a Soft Red Winter, and Sturdy is a Hard Red Winter; the latter two were the first of their type to be released.

Subsequent releases included Timwin in 1967 and Yorkstar in 1968. Timwin, another Soft Red Winter variety, was released by the Wisconsin AES and USDA.[35] Yorkstar, a soft White Winter variety, was developed by the New York AES (at Cornell University).[36]

Plate 7. "Semi-Dwarf Parental Material (left foreground) Used in Cornell Breeding Program," Cornell University, Ithaca, N.Y., July 1958.

In 1968, two selections from crosses made in Mexico by Borlaug and his associates were introduced: Chaparral and Red River 68. Chaparral, a Hard Red Spring variety, was released by DeKalb AgResearch, Inc., for use in southern Texas. The original cross was made by CIMMYT and the variety evolved from a selection made by DeKalb from an F_5 population.[37] Red River 68, another Hard Red Spring variety, was introduced by World Seeds for use in the North Central States. The original cross was made in Mexico (where offspring are known as Tobari "S") and selections made in the United States.[38]

Also in 1968, the California AES reported on tests of several introductions from Mexico. Two—Siete Cerros 66 and INIA 66—were found to have outstanding performance and were approved for certification by the California Crop Improvement Association.[39]

Thus, by the close of 1968, the U.S. wheat industry began to experience a pattern that was to be repeated with increasing frequency in the future: The release of varieties developed from hybridization in the United States, or, to a lesser extent, the release of selections from crosses originally made by CIMMYT and the introduction of varieties developed in Mexico.

Expansion of Semi-Dwarf Releases

During the 11 years from 1969 through 1979, there was a significant increase in the number of semi-dwarf varieties released. While it is difficult (as indicated in footnote 31) to be precise about exact year of release, it appears that about 120 varieties—selections and crosses—were released. In addition, some CIMMYT/Mexican varieties were introduced. Of the total of 120 varieties, 32 represented (with one exception) selections from CIMMYT/Mexican crosses, and 87 were derived from crosses made in the United States. In the latter case, 14 of the crosses had one or more parents or grandparents of CIMMYT/Mexican origin. (Further details on the varieties noted here may be found in tables 1 to 3 in the next section.)

States initially releasing varieties (usually in cooperation with USDA) were generally around the border of the country: Arizona (1966), California, Oregon, Washington, Idaho, Montana, North Dakota, Minnesota, Wisconsin, Michigan (1979), New York, North Carolina, Georgia, and Texas. Colorado and Utah were the main exceptions. Illinois, Oklahoma, and Kansas released their first semi-dwarfs in 1977. No semi-dwarfs have yet been released by the State agricultural experiment stations in the important wheat States of Indiana, Ohio, Nebraska, and South Dakota (semi-dwarfs are not grown in the first three States, but are rather widely raised in South Dakota). In 1966, Missouri developed a variety that might be considered a semi-dwarf. Some reasons for the relative lack of development in the Midwest and Central Plains States will be discussed in following chapters. The private firms do not follow a similar geographic pattern.

In any case, it takes substantial time to develop a new variety. Once the first cross is made, many further selections must be made and many field tests conducted. A review of genealogical information gathered for this study suggests that the average interval from first cross to release in the public sector was 10 to 12 years. If this estimate is correct, and continues to hold, the first crosses of most of the varieties to be released during the 1980's already have been made.

The Varietal Situation as of 1979

As of late 1979, at least 147 semi-dwarf varieties of wheat have been released or introduced for use in the United States. Of this total, 18 varieties represent known introductions; the actual number may be larger. Another 34 represent selections from crosses made, with one exception, in Mexico by CIMMYT and INIA. Finally, 95 represent crosses made in the United States, 14 of which have some Mexican parentage. This section outlines the process used in selecting these varieties and then provides certain details on each in tabular form.

Definition of Varieties

Some of the difficulties in defining semi-dwarf varieties of wheat were noted in Chapter I. Because of the wide variability in height from region to region, and, to a lesser extent, from year to year, it is not possible to identify a specific absolute or relative height level. Also, non-dwarf varieties may sometimes be as short or shorter than a given semi-dwarf (though this would not normally be expected to be the case).

Hence, we shall partly make use of genealogy in defining semi-dwarfs. Specifically, a semi-dwarf wheat variety is normally one that carries a semi-dwarf gene of Daruma ancestry—usually from Norin 10, but sometimes from Norin 16, Seu Seun 27, or Suweon 92. This process excludes several short to medium varieties (such as Arrow and Guide).[40] In some cases, Daruma ancestry was not evident from the published pedigree but was established through conversations with the breeders involved[41] and/or through study of unpublished records.[42]

But it is not enough that the variety have Daruma ancestry because the dwarfing gene is recessive; the plant must also be at least short. Thus, while three current U.S. varieties (Argee, Bannock, and Potomac) have Norin 10 ancestry, they are medium in height and are not included in the listing provided here.[43]

Another category also is excluded: varieties having a semi-dwarf in their ancestry, but getting their shortness from some other source. This is true of several short to semi-dwarf varieties (Hart, S-76, S-77, and S-78).[44] It could well be argued that these varieties should be included in the semi-dwarf listing, but this has not been done here.

On the other hand, a few varieties, which might be considered too tall to properly qualify as semi-dwarfs, are still included. I particularly have Blueboy and Yorkstar in mind, though others might be mentioned. Yorkstar has been variously described as short, medium-short, and medium.[45] If either variety were a recent release I might exclude it, but since both were early releases and short for their time (1966 and 1968), I have decided to include them. A somewhat similar process was followed for several other "marginal" cases (I may not have been entirely consistent).

In a few cases, the requirement of proven Daruma ancestry has been relaxed. It has not been possible to ascertain Daruma ancestry for Norin 26 and Norin 33. However, Norin 26 is a semi-dwarf and in the cases where it was used as a parent (Plainsman V, 5411, 5422, and 5466) there is a possibility that it may have outcrossed with Norin 10.[46] Norin 33 is a more difficult problem. Although an authoritative source indicates that it has Daruma/Fultz in its ancestry,[47] recent information from Japan suggests that this is not the case.[48] Since the two varieties carrying it in their pedigree, Coker 68-15 and Coker 68-19, are slightly shorter than some other varieties classified as semi-dwarfs, I have elected to retain them.[49]

In one case, McNair 4823, it has not been possible—despite an extensive search—to determine the source of shortness. The published pedigree and other information simply do not reveal any known source of dwarfism. Yet the variety is clearly short—shorter than the other McNair varieties of known Norin 10 ancestry. Possibly the pedigree was incompletely listed at some point, or there was an accidental outcross with Norin 10. Tests could verify the presence of Norin-type genes, but these have not been carried out as yet.[50]

A new breeding technique, "male sterile facilitated recurrent selection," recently has been utilized to develop a semi-dwarf wheat variety (WestBred Aim). It is a breeder's delight, but a genealogist's despair because of the large number of varietal crosses involved—about 50 in the case of WestBred Aim.[51]

Any decision on where to draw a line between semi-dwarf and short varieties necessarily will involve troublesome twilight questions such as these. There simply is no clear-cut and widely accepted definition, or at least one that I have been able to determine. Nevertheless, a starting point has been defined and some of its limitations and exceptions outlined.

Varietal Introductions

At least 18 semi-dwarf varieties appear to have been introduced into the United States, with all but one coming from Mexico (and the exception has a Mexican parent). The total may have been even larger, in that 10 other CIMMYT/INIA bread varieties have been released during the 1973-77 period, and at least some have probably been introduced.[52]

The 18 known varieties—partly based on USDA varietal surveys and partly on registrations in *Crop Science*—are listed in table 1 along with major sources of information and notes. All are based on crosses or hybridization and all derive their semi-dwarf nature from Norin 10.

Table 1—Semi-Dwarf Wheat Varieties Introduced Into the United States

Variety[1]	Market Type	P.I. Number	C.I. Number	Crop Science Registration (Volume/Number)	Listing in S&R[2]	Listing in Zeven[3]	Other Names and Notes
1. Bluebird 2	HRS/HWS	412954			p. 2	p. 17	Yecora 70 (white grain)
2. Cajeme 71	HRS				p. 3	p. 20	Bluebird 4
3. Ciano 67	HRS		14490	1972(12/1), p. 131	p. 4	p. 25	
4. Cocorit 71	D	422277				p. 26	
5. Inia 66	HRS		14195	1972(12/1), p. 130[5]	p. 6	p. 52	
6. Lerma Rojo 64	SRS		13929		p. 6	p. 63	
7. Mexicali 75	D						
8. Nadadores 63	HRS		13931		p. 7	p. 73	
9. Norquay (Canada)	HWS		17343				Lerma Rojo/Sonora 64/Justin Dev. at U. of Manitoba
10. Penjamo 62	SRS		13924		p. 8	p. 81	
11. Pitic 62	HRS		13927	1972(12/1), pp. 130-131	p. 8	p. 83	
12. Prospur (75)	HRS		17408		p. 8	p. 86	[4]
13. Protor (75)	HRS		17409		p. 8	p. 86	[4]
14. Siete Cerros 66	HWS		14493	1972(12/1), p. 131[5]	p. 9	p. 100	White-grained sister of Super X
15. Sonora 64	HRS		13930	1972(12/1), p. 130	p. 9	p. 101	
16. Super X (66)	HRS		15230	1972(12/1), p. 131	p. 9	p. 103	Red-grained sister of Siete Cerros 66
17. Tanori 71	HRS		17416		p. 10	p. 105	
18. Yecora 70	HWS		15390		p. 11	p. 117	Bluebird 2

Key: HRS = Hard Red Spring HWS = Hard White Spring SRS = Soft Red Spring D = Durum

[1] Year after number indicates year of release in Mexico (in case of Prospur, Protor, and Yecora Rojo, year of U.S. release).

[2] "S&R" refers to B. Skovmand and S. Rajaram, *Semidwarf Bread Wheats, Names, Parentages, Pedigrees, Origins*, CIMMYT Information Bulletin No. 34, 1978, 16 pp.

[3] A. C. Zeven and N. Ch. Zeven-Hissink, *Genealogies of 14000 Wheat Varieties*, CIMMYT, 1976, 119 pp.

[4] Released by Northrup King Co. Protor was not released in Mexico (it was not competitive at lower altitudes).

[5] Also see *California Agriculture*, December 1978 (Vol. 22, No. 12), p. 6.

Selections From Mexican Crosses

Another 34 varieties have been selected, with one exception, from crosses originally made by CIMMYT and INIA in Mexico. They are listed in table 2. Somewhat more information is provided than in the case of the introductions noted in the previous section: the year of release (approximate in some cases), the organization releasing the variety, and, for some, the Plant Variety Protection number. The relatively important role of private firms, particularly of one firm, is evident. All but one of the selections derive their semi-dwarf nature from Norin 10.

Varieties Developed in the United States

Following the procedure outlined earlier, 95 varieties developed in the United States have been identified as semi-dwarfs. These include a few varieties which are marginal and exclude a few others which might be included. Of these varieties, 14 have one or more Mexican parents or grandparents. The 95 varieties and associated information and sources are listed in table 3.

All derive their semi-dwarf stature from Norin 10 except the following:

–Norin 16: TAM W-101. Also, along with Norin 10, in pedigree of Lindon, Wings, and Vona (in KS 62136).
–Norin 26 (and possibly Norin 10): Plainsman V, 5411, 5422, and 5466.
–Norin 33: Coker 68-15 and Coker 68-19.
–Suweon 92: Coulee, Faro, and Paha.
–Seu Seun 27: Caprock, Maverick, Payne, Sturdy, TAM 105 and TAM 106, TexRed, III, 4555 (Century II), 4578, 5210, 5221, and 5232. (All but Caprock through Sturdy.)

(Text continued on p. 54.)

Table 2—Semi-Dwarf Varieties Developed by Selection From Mexican Crosses

Variety	Type	Year Released	Released By	C. I. Number	Plant Variety Protection No.	Crop Science Registration (Volume/Number)	Other Notes
1. Anza	HRS	1971	California AES & USDA	17744		(California Agriculture, Feb. 1973, pp. 14-15)	
2. Bonanza	HRS	1969	DeKalb AgResearch Inc.	14077	7100023 3/19/74	1972(12/1) p. 129	Sister of Chaparral
3. Bounty 208	HRS	1971	Cargill Wheat Research	15078		1973(13/4) pp. 495-496	
4. Bounty 309	HRS	1974	Cargill Wheat Research	17315	7400068 10/17/75	1975(15/1) p. 104	
5. Chaparral	HRS	1968	DeKalb AgResearch Inc.	14076		1972(12/1) p. 129	Sister of Bonanza
6. Colano	HRS	1971	Colorado AES	15333		1974(14/5) p. 777	
7. DK-22S	HRS	1978	Douglas W. King Co. Inc.		7800002 9/13/79		[1]
8. DK-33S	HRS	1978	Douglas W. King Co. Inc.		7800003 8/10/78		[1]
9. DK-49S	HRS	1978	Douglas W. King Co. Inc.		7800004 12/28/78		[1]
10. INIA 66R	HRS	1969	California AES	15328			[2]
11. Lark	HRS	1971	World Seeds Inc.	17338			Sister of WS-1651
12. Peak	HRS	1971	Idaho AES & USDA	14587		1972(12/2) p. 259	
13. Peak 72	HRS	1972	Idaho AES & USDA	15319		1973(13/2) p. 288	Selection from Peak
14. Portola	HRS	1975	California AES	17415			Jilguero "S" in Mexico

15. Probred	HRS	1974	Northrup, King Co.	17410	75000033 6/30/75	Selection from Bluebird 2
16. Prodax	HRS	1974	Northrup, King Co.	17407	7500005 6/30/75	
17. Produra	D	1975	Northrup, King Co.	17406	7400009 6/30/75	
18. Profit 75	HRS	1975	World Seeds Inc.	17348	7400087 4/18/75	Sister of WS-25
19. Red River 68	HRS	1968	World Seeds Inc.	14193		Sister of Tobari 66
20. Solar	HRS	1978	Northrup, King Co.		7800010 3/29/79	[3]
21. WestBred 1000D	D	1978	Western Plant Breeders[4]		7900004 11/27/79	Italian ancestry
22. W-433	HRS	1972	Germains Inc.	17245		
23. W-444	HRS	1976	Germains Inc.		7600079 12/20/76	
24. WS-1[5]	HWS	1974	World Seeds Inc.	17347	7400099 12/12/75	
25. WS-3	D	1973	World Seeds Inc.	17346	7300074 1/10/75	
26. WS-6	HRS	1973	World Seeds Inc.	17345	7300067 3/5/76	
27. WS-25	HRS	1976	World Seeds Inc.		7605019 5/16/77	Sister of Profit 75
28. WS-1616	HRS	1971	World Seeds Inc.			
29. WS-1651	HRS	1969	World Seeds Inc.	15334		Sister of Lark
30. WS-1809	HRS	1971	World Seeds Inc.	15012	7200029 5/16/74	
31. WS-1812	HRS	1969	World Seeds Inc.	14585		
32. WS-1859	HRS	1969	World Seeds Inc.			
33. WS-1877	HRS	1969	World Seeds Inc.			
34. Yecora Rojo	HRS	1976	California AES	17414		[6]

Key: HRS = Hard Red Spring D = Durum

[1] Developed by Dr. I. M. Atkins while at Texas AES.
[2] Reselection of INIA 66 (INIA 66 was not certified after 1969).
[3] Derived from a single-head selection made in 1969 in a plot of UM-953A at the University of Manitoba. UM-953A was derived from the cross Sonora/Tezanos Pintos Precoz.
[4] Valley Seed Co. and Montana Seeds.
[5] A standardized abbreviation has been used for the World Seeds varieties. WS-3, for instance, is technically recorded as W.S. 6, while WS-1616 is listed World Seeds 1616.
[6] Red-seeded sib of Yecora 70.

Table 3—Semi-Dwarf Wheat Varieties Developed From Crosses Made in the United States

Variety	Market Type	Year Released	Developed and/or Released By	C.I. Number	Plant Variety Protection No.	Crop Science Registration (Volume/Number)	Other Notes
1. Aldura[1]	D	1979	Northrup, King Co.				For Arizona, Calif.
2. Angus	HRS	1978	Minnesota AES & USDA	17744		1979(19/5) pp. 749-750	Sister of Kitt
3. Augusta	SWW	1979	Michigan AES	17831			
4. Barbee	C	1976	Washington AES & USDA	17417		1977(17/4) p. 675	
5. Blueboy	SRW	1966	North Carolina AES	14031		1967(7/1) p. 82	
6. Blueboy II	SRW	1971	North Carolina AES	15281	7200033 2/26/74	1972(12/3) p. 398	
7. Borah	HRS	1974	Idaho AES & USDA	17267		1975(15/1) p. 104	
8. Calvin	D	1978	North Dakota AES	17747			
9. Cando[1]	D	1975	North Dakota AES & USDA	17438		1976(16/6) p. 885	
10. Caprock	HRW	1969	Texas AES & USDA	14516		1969(9/6) p. 852	Sister of Sturdy
11. Chanute	HRW	1969	DeKalb AgResearch Inc.	14581		1970(10/4) p. 461	Sister of Palo Duro, Satanta, Yukon
12. Coker 68-15	SRW	1971	Coker's Pedigreed Seed Co.	15291	7200014 3/6/74		
13. Coker 68-19	SRW	1970	Coker's Pedigreed Seed Co.	15229	7200015 3/6/75		
14. Coker 747	SRW	1976	Coker's Pedigreed Seed Co.		7605015 9/20/78		From a cross of Coker 68-15, Arthur
15. Coulee	HWW	1971	Washington AES & USDA	14483		1974(14/2) p. 340	

Table 3—Semi-Dwarf Wheat Varieties Developed From Crosses Made in the United States (Continued)

Variety	Market Type	Year Released	Developed and/or Released By	C.I. Number	Plant Variety Protection No.	Crop Science Registration (Volume/Number)	Other Notes
16. Daws	SWW	1976	Washington AES & USDA	17419		1977(17/4) pp. 674-675	
17. Era	HRS	1970	Minnesota AES & USDA	13986		1971(11/4) p. 604	Sister of Fletcher, Wared
18. Faro	C	1976	Oregon AES & USDA	17590		1978(16/6) p. 1095	
19. Fielder	SWS	1974	Idaho AES & USDA	17268		1975(15/1) p. 104	Sister of Fieldwin
20. Fieldwin	SWS	1977	Idaho AES & USDA	17425		1978(18/5) p. 916	Sister of Fielder
21. Fletcher	HRS	1970	Minnesota AES & USDA	13985		1971(11/4) p. 604	Sister of Era, Wared
22. Frakenmuth	SWW	1979	Michigan AES	17830			
23. Fremont	HRS	1970	Utah AES & USDA	14056		1972(12/1) p. 130	
24. Gaines	SWW	1961	Washington AES & USDA	13448		1964(4/1) pp. 116-117	
25. GB-2148 (Century II)	HRW	1975	Greenbush Seed & Supply		7600025 3/16/78		Developed by SRI[1] Sister of 5210
26. Houser	SWW	1977	New York AES (Cornell)	17736		1979(19/3) p. 415	
27. Hyslop	SWW	1971	Oregon AES	14564		1972(12/3) p. 398	
28. Kitt	HRS	1975	Minnesota AES & USDA	17297		1976(16/5) p. 744	Sister of Angus

29.	Len	HRS	1979	North Dakota AES & USDA	17790			
30.	Lindon[1]	HRW	1975	Colorado AES	17440	7600076 3/18/77	1977(17/2) p. 346	Sister of Vona, Wings
31.	Luke	SWW	1970	Washington AES & USDA	14586		1974(14/1) p. 129	
32.	Marberg[1]	HRS	1979	Montana AES & USDA	17829			
33.	Maricopa	HWS	1966	Arizona AES & USDA	14129		1967(7/4) p. 405	
34.	Maverick	HRW	1977	Harpool Seeds Inc. & McGregor Milling & Grain Co.	17728	7700108 9/29/78		Sister of TexRed[2]
35.	McDermid	SWW	1974	Oregon AES & USDA	14565		1976(16/5) p. 745	
36.	McNair 701	SRW	1972	McNair Seed Co.	15288	7200038 2/26/74	1973(13/5) p. 585	Selection from McNair 2203
37.	McNair 1003	SRW	1977	McNair Seed Co.		7700084 8/10/78		
38.	McNair 1587	SRW	1973	McNair Seed Co.	17279			Not marketed; sister of McNair 701
39.	McNair 1813	SRW	1975	McNair Seed Co.	15289	7500006 5/1/75		
40.	McNair 2203	SRW	1970	McNair Seed Co.	15228			
41.	McNair 4823	SRW	1972	McNair Seed Co.	15290	7200037 4/8/75	1973(13/5) p. 585	
42.	Modoc[1]	D	1975	California AES	17466		1978(18/5) p. 916	
43.	Newana	HRS	1976	Montana AES & USDA	17430		1977(17/4) p. 674	Sister of Norana
44.	Newton[1]	HRW	1977	Kansas AES & USDA	17715	7800100 3/1/79	1978(18/4) p. 696	
45.	Norana	HRS	1973	Montana AES & USDA	15927		1974(14/1) p. 128	

Table 3—Semi-Dwarf Wheat Varieties Developed From Crosses Made in the United States (Continued)

	Variety	Market Type	Year Released	Developed and/or Released By	C.I. Number	Plant Variety Protection No.	Crop Science Registration (Volume/Number)	Other Notes
46.	Nugaines	SWW	1965	Washington AES & USDA	13968		1974(14/4) p. 609	
47.	Olaf	HRS	1973	North Dakota AES & USDA[4]	15930		(North Dakota Farm Research, March-April 1973)	
48.	Omega 78	SRW	1978	Georgia AES	17721			
49.	Paha	C	1970	Washington AES & USDA	14485		1972(12/2) p. 260	
50.	Palo Duro	HRW	1969	DeKalb AgResearch Inc.	14584		1970(10/3) p. 462	Sister of Chanute, Satanta, Yukon
51.	Payne	HRW	1977	Oklahoma AES & USDA	17717			
52.	Peck	SWW	1974	Idaho AES & USDA	17298			
53.	Plainsman V	HRW	1974	Dixie Portland Milling Co.		7500082 9/07/76		Developed by SRI[2]
54.	Pondera[1]	HRS	1979	Montana AES & USDA	17828			
55.	Powell[1]	HRS	1978	Utah AES	17761			
56.	Pronto	HRW	1970	DeKalb AgResearch Inc.	14078		1971(11/6) p. 944	
57.	Purcell	SWW	1979	New York AES (Cornell)	17787			
58.	Raeder	SWW	1976	Washington AES & USDA	17418		1977(17/4) p. 675	
59.	Roland	SRW	1977	Illinois AES & USDA	17716			
60.	Roy	SRW	1979	North Carolina AES	17763		1979(19/3) p. 414	

61.	Satanta	HRW	1969	DeKalb AgResearch Inc.	14583		1970(10/4) p. 461	Sister of Chanute, Palo Duro, Yukon
62.	Sawtell[1]	HRS	1977	Idaho AES & USDA	17424		1978(18/5) pp. 915, 916	
63.	Shasta[1]	HRS	1976	California AES	17651			
64.	Shortana	HRS	1971	Montana AES & USDA	15233		1971(11/6) pp. 944-945	
65.	Sprague	SWW	1972	Washington AES & USDA	15376		1978(18/4) pp. 695-696	
66.	Springfield	SWS	1970	Idaho AES & USDA	14589		1972(12/2) p. 259	
67.	Stephens	SWW	1977	Oregon AES & USDA[3]	17596		1978(18/6) p. 1097	
68.	Sturdy	HRW	1966	Texas AES & USDA	13684		1967(7/4) p. 406	Sister of Caprock
69.	TAM W-101	HRW	1971	Texas AES & USDA[3]	15324		1974(14/4) p. 608	
70.	TAM W-103	HRW	1973	Texas AES & USDA[3]	17336		1976(16/5) pp. 744-745	
71.	TAM 105	HRW	1979	Texas AES & USDA[3]	17826		1980(20/1)	
72.	TAM 106	HRW	1979	Texas AES & USDA[3]	17827		1980(20/1)	
73.	TexRed	HRW	1977	Esco, Harpool, & George Warner Seed Co.	17729	7700109 8/10/78		Sister of Maverick[3]
74.	Ticonderoga	SWW	1973	New York AES (Cornell)	17290		1977(17/4) p. 673	
75.	Timwin	SRW	1967	Wisconsin AES & USDA	13787		1974(14/6) p. 908	
76.	Twin	SWS	1971	Idaho AES & USDA	14588		1972(12/2) p. 259	
77.	Urquie	SWS	1975	Washington AES & USDA	17413		1976(16/5) p. 742	

Table 3—Semi-Dwarf Wheat Varieties Developed From Crosses Made in the United States (Continued)

	Variety	Market Type	Year Released	Developed and/or Released By	C.I. Number	Plant Variety Protection No.	Crop Science Registration (Volume/Number)	Other Notes
78.	Vona[1]	HRW	1976	Colorado AES	17441	7700029 5/16/77	1978(18/4) p. 695	Sister of Lindon, Wings
79.	Walladay	SWS	1979	Washington AES & USDA	17759			
80.	Wandell	D	1971	Washington AES	15070		1974(14/6) p. 910	
81.	Wared	HRS	1972	Washington AES & USDA[4]	15926		1974(14/6) p. 910	Sister of Era, Fletcher
82.	WestBred Aim[1]	HRS	1978	Western Plant Breeders (Valley Seed/Montana Seeds)		7900005 10/18/79	1978(18/4) p. 698[5]	
83.	Wings[1]	HRW	1977	North American Plant Breeders		7700053 8/11/77		Developed by Col. AES. Sister of Lindon, Vona
84.	WS-13[1] (World Seeds 13)	SWW	1979	World Seeds Inc.		7900074 Apl.		
85.	Yorkstar	SWW	1968	New York AES (Cornell)	14026		1968(8/5) pp. 641-642	
86.	Yukon	HRW	1969	DeKalb AgResearch Inc.	14583		1970(10/4) p. 462	Sister of Chanute, Palo Duro, Satanta
87.	III	HRW	1974	Shallow Water Grain Co.		7500080 9/7/76		Developed by SRI[2]
88.	4555 (Century II)	HRW	1977	Greenbush Seed Co.		7600050 7/19/77		Developed by SRI[2]
89.	4578	HRW	1978	Seed Research Inc.		7800006 10/18/79		

90.	5210	HRW	1973	Dixie Portland Milling Co.	7600045 12/20/76	Developed by SRI[2] Sister of GB-2148 and 5232
91.	5221	HRW	1976	Seed Research Inc.	7600049 9/28/77	
92.	5232	HRW	1976	Seed Research Inc.	7600051 6/7/77	Sister of GB-2148 and 5210
93.	5411	HRW	1973	Dixie Portland Milling Co.	7600046 10/29/76	Developed by SRI[2] Sister of 5422
94.	5422	HRW	1977	Seed Research Inc.	7700105 1/25/79	Sister of 5411
95.	5466	HRW	1978	Seed Research Inc.	7700106 8/16/79	

KEY:

HRS	= Hard Red Spring	HWW	= Hard White Winter	SWW	= Soft White Winter
HRW	= Hard Red Winter	SRW	= Soft Red Winter	C	= Club
HWS	= Hard White Spring	SWS	= Soft White Spring	D	= Durum

[1] One or more ancestors of Mexican/CIMMYT origin.
[2] SRI = Seed Research Incorporated.
[3] Developed by I. M. Atkins while at Texas AES.
[4] Not released by USDA.
[5] Registration of parental germplasm.

Summary of Varieties Introduced and Released

An integrated, alphabetical listing of the 147 varieties reported in the previous three sections and tables is provided in table 4. The origin is indicated by a code letter: I for introduction, S for selection, and X for cross. The list includes known semi-dwarf varieties released or introduced from 1961 through late 1979. As noted earlier, some additional introductions may have been made from Mexico.

The listing, reflecting reservations mentioned earlier, has some limitations. Certain varieties might not be considered semi-dwarfs by everyone, while some other varieties—particularly Hart, S-76, S-77, and S-78—might be added to the list. In addition, not all of the varieties may be in active use, as of 1979; a fuller picture will be available when the national summary of the 1979 variety survey—to be discussed in the next section—is released.

Of the 129 selections and crosses listed, 71 were released by the public sector and 58 by the private sector. The role of the public sector (Federal and State agricultural experiment stations) was relatively larger in the case of crosses, where it was responsible for 64 of the 95; the private sector was relatively more important in the case of selections, developing 27 out of 34. Altogether, USDA, 19 States, and 17 private firms were involved. Among the States, two released 22 varieties (Washington, 13 and Idaho, 9), while two private firms produced 25 varieties (World Seeds, 14 and Seed Research, Inc., 11—though 6 of the latter were marketed through other firms). In many cases, private firms utilized parental materials developed in the public sector.

Estimated Area Planted, 1964, 1969, and 1974

The U.S. Department of Agriculture, in cooperation with 42 States, has conducted variety surveys every 5 years since 1919.[53] The surveys reveal the breakdown of the area planted/seeded. Since the first U.S. semi-dwarf, Gaines, was introduced in 1962, the results of three surveys have been published—for 1964, 1969, and 1974.[54] Another national survey was conducted in 1979, but it has not yet been published. Partial data from this survey are briefly summarized in the final section of this chapter.

Once a list of semi-dwarf varieties has been prepared, it is relatively easy to determine the area planted to these varieties in the survey years. Results of such tabulations will be presented on the following pages. In viewing the statistics, it should be noted that the actual harvested area of all varieties is always less than the planted area. For the 3 survey years, the total harvested area formed the following percentages of planted area: 1964, 85.7; 1969, 88.2; and 1974, 92.0. Consequently, the semi-dwarf area actually harvested would be less than the area reported planted here. Whether the nonharvested proportion would be the same as for other varieties is not known.

Table 4—Summary Listing of Semi-Dwarf Wheat Varieties Introduced and Released in the United States

Variety	Origin	Variety	Origin
1. Aldura	X	38. GB-2148 (Century II)	X
2. Angus	S	39. Houser	X
3. Anza	S	40. Hyslop	X
4. Augusta	X	41. INIA 66	I
5. Barbee	X	42. INIA 66R	S
6. Bluebird 2	I	43. Kitt	X
7. Blueboy	X	44. Lark	S
8. Blueboy II	X	45. Len	X
9. Bonanza	S	46. Lerma Rojo 64	I
10. Borah	X	47. Lindon	X
11. Bounty 208	S	48. Luke	X
12. Bounty 309	S	49. Marberg	X
13. Cajeme 71	I	50. Maricopa	X
14. Calvin	X	51. Maverick	X
15. Cando	X	52. McDermid	X
16. Caprock	X	53. McNair 701	X
17. Chanute	X	54. McNair 1003	X
18. Chaparral	S	55. McNair 1587	X
19. Ciano 67	I	56. McNair 1813	X
20. Cocorit 71	I	57. McNair 2203	X
21. Coker 68-15	X	58. McNair 4823	X
22. Coker 68-19	X	59. Mexicali 75	I
23. Coker 747	X	60. Modoc	X
24. Colano	S	61. Nadadores 63	I
25. Coulee	X	62. Newana	X
26. Daws	X	63. Newton	X
27. DK-22S	S	64. Norana	X
28. DK-33S	S	65. Norquay	I
29. DK-49S	S	66. Nugaines	X
30. Era	X	67. Olaf	X
31. Faro	X	68. Omega 78	X
32. Fielder	X	69. Paha	X
33. Fieldwin	X	70. Palo Duro	X
34. Fletcher	X	71. Payne	X
35. Frakenmuth	X	72. Peak	S
36. Fremont	X	73. Peak 72	S
37. Gaines	X	74. Peck	X

KEY: I = introduction; S = selection; X = cross made in United States.

Table 4—Summary Listing of Semi-Dwarf Wheat Varieties Introduced and Released in the United States (Continued)

Variety	Origin	Variety	Origin
75. Penjamo 62	I	112. Timwin	X
76. Pitic 62	I	113. Twin	X
77. Plainsman V	X	114. Urquie	X
78. Pondera	X	115. Vona	X
79. Portola	S	116. Walladay	X
80. Powell	X	117. Wandell	X
81. Probred	S	118. Wared	X
82. Prodax	S	119. WestBred Aim	X
83. Produra	S	120. Westbred 1000D	S
84. Profit 75	S	121. Wings	X
85. Pronto	X	122. W-433	S
86. Prospur	I	123. W-444	S
87. Protor	I	124. WS-1[1]	S
88. Purcell	X	125. WS-3	S
89. Raeder	X	126. WS-6	S
90. Red River 68	S	127. WS-13	X
91. Roland	X	128. WS-25	S
92. Roy	X	129. WS-1616	S
93. Satanta	X	130. WS-1651	S
94. Sawtell	X	131. WS-1809	S
95. Shasta	X	132. WS-1812	S
96. Shortana	X	133. WS-1859	S
97. Siete Cerros 66	I	134. WS-1877	S
98. Solar	S	135. Yecora 70	I
99. Sonora 64	I	136. Yecora Rojo	I
100. Sprague	X	137. Yorkstar	X
101. Springfield	X	138. Yukon	X
102. Stephens	X	139. III	X
103. Sturdy	X	140. 4555 (Century II)	X
104. Super X	I	141. 4578	X
105. TAM W-101	X	142. 5210	X
106. TAM W-103	X	143. 5221	X
107. TAM 105	X	144. 5232	X
108. TAM 106	X	145. 5411	X
109. Tanori 71	I	146. 5422	X
110. TexRed	X	147. 5466	X
111. Ticonderoga	X		

[1] Standardized abbreviation for World Seeds Co. varieties (see table 2, fn. 5).

Total Semi-Dwarf Area

Although the composite listing of all known semi-dwarfs in 1979 totaled 147 (table 4), the number of varieties reported in early varietal listings was, of course, considerably less. The actual totals were: 1964, 3; 1969, 24; and 1974, 69.[55] A number of varieties (60 selections and crosses) have been released subsequently, others have gone out of use, some may not have been used commercially, and the varietal names of some may not have been known. The semi-dwarfs were part of a more general proliferation of varieties.

The total area planted to semi-dwarf wheat varieties as defined in this report increased as follows:

Year	Semi-Dwarf	All Varieties	Proportion Semi-Dwarf
	Acres (rounded)		*Percent*
1964	1,609,000	55,046,000	2.92
1969	3,806,000	54,312,000	7.01
1974	15,756,400	71,169,000	22.14

Clearly there was a significant increase in the semi-dwarf area, both in terms of actual area and in proportion of total area. The increase was particularly sharp between 1969 and 1974. Actually, the semi-dwarf area was probably slightly higher in each year because a varietal breakdown is not available for a small portion of total area (1.54 percent in 1964; 1.23 in 1969; and 1.95 in 1974), and a part of this may be composed of semi-dwarfs.

In terms of origins, the breakdown of the semi-dwarf area was:

Category	1964		1969		1974	
			Acres (Percent)			
Introductions	5,059	(0.3)	277,342	(7.3)	861,063	(5.5)
Selections	0	(0)	169,938	(4.5)	3,183,811	(20.2)
Crosses	1,603,867	(99.7)	3,358,759	(88.2)	11,711,491	(74.3)
Total	1,609,006	(100.0)	3,806,039	(100.0)	15,756,365	(100.0)

Clearly, there were substantial increases in each category. In terms of total wheat area in 1974, the semi-dwarfs—broken down by origin—represented the following proportions: introductions, 1.21 percent; selections, 4.47 percent; and crosses, 16.46 percent. Although 14 of the U.S. crosses extant in 1979 contained one or more Mexican parents, all of these varieties were released after 1974 and hence do not show up in the area figures.

Area of Individual Varieties

Changes in the area of the 69 semi-dwarf varieties reported in the 3 survey years are listed in table 5, divided on the basis of origin.[56] Gaines and Nugaines occupied over 1.6 million acres, or 99.7 percent of semi-dwarf area in 1964 (0 for Nugaines that year); nearly 2.5 million acres, or 66 percent in 1969; and nearly 2.2 million acres, or 14 percent in 1974. Nugaines gradually replaced Gaines. Between 1964 and 1969 the largest increases, aside from Nugaines, were for Blueboy and Sturdy. Between 1969 and 1974, the largest jumps (about 300,000 acres or more) were for: Bonanza, Bounty 208, Lark, WS-1809, Caprock, Era (the largest increase of any variety), Hyslop, Olaf, Paha, Palo Duro, Satanta, Springfield, Sturdy, and Twin. Decreases were reported for Blueboy, Gaines, and Red River 68.

As of 1974, the top 12 semi-dwarf varieties occupied 68.3 percent of the semi-dwarf area. The largest areas were occupied by Era (15.4 percent of semi-dwarf area), Nugaines (10.5 percent), and Sturdy (9.8 percent). The other nine leading varieties, in decreasing order of importance, were: Lark, Bounty 208, Hyslop, Satanta, Gaines, Palo Duro, Paha, Bonanza, and Chanute. (Lark, Bounty, and Bonanza were selections; the remainder were U.S. crosses.)

Of total area in 1974, 85.3 percent was composed of varieties developed by public agencies and 14.7 percent was composed of varieties released by private firms.

Area by Market Type

The varietal surveys broke the area down into six market types. These were the same as those listed in the Introduction and in tables 1 to 3, with the exception that the Soft White Spring and Soft White Winter wheats were combined into a White category.

The breakdown of these types is as follows for the 3 survey years:

Market Type	1964	1969	1974
		Acres (Percent[1])	
Hard Red Spring	5,139 (0.1)	396,479 (5.4)	6,639,509 (45.0)
Hard Red Winter	0	303,330 (0.9)	3,859,491 (10.6)
Soft Red Winter	0	479,625 (7.7)	776,360 (8.1)
White	1,603,867 (33.0)	2,626,605 (54.0)	3,995,139 (63.6)
Club (white)	0	0	479,301 (48.1)
Durum	0	0	6,565 (1.6)
Total	1,609,006 (2.9)	3,806,039 (7.0)	15,756,365 (22.1)

[1] The percentage figure in parentheses indicates proportion of total area of that market type planted to semi-dwarfs.

Table 5—Area Planted to Individual Semi-Dwarf Varieties Of Wheat in the United States 1964, 1969, and 1974 (In Acres)

Source/Variety	1964	1969	1974
INTRODUCTIONS			
Bluebird 2			87,686
Cajeme 71			130,604
INIA 66/INIA 66R[1]		2,018	242,985
Lerma Rojo 64	748	7,329	
Nadadores 63		962	12,235
Penjamo 62		14,903	68,000
Pitic 62	4,391	111,098	133,712
Prospur			377
Protor			15,453
Siete Cerros 66		50,162	157,248
Sonora 64		90,682	3,736
Super X		188	8,669
Yecora 70			358
Subtotal	5,059	277,342	861,063
SELECTIONS			
Anza			178,419
Bonanza		659	373,031
Bounty 208			786,735
Chaparral			24,200
Colano			24
Lark			791,261
Peak			15,304
Peak 72			13,650
Prodax			20
Produra			5,409
Profit 75			3,168
Red River 68		130,068	100,582
WS-1			1,330
WS-3			806
WS-6			21,493
WS-1616			400
WS-1651		1,447	40,424
WS-1809		10,405	728,839
WS-1812		27,359	19,753
WS-1859			2,854
WS-1877			76,109
Subtotal		169,938	3,183,811

Table 5—Area Planted to Individual Semi-Dwarf Varieties Of Wheat in the United States 1964, 1969, and 1974 (Continued) (In Acres)

Source/Variety	1964	1969	1974
CROSSES			
Blueboy		475,871	340,472
Blueboy II			59,368
Caprock			293,456
Chanute		1,224	342,067
Coker 68-15			165,496
Coker 68-19			70,932
Era		323	2,431,361
Fielder			970
Fletcher			6,922
Fremont			10,280
Gaines	1,603,867	1,043,435	533,175
Hyslop			680,216
Luke			63,101
Maricopa		4,037	
McDermid			9,680
McNair 1813			386
McNair 2203		59	5,247
McNair 4823			3,408
McNair 701			107,302
Norana			10,243
Nugaines		1,455,245	1,649,090
Olaf			296,432
Paha			479,301
Palo Duro			499,445
Pronto			80,387
Satanta		1,516	650,539
Shortana			4,548
Sprague			6,860
Springfield			314,385
Sturdy		300,590	1,538,365
TAM W-101			281,249
TAM W-103			3,627
Timwin		2,733	23,749
Twin			327,843
Wandell			350
Yorkstar		73,726	250,883
Yukon			170,356
Subtotal	1,603,867	3,358,759	11,711,491
Total	1,609,006	3,806,039	15,756,365

[1] INIA 66R is a reselection of INIA 66 and technically should be listed as a selection. The statistical reporting does not distinguish between the two.

In terms of the total 1974 semi-dwarf area, 42.1 percent was Hard Red Spring, 25.4 percent White, 24.5 percent Hard Red Winter, 4.9 percent Soft Red Winter, 3.0 percent Club, and negligible for Durum.

Clearly, the semi-dwarfs quickly started out as a significant portion of the White wheat area and moved up fast. They started out later for Club wheat, but increased quickly as a proportion of total area. They started out slowly for Hard Red Spring wheats, then expanded quickly between 1969 and 1974. They grew more slowly in the case of Hard Red Winter, Soft Red Winter, and, particularly, Durum wheat.

Area by State

The area of semi-dwarf wheat planted in individual States during the 3 survey years is presented in table 6. (The figure in parentheses indicates the area of semi-dwarfs as a proportion of the area of all varieties planted in that State.) The number of States represented grew from 18 in 1964 to 39 in 1969, and to 42 in 1974.

The largest areas in absolute terms as of 1974 were found in Minnesota (15.3 percent of total semi-dwarf area), North Dakota (13.4 percent), and Washington (13.3 percent). Other leaders, in decreasing order of area, were; Texas, Oklahoma, Kansas, Idaho, Oregon, South Dakota, and California. The total semi-dwarf area in the four Midwestern States of Ohio, Indiana, Illinois, and Missouri was only 114,000 acres, consisting principally of Blueboy and Blueboy II. The area in Nebraska, an important wheat State, was negligible.

As a proportion of total wheat area in a State in 1974, the semi-dwarfs were highest in the Southwestern States of Arizona (98.8 percent), California (89.6 percent), and Nevada (88.8 percent). Other leading producing States, in decreasing order, were: Minnesota, Oregon, and Idaho. Among the smaller producers, Florida, New York, and South Carolina had relatively high proportions. Despite the rather large areas of semi-dwarfs in some of the States noted in the preceding paragraph, their proportions of semi-dwarfs were moderate (in percent): North Dakota, 20.5; Texas, 28.4; Oklahoma, 16.5; Kansas, 9.4; and South Dakota, 24.9. The proportion in the four Midwestern States was only 1.8 percent.

Major changes in absolute area between survey years were as follows. Between 1964 and 1969, the increases were largest (more than 100,000 acres) in (in decreasing order): Washington, California, North Carolina, and Idaho. From 1969 to 1974, the increases were largest (more than 500,000 acres) in (in decreasing order): Minnesota, North Dakota, Texas, Oklahoma, Kansas, South Dakota, Washington, California, and Idaho. A substantial decrease was recorded in North Carolina from 1969 to 1974 because of a decline in the use of Blueboy due to disease problems (leaf rust and powdery mildew).

Table 6—Area Planted to Semi-Dwarf Varieties of Wheat in Individual States, 1964, 1969, and 1974

State	1964	1969	1974
		Acres (Percent[1])	
1. Alabama		16,888 (14.8)	69,981 (37.8)
2. Arizona	26 ([2])	66,549 (82.2)	246,946 (98.8)
3. Arkansas		32,361 (8.5)	36,955 (7.9)
4. California	6,653 (1.8)	222,308 (57.1)	738,133 (90.5)
5. Colorado	449 ([2])	6,854 (.2)	71,726 (2.5)
6. Delaware		1,667 (7.6)	6,626 (18.9)
7. Florida			42,000 (80.8)
8. Georgia		11,641 (11.8)	47,866 (22.3)
9. Idaho	302,285 (24.4)	454,030 (38.9)	951,267 (61.4)
10. Illinois	423 ([2])	309 ([2])	79,251 (.4)
11. Indiana			129 ([2])
12. Iowa		37 ([2])	610 (1.4)
13. Kansas	473 ([2])	2,740 ([2])	1,132,191 (9.4)
14. Kentucky	158 ([2])	15,644 (6.4)	23,602 (5.1)
15. Louisiana		5,811 (7.1)	612 (.8)
16. Maryland		12,366 (9.8)	28,178 (17.8)
17. Michigan	317 ([2])	4,211 (.6)	80,187 (8.4)
18. Minnesota		25,351 (3.0)	2,409,622 (84.3)
19. Mississippi		15,215 (9.9)	69,627 (35.7)
20. Missouri		6,731 (.6)	30,749 (2.1)
21. Montana	20,630 (.5)	31,372 (.8)	321,469 (6.4)
22. Nebraska	140 ([2])		8,451 (.3)
23. Nevada	1,189 (5.7)	7,882 (60.6)	17,768 (88.8)
24. New Jersey	2 ([2])	91 (.2)	13,641 (22.7)
25. New Mexico	275 ([2])	4,175 (1.4)	31,905 (7.4)
26. New York	2,762 ([2])	69,404 (35.4)	170,015 (77.3)
27. North Carolina		178,381 (78.6)	72,098 (22.2)
28. North Dakota		85,896 (1.2)	2,117,799 (20.7)
29. Ohio		613 ([2])	4,189 (.3)
30. Oklahoma		18,994 (.4)	1,151,797 (16.5)
31. Oregon	429,041 (53.0)	431,790 (51.8)	925,000 (72.4)
32. Pennsylvania		1,056 (.3)	44,137 (12.6)
33. South Carolina		33,658 (38.2)	96,922 (53.8)
34. South Dakota		40,863 (1.9)	828,345 (24.9)
35. Tennessee		47,621 (17.4)	33,893 (8.6)
36. Texas	2,520 ([2])	294,810 (7.1)	1,589,400 (28.4)
37. Utah	8,351 (3.7)	29,374 (12.1)	77,070 (24.2)
38. Virginia		99,173 (56.7)	57,988 (19.3)
39. Washington	833,312 (39.8)	1,525,060 (52.8)	2,098,980 (64.0)
40. West Virginia		1,965 (11.6)	3,735 (17.8)
41. Wisconsin		3,076 (6.5)	22,107 (26.6)
42. Wyoming		72 ([2])	3,396 (1.2)
Total	1,609,006 (2.9)	3,806,039 (7.0)	15,756,365 (22.1)

[1] Percent refers to proportion of total wheat area in State represented by semi-dwarfs.
[2] Less than 0.1 percent.

The introductions from Mexico were heavily concentrated in Arizona and California. In 1974, 85.3 percent of the total area of semi-dwarf introductions was found in these two States. The introductions represented 68.9 percent of the total wheat area in the two States. If selections from Mexican crosses are added, the total use of Mexican varieties represented 86.8 percent of the total wheat area (82.2 percent in Arizona and 88.2 percent in California).

Varieties developed in one State are also commonly planted in other States (in more general terms, this is referred to as the pervasiveness of agricultural research). Of the 9.6 million acres planted in 1974 to crosses released by public agencies, 38.6 percent (3.7 million acres) represented varieties developed in another State. Among the major varieties, the proportions were particularly high for: Blueboy (North Carolina), 90.6 percent; Caprock (Texas), 72.4 percent; TAM W-101 (Texas), 71.6 percent; and Twin (Idaho), 65.8 percent. Blueboy was raised in 21 States, far more than any other variety. Virtually all States "borrowed" varieties developed by public agencies in other States.

Partial Estimates of Planted Area, 1979

As noted earlier, a wheat varietal survey was conducted in 1979, but the national summary report may not be available for awhile (the 1969 report carried a publication date of May 1972; the 1974 report a date of June 1978).[57] Many of the States, however, have issued summary reports of their findings. These reports have some limitations, chiefly because of the summary nature of the reporting. The varietal reporting is less detailed than in the national report (more are grouped in the category marked "other") and the area is sometimes given only as a rounded percentage of total rather than as an actual area.

While a complete and precise tally will not be available until the national report is issued, some trends may be discerned. Available State data (including a 1978 estimate for Oregon), as of December 1979, are summarized in table 7.[58] The major wheat States not included are Idaho and Washington, both of which have high proportions of their area planted to semi-dwarfs. It may be seen that the semi-dwarf area in the 32 States totaled nearly 16.98 million acres in 1979, or 26.2 percent of the total planted area in these States.[59] The 1979 semi-dwarf area increased nearly 4.56 million acres or 36.7 percent over the 1974 total. The increase was largest, in absolute terms, in Oklahoma (+1.8 million acres), followed by North Dakota (+1.2 million acres), and Montana (+0.95 million acres). Substantial increases were also recorded in Kansas, Texas, and South Dakota. The increase as a proportion of total area also was largest in Oklahoma (+26.2 percent), followed by Montana, Georgia, and North Dakota. There were, on the other hand, modest declines in several mid-Atlantic, Southern, and Midwestern states, chiefly because of decreased use of Blueboy (due to previously noted disease problems).

It is difficult, as noted earlier, to make up a precise compilation of individual varieties, but some indication of changes in leading varieties can be secured.

Table 7—Estimated Area Planted to Semi-Dwarf Varieties of Wheat in 32 States, 1974 and 1979

State	1974		Preliminary 1979[1]	
		Acres (Percent)		
1. Arizona	246,900	(98.8)	117,800[2]	(94.2)
2. Arkansas	37,000	(7.9)	18,500	(3.5)
3. California	738,100	(90.5)	742,800	(93.4)
4. Colorado	71,700	(2.5)	82,100[2]	(2.6)
5. Delaware	6,600	(18.9)	1,600	(4.9)
6. Georgia	47,900	(22.3)	69,400	(36.5)
7. Illinois	79,300	(.4)	0	(0)
8. Indiana	100	(–)	0	(0)
9. Iowa	600	(1.4)	0	(0)
10. Kansas	1,132,200	(9.4)	1,512,500	(12.5)
11. Kentucky	23,600	(5.1)	0	(0)
12. Maryland	28,200	(17.8)	4,300	(3.5)
13. Michigan	80,200	(8.4)	93,600[2]	(11.7)
14. Minnesota	2,409,600	(84.3)	2,399,500	(89.2)
15. Mississippi	69,600	(35.7)	10,100	(6.3)
16. Missouri	30,700	(2.1)	0	(0)
17. Montana	321,500	(6.4)	1,273,600	(21.5)
18. Nebraska	8,500	(.3)	21,000	(.7)
19. New Jersey	13,600	(22.7)	900[2]	(2.2)
20. New York	170,000	(77.3)	123,800[2]	(72.8)
21. North Carolina	72,100	(22.2)	76,100	(32.4)
22. North Dakota	2,117,800	(20.7)	3,300,500	(33.3)
23. Ohio	4,200	(.3)	24,000	(1.8)
24. Oklahoma	1,151,800	(16.5)	2,989,000	(42.7)
25. Oregon	925,000	(72.4)	(940,000)[3]	(81.7)[3]
26. South Carolina	96,900	(53.8)	65,100	(54.3)
27. South Dakota	828,300	(24.9)	1,137,200	(33.8)
28. Tennessee	33,900	(8.6)	8,000	(2.0)
29. Texas	1,589,400	(28.4)	1,938,900	(33.4)
30. Virginia	58,000	(19.3)	19,400	(9.0)
31. Wisconsin	22,100	(26.6)	13,700[2]	(25.4)
32. Wyoming	3,400	(1.2)	2,600	(.8)
Total	12,418,800	(19.1)	16,976,000[2]	(26.2)

[1] Figures reported for 1979 do not include areas of semi-dwarfs not reported separately by the States. Small additional areas may be grouped in "other" or "variety not reported" categories. Data for semi-dwarfs in "other" category, however, are included for California, Georgia, and South Carolina.

[2] Derived by applying semi-dwarf percentage reported by State to total State area of all wheat varieties planted as reported in *Acreage*, USDA, Crop Reporting Board, June 28, 1979, p. B-8.

[3] Estimate for 1978.

In the case of the seven States with the largest semi-dwarf area in 1979 (excluding Idaho and Washington, for which data are not yet available), the top five varieties, in decreasing order of importance, were (with area in millions of acres in parentheses): Olaf (3.0), TAM W-101 (2.3), Era (1.9), Sturdy (0.69), and Prodax (0.66). In 1974, Era was the leading semi-dwarf variety nationally, and Sturdy ranked third.

What is the overall situation apt to be when it is possible to add data for the other 10 States for 1979? The semi-dwarf proportion will probably be slightly higher than the present average for the 32 States. Of the other 10 States, the semi-dwarf areas were already high in Washington and Idaho in 1974 (64.0 and 61.4 percent, respectively) and were relatively unimportant in the remaining 8 States. If the 10 States only maintained the *same* semi-dwarf area or the same proportion of overall area as in 1974, the total semi-dwarf proportion for the 42 States would be about 28.5 percent. If the semi-dwarf area were to have *risen* by 10 percent, the total semi-dwarf proportion for the 42 States would be 29.0 percent. Allowance for semi-dwarf varieties presently reported under the category of "other" would raise the proportion a bit more. Therefore, if one had to make a single estimate for 1979 at this point, a figure of about 29.0 percent, or slightly more than 20 million acres, would not seem unreasonable.

* * *

Without question, the semi-dwarfs have attained a significant place in wheat production in the United States. This role may be expected to expand—both in terms of extent and impact—as improved semi-dwarfs are developed and as interest in increasing yields continues.

References and Notes

*J. Allen Clark, "Improvement in Wheat," *Yearbook of Agriculture, 1936*, USDA, p. 207.

[1] L. W. Briggle and O. A. Vogel, "Breeding Short-Stature, Disease-Resistant Wheats in the United States," *Euphytica*, Supplement No. 1, 1968, pp. 107-110. Details on Arthur wheat, which is not mentioned by Briggle and Vogel, are provided in F. L. Patterson, R. L. Gallum, and J. J. Roberts, "Registration of Arthur Wheat," *Crop Science*, Nov.-Dec. 1974 (Vol. 14, No. 6), p. 910.

[2] S. C. Salmon, O. R. Mathews, and R. W. Leukel, "A Half Century of Wheat Improvement in the United States," *Advances in Agronomy*, Vol. V, Academic Press, New York, 1953, pp. 86, 90-92, 110.

[3] This section is based, except as otherwise noted, on Dana G. Dalrymple, *Development and Spread of High-Yielding Varieties of Wheat and Rice in the Less Developed Nations*, USDA/OICD, FAER 95, September 1978 (6th edition), pp. 12, 22-23.

[4] A Korean researcher has suggested that Daruma was selected from a Korean variety known as Anznbaengi Mill (cripple wheat) (Chang Hwan Cho, Wheat Breeder, Wheat and Barley Research Institute, Office of Rural Development, Suweon). Daruma was one of 1,000 wheats studied by USDA from 1895 to 1897 and was one of 245 briefly listed by Carleton; he noted that "The earliest ripening wheats are often dwarfed and come principally from India, Australia, and Japan." (Mark Alfred Carleton, *The Basis for Improvement of American Wheats*, USDA, Division of Vegetable Physiology and Pathology, Bulletin No. 24, 1900, pp. 46, 47, 62-63.) USDA has received seed of Shiro-Daruma (P.I. 325845), Aka-Daruma (P.I. 325843), and Fultz-Daruma (P.I. 325844).

[5] This account is based on letters from: T. Gotoh, Wheat Breeder, Tohoku National Agricultural Experiment Station, Morioka, Japan, Feb. 9, 1978; and Chang Hwan Cho, *op. cit.*, Mar. 15, 1978, Aug. 16, and Sept. 21, 1979. (Aka Daruma x Glassy Fultz) was the male parent and Kanred was the female parent of Suweon 85.

[6] Based on letters from Gotoh, Feb. 21, Apr. 4, 1979. The ancestry of Hon-Iku 49 reported here differs from that reported by Anton C. Zeven and N. Ch. Zeven-Hissink in *Genealogies of 14000 Wheat Varieties*, CIMMYT, 1976, p. 48.

[7] The standard accounts of this process are: Louis P. Reitz, "Short Wheats Stand Tall," *Science for Better Living, The Yearbook of Agriculture, 1968*, USDA, p. 236; and L. P. Reitz and S. C. Salmon, "Origin, History, and Use of Norin 10 Wheat," *Crop Science*, Nov.-Dec. 1968 (Vol. 8, No. 6), p. 686.

[8] Information provided by June Jones, Plant Genetics and Germplasm Institute, AR/SEA, USDA, Beltsville.

[9] Reitz, *op. cit.*, p. 236; telephone conversation with Dr. Reitz, Mar. 15, 1979.

[10] Reitz and Salmon, *op. cit.*, p. 686.

[11] Reitz, *op. cit.*, p. 237. Also see Torao Gotoh, "Semi-dwarf Norin 10 Wheat and Its Contribution to the Progress of Wheat Breeding," *Gamma-Field Symposia*, IRB (Institute for Radiation Breeding, Japan), No. 16 ("Use of Dwarf Mutation"), 1977, pp. 85-100.

[12] For his work on wheat, Vogel was subsequently to receive the Edward W. Browning Award of the American Society of Agronomy in 1972 and the National Medal of Science for 1975 (Vogel was one of 15 scientists to receive the award from President Ford in October 1976).

[13] Brevor was developed from a cross between Brevon (Turkey/Florence//Fortyfold/Federation) and an unnamed cross between Brevon's parents and Oro. The original cross was made in 1938 and the variety was released in the fall of 1949. It was developed cooperatively by USDA and the Washington Agricultural Experiment Station. (L. W. Briggle and L. P. Reitz, *Classification of Triticum Species of Wheat Varieties Grown in the United States*, USDA, Technical Bulletin No. 1278, May 1963, p. 64.)

[14] Letter from Dr. Orville A. Vogel, Pullman, Washington, August 24, 1979. Nagamitso also made crosses of Norin 10 with Baart for Dr. Elliot. Vogel notes that "since the Norin 10 plants produce no pollen in the greenhouse, Dick could only make the cross [with] Norin 10 as the female parent."

[15] O. A. Vogel, J. C. Craddock, C. E. Muir, E. H. Everson, and C. R. Rohde, "Semidwarf Growth Habit in Winter Wheat Improvement for the Pacific Northwest," *Agronomy Journal*, February 1956 (Vol. 48, No. 2), pp. 76-78. Also telephone conversations with: Dr. Vogel, Dr. Craddock, Dr. Everson, and Dr. Elliott (all March 1979). Popular accounts, containing some errors, are: Jack Jenkins, "Orville Vogel—Wheat Breeder," *Farm Quarterly*, Summer 1967 (Vol. 22, No. 3), pp. 121-122; R. D. Wennblom and Glenn Lorang, "Short Wheats for Everybody," *Farm Journal*, July 1969, pp. 16, 27.

[16] Dalrymple, *op. cit.* (1978), p. 15.

[17] E. G. Heyne and L. G. Campbell, "Experiments with Semidwarf Wheats in Kansas," *Transactions of the Kansas Academy of Science*, Summer 1971 (Vol. 74, No. 2) (published April 7, 1972), p. 147.

[18] K. B. Porter, I. M. Atkins, et al., "Evaluation of Short Stature Winter Wheats (*Triticum aestivum L.*) for Production Under Texas Conditions," *Agronomy Journal*, July-Aug. 1964 (Vol. 56, No. 4), p. 393. Atkins had previously done considerable research on lodging in wheat (see *Journal of Agricultural Research*, USDA: Jan. 15, 1938, Vol. 56, No. 2, pp. 99-120; Jan. 15, 1948, Vol. 76, No. 2, pp. 53-72). Atkins will review the research on semi-dwarf wheat in Texas in detail in *A History of Small Grain Crops in Texas . . . 1582-1976*, Texas Agricultural Experiment Station, B-1301, in press.

[19] Neal F. Jensen, "Registration of Yorkstar Wheat," *Crop Science*, Sept.-Oct. 1968 (Vol. 8, No. 1), pp. 641-642. The Brevor/Norin selection utilized was obtained from Vogel.

[20] A. D. Day, R. K. Thompson, and F. M. Carasso, "Registration of Maricopa Wheat," *Crop Science*, July-Aug. 1967 (Vol. 7, No. 4), p. 405. Selection 14 from Washington was utilized.

[21] F. H. McNeal, M. A. Berg, and M. G. Klages, "Evaluation of Semidwarf Selections From a Spring Wheat Breeding Program," *Agronomy Journal*, December 1960 (Vol. 52, No. 12), p. 710. Selection 14 from Washington was utilized.

[22] Charles F. Murphy, "Registration of Blueboy Wheat," *Crop Science*, Jan.-Feb. 1967 (Vol. 7, No. 1), p. 82. Norin 10/Brevor was utilized.

[23] R. G. Shands, "Registration of Timwin Wheat," *Crop Science*, Nov.-Dec. 1974 (Vol. 14, No. 6), p. 908. Selection 10 from Washington was utilized.

[24] Letter from C. O. Qualset, Dept. of Agronomy and Range Science, University of California, Davis, Sept. 10, 1979. The research was begun by C. W. Schaller but was largely "shelved" with the introduction of the Mexican semi-dwarfs in the early 1960's.

[25] Letter from Dr. E. H. Everson, Professor of Crop Science, Michigan State University, East Lansing, September 7, 1979 (Everson heads the soft wheat breeding program); O. A. Vogel, "Registration of Gaines Wheat," *Crop Science*, Jan.-Feb. 1964 (Vol. 4, No. 1), pp. 116-117. The full pedigree is depicted in graphic form in John W. Schmidt, "Wheat—Its Role in America's Heritage," *Agronomists and Food: Contributions and Challenges*, American Society of Agronomy, Special Publication No. 30, 1977, p. 51 (Fig. 5).

[26] B. R. Bertramson, "The Making of a New Variety" (talk to the Washington State Crop Improvement Association, Spokane, Dec. 1, 1970), Dept. of Agronomy and Soils, Washington State University, Pullman, p. 1.

[27] Vogel, *op. cit*; Wennblom and Lorang, *op. cit.*, p. 27.

[28] O. A. Vogel and C. J. Peterson, "Registration of Nugaines Wheat," *Crop Science*, July-Aug. 1974 (Vol. 14, No. 4), p. 609; Briggle and Vogel, *op. cit.*, p. 120.

[29] O. A. Vogel, R. E. Allan, and C. J. Peterson, "Plant and Performance Characteristics of Semidwarf Winter Wheats Producing Most Efficiently in Eastern Washington," *Agronomy Journal*, July-Aug. 1963 (Vol. 55, No. 4), pp. 397-398.

[30] Letter from Qualset, *op. cit.*; C. O. Qualset, et al., "Breeding Success With Spring Wheat Germplasm," *California Agriculture*, September 1977 (Vol. 31, No. 9), pp. 26-27.

[31] The year of release noted here is only approximate. Definitions of what entails release vary; while public announcements may be made when seed is sent to certified growers for multiplication, some varieties may be announced either before or after this step. Hence some time may elapse between date of announcement and availability of seed for farmer use. The usual practices of public agencies and private firms may differ.

[32] Murphy, *op. cit.*

[33] Day, et al., *op. cit.*

[34] I. M. Atkins, K. B. Porter, and O. G. Merkle, "Registration of Sturdy Wheat," *Crop Science*, July-Aug. 1967 (Vol. 7, No. 4), p. 406.

[35] Shands, *op. cit.*

[36] Jensen, *op. cit.*

[37] G. Vazquez and W. W. Roath, "Registration of Chaparral Wheat," *Crop Science*, Jan.-Feb. 1972 (Vol. 12, No. 1), p. 129.

[38] Zeven and Zeven-Hissink, *op. cit.*, pp. 89, 107; *CIMMYT Review, 1975*, p. 97; C. I. 14193 card, SEA/USDA.

[39] J. D. Prato, et al., "Two New Wheat Varieties From Mexico . . . Siete Cerros 66—INIA 66," *California Agriculture*, December 1968 (Vol. 22, No. 12), p. 6.

[40] For details on these varieties, see *Crop Science* as follows: Arrow, July-Aug. 1973 (Vol. 13, No. 4), p. 495; and Guide, Jan.-Feb. 1971, (Vol. 11, No. 1), p. 138.

[41] Even then the unpublished records are not always complete. An important example is provided by the varieties Angus, Era, Fletcher, Kitt, and Wared. All obtain their semi-dwarf character through a selection from the Montana AES and labelled III-58-4 at the Minnesota AES. In the Minnesota pedigree book, however, the only information for this selection is "Montana Row Number 839;" the year is not given. This is not enough information for the Montana AES to document the precise parentage, though it is thought to be Norin 10/Brevor 14/ /Centana. (Based on correspondence and phone conversations with R. H. Busch, R. E. Heiner and Harry McNeal.)

[42] One particularly involved case was Roland, developed in Illinois. The semi-dwarf characteristic was derived from a line from New York State (Cornell). This line was not particularly short, and it was necessary to go back through the Cornell records for six generations to track down the Norin 10 ancestry ("from Vogel, 9/8/52"). (I am indebted to Mark Sorrells for this review.)

[43] Information on these varieties may be obtained as follows: Argee, Wisconsin AES, Plant Variety Protection No. 7800016, Sept. 20, 1978; Bannock, *Crop Science*, Mar.-Apr. 1973 (Vol. 13, No. 2), p. 288; Potomac, *Crop Science*, July-Aug. 1978 (Vol. 18, No. 4), pp. 694-695.

[44] All four varieties have Etoile de Choisy in their ancestry. It is a descendant, through Ardito, of the Japanese semi-dwarf variety Akahomugi (the latter two varieties are discussed by Dalrymple, *op. cit.* (1978), pp. 11, 13). The short stature of these varieties, however, is believed to be due to a natural mutant (based on telephone conversations with Dr. Charles Hayward, Dept. of Cereal Seed Breeding, Pioneer Seed Co., Hutchinson, Kansas, Jan. 26, 1979, Apr. 17, 1979). Information on Hart is provided in *Crop Science*, Nov.-Dec. 1977 (Vol. 17, No. 6), p. 980. S-76 to S-78 were developed by Dr. Hayward; S-76 carries Plant Variety Protection (PVP) No. 7600065, Oct. 29, 1976; a PVP application (No. 7800007) is pending for S-78.

[45] Reitz and Salmon, *op. cit.*, (1968), p. 687; Briggle and Vogel, *op. cit.* (1968); and Jensen, *op. cit.*, pp. 641-642.

[46] Letter from Kenneth L. Goertzen, Seed Research Inc., Scott City, Kansas, Mar. 5, 1979.

[47] Zeven and Zeven-Hissink, *op. cit.*, pp. 48, 75.

[48] Letter from Gotoh, *op. cit.*

[49] Based on comparative height figures reported in Plant Variety Protection applications (both were reported shorter than Blueboy, and 68-15 was also reported shorter than Penjamo 62). Reitz classifies both varieties as having semi-dwarf plant height (L. P. Reitz, *Wheat in the United States*, USDA, Agricultural Research Service, Agricultural Information Bulletin 386, February 1976, p. 7, fn. on p. 10).

[50] The published pedigree of McNair 4823 is Dual/2/Chancellor/T. hybrid. Chancellor/T. hybrid is Coker 55-3 (C.I. 13250). The cross with Dual was made by the South Carolina AES; selection and testing was done by McNair. T. hybrid was developed by J. W. Taylor of USDA, Beltsville from the following cross: Trumbull^2/Red Wonder/Steintim (C.I. 12667); Steintim in turn represents a cross of *T. timopheevi* and Steinwedel. None of these varieties is a known source of dwarfism—though Steinwedel, of Australian origin, was one of a group of early maturing varieties, including Daruma, which were "often dwarfed" in a series of USDA tests from 1895 to 1897 (Carleton, *op. cit.* ("Basis"),

pp. 62-63). One person involved in the original cross (Dr. Wilburt Byrd of the South Carolina AES) recalls that it used to throw off some dwarf rosetted plants, which sometimes happens when a wide cross such as was involved in developing Steintim is involved. (Helpful comments on this matter were provided by Drs. L. W. Briggle of AR/USDA, Howard Harrison of Coker's Pedigreed Seed Co. and Cal Newton of McNair Seed Co.)

[51] Telephone conversation with Bill Corpstein, Western Plant Breeders (Valley Seed Co.), Phoenix, Arizona, Nov. 30, 1979. This technique was previously utilized for barley by Dr. R. T. Ramage, a USDA scientist stationed at the University of Arizona, Tucson. For further information, see R. K. Thomson and K. C. Shantz: "Male-Sterile Facilitated Recurrent Selection," *Annual Wheat Newsletter*, 1977 (Vol. 23), pp. 65-67; "Registration of MSFRS Wheat Germplasm Composite Crosses A and B-76," *Crop Science*, July-Aug. 1978 (Vol. 18, No. 4), p. 698.

[52] The 10 varieties are Torim 73, Cocoraque 75, Salamanca 75, Zaragoza 75, Nacozari 76, Pavon 76, Tezopaco 76, Pima 77, Hermosillo 77, and Jauhara 77 (*CIMMYT Review, 1978*, p. 62). None as yet have been assigned plant introduction numbers.

[53] Long-term analyses of the data from these surveys have been provided by: S. C. Salmon, et al. in "A Half Century of Wheat Improvement in the United States," *Advances in Agronomy*, Vol. V, Academic Press, 1953, pp. 1-151; F. R. Gomme, "Wheat Varieties Over the Years," *Wheat Situation*, USDA, Economic Research Service, August 1967, pp. 17-19, 43; Louis P. Reitz, "60 Years of Wheat Cultivar History in the United States," *Annual Wheat Newsletter*, June 1979 (Vol. 25), pp. 12-17.

[54] The data reported in this section were obtained from the following two reports:

- L. P. Reitz, K. L. Lebsock and G. D. Hasenmyer, *Distribution of the Varieties and Classes of Wheat in the United States in 1969*, USDA, Agricultural Research Service, Statistical Bulletin No. 475, May 1972, 70 pp. (Contains summary of 1964 data.)
- L P. Reitz and W. G. Hamlin, *Distribution of the Varieties and Classes of Wheat in the United States in 1974*, USDA, Science and Education Administration, Statistical Bulletin No. 604, June 1978, 98 pp.

[55] In a listing of adapted varieties by major type and producing region in 1974, Reitz indicated (by means of a footnote) 39 varieties of semi-dwarf plant height. All are classified as semi-dwarf in the report. On the other hand, 28 semi-dwarf varieties (as defined here) were not listed by Reitz. Most were planted on relatively small areas: major exceptions (over 100,000 acres) were Red River 68, Palo Duro, TAM W-101, and Yukon. Yorkstar was listed but not noted as having semi-dwarf plant height. (Reitz, *op. cit.* (1976), pp. 7-10.)

[56] The table includes WS-1651 for 1974, even though such a variety was not listed in the USDA variety summary. The summary, however, did include a WS-1657 which does not exist. An error was made in punching the data and WS-1657 should have been entered as WS-1651. (I am grateful to Larry Dosier of USDA for resolving this question.)

[57] Estimates have been filed by all but three States—Idaho, Oregon, and Washington. These States, however, do not plan to submit their 1979 varietal estimates until they are checked with a production survey to be conducted in the spring of 1980.

[58] The 32 States reported represented 91.2 percent of the total wheat area planted in 1974 and 90.9 percent of the 1979 area. The semi-dwarf area in the 32 States represented 78.8 percent of the total semi-dwarf area in 1974.

[59] If the definition of semi-dwarfs is relaxed to include Hart, S-76, and S-78, the total semi-dwarf area in 1979 in the 32 States would rise by 0.29 million acres to 17.26 million acres or to 26.7 percent.

IV. SEMI-DWARF RICE VARIETIES

Rice improvement requires years of constant, hard, dirty work, with many failures and rare successes. Perhaps one cross in 500 or more results in a new variety, and tens of thousands of lines are evaluated and discarded for every one that reaches the farmers' fields.

–Jennings, Coffman, and Kauffman, 1979*

Semi-dwarf rice varieties made a later appearance in American agriculture than did semi-dwarf wheat varieties. In fact, the first semi-dwarf rice variety was not introduced for commercial use until the mid-1970's, and since that time only a few other varieties have been released. Semi-dwarf development and use, however, is gaining rapid momentum.

As in the case of wheat, the principal advantage of the semi-dwarf varieties is their resistance to lodging and their subsequent yield responsiveness to fertilizer. All but one (Calrose 76) of the semi-dwarf rice varieties used in the United States are the products of hybridization—hence, the use of the term "introduction" will also refer to foreign crosses. And as with wheat, the semi-dwarfs were preceded by a number of improved varieties with short stature.

Development[1]

There has long been interest in developing greater resistance to lodging in rice in the United States. This interest stemmed in part from the fact that rice was usually fertilized and harvested with mechanical equipment. Lodging led to difficulties in harvesting and to poor milling quality.

Short-Strawed Varieties

The importance of short straw was not immediately recognized. Had it been, one promising variety was readily at hand. Shinriki (P.I. 8300), one of the Japanese varieties introduced by Knapp in 1902, had relatively short, stiff straw. The average height over a 9-year period from 1913 to 1921 at Crowley, La., was 37 inches (94 centimeters), well below any other variety tested, and in the semi-dwarf height range. Prior to 1910 it was the best known of the Japanese varieties grown in Louisiana and Texas. Ironically, in the words of a 1922 report, the variety was:

> . . . not grown on a large acreage in the United States mainly because its culms (stems) are *too short* to be cut with a binder without the loss of some grain, even when the plants produce a normal yield.[2]

After World War II, attention began to be given to plant height. The 1946 Annual Report of the Texas Agricultural Experiment Station indicated that one of the objectives of the rice improvement program was "shorter, stiffer strawed varieties."[3] In 1953, H. M. Beachell, a USDA employee stationed in Texas, wrote:

> Each year more rice farmers are using higher rates of high analysis fertilizer and also following rotation systems that involve improved pasture and other soil building crops. Such practices are resulting in increased field yields of rice but are increasing the likelihood of lodging of the rice crop. Shorter, sturdier strawed varieties may be the answer to this problem.

He reported the results of yield experiments with two short-strawed varieties and concluded that "short-strawed types probably can be developed without sacrificing yield."[4] Subsequently, according to Athwal:

> Beachell and Scott (1963) reported that, in order to breed for the desired plant type, a search for dwarf strains with small stems and narrow leaves had been in progress for several years but that the strains available until then had no practical value.

Beachell joined the staff of the International Rice Research Institute in 1963 and was partly responsible for the semi-dwarf varieties developed there.[5]

T. H. Johnston, a USDA rice breeder stationed in Arkansas, traced the development of short straw varieties in these terms in 1972:

> Considerable lodging resistance has been available in long-grain rice since the release of Bluebonnet in 1944 and Bluebonnet 50 and Century Patna 231 in 1951 . . . However, as N-fertilization rates were increased in efforts to raise grain yields, increased lodging followed. Bluebelle, released from Beaumont (Texas) in 1965, and Starbonnet, released from Stuttgart, Arkansas, in 1967, both had shorter straw and more lodging resistance than Bluebonnet 50. Growers continued to increase N-fertilizer rates in their push for higher grain yields so that sources of even shorter stature and increased lodging resistance are needed.[6]

During the 1970's, a number of such short varieties have been released.[7] Those with the shortest straw and highest yields to date in the Southern States are Nortai (Arkansas AES and USDA/ARS, 1972), Brazos (Texas AES and USDA/ARS, 1974), and Mars (Arkansas AES and USDA/SEA/AR, 1977).[8] In experimental trials over the 1971-75 period in Arkansas, both Nortai and Brazos averaged only 94 centimeters (37 inches) in height and produced high yields (6,294 and 6,048 pounds per acre, respectively).[9] Mars is slightly (5 centimeters) taller than Brazos, but yields about the same as both Brazos and Nortai.

Shorter height and reduced lodging also have been obtained in the South through the use of split applications of nitrogen fertilizer. This technique was developed in Arkansas in the mid-1960's.[10] Up to 50 percent of the nitrogen is applied early in the season and the remainder is applied in two increments at midseason.[11] The result is that relatively high yields can be obtained with little lodging from varieties of moderate plant height and relatively stiff straw. The technique is widely adopted in Arkansas and in other areas in the South.[12]

The combination of productive short-strawed varieties and split fertilizer applications has lessened the urgency to develop semi-dwarf varieties in the Southern States. Moreover, breeding programs give high priority to improving other factors, particularly cooking and milling quality (see Appendix B). Semi-dwarfs from abroad have not ranked high in these latter factors and, hence, have not been directly used except for industrial purposes. They are, however, used in breeding programs—especially in California.

Varietal Introduction

The first modern semi-dwarf to be introduced was Taichung Native 1 (TN-1), an indica. It was developed in Taiwan from a cross between Dee-geo-woo-gen and Tsai-yun chung. The first cross was made in 1949, the selection was named in 1956, and officially released in 1960.[13] TN-1 was introduced into the United States in February 1961 (P.I. 271672) and was used in the cooperative breeding program in Texas in 1962, and subsequently in other States. Although very high yielding, its grain quality was not up to U.S. standards; thus, it was not considered suitable for direct use. It was, however, widely utilized as a parent in experimental breeding programs.[14]

When the International Rice Research Institute began to produce new indica varieties, such as IR-8 and IR-5, these too were introduced into the United States. Both were received by USDA in March 1966 (IR-8, P.I. 312627; IR-5, P.I. 312733). As with TN-1, their grain quality proved unsuitable for direct use but they were also widely utilized in breeding programs.[15]

All foreign rice introductions must be grown for one generation in a plant quarantine nursery isolated from commercial rice growing areas to ensure against accidental release of new diseases and insect pests. Through 1969, this was done by USDA in a greenhouse in Beltsville, Md. That year, a second quarantine nursery was opened at the University of California's Imperial Valley Field Station near El Centro. Much of the material cleared through this station, and subsequently tested in California, is from IRRI.[16]

Irradiation[17]

Calrose 76 (C.I. 9966), a short-statured medium-grain japonica mutant, was developed at the University of California Rice Research Facility, Davis, by irradiation of Calrose seed. Calrose 76 is similar to Calrose except that its straw is about 25 centimeters shorter at maturity—averaging 87 centimeters (34 inches) over a 3-year period. Compared with CS-M3 (a tall check cultivar that was expected to replace Calrose),[18] Calrose 76 was about 35 centimeters (13.8 inches) shorter (plate 8), considerably more resistant to lodging, and much more responsive to high levels of fertilizer (see figure 7, p. 85). Over 3 years of yield tests (1975-77), Calrose 76 yielded 13 percent more than CS-M3.

Plate 8. Calrose 76, the first semi-dwarf variety released in California, is about 35 centimeters (13.8 inches) shorter than the tall check variety, CS-M3.

Calrose was first irradiated in 1969. Selection and testing followed under the experimental label of D7. Calrose 76 was jointly released in June 1976 by USDA, the California AES, and the California Cooperative Rice Research Foundation. Genetic studies have shown that Calrose 76, like other semi-dwarfs, carries a single recessive gene for short stature.

Hybridization

VARIETIES RELEASED. As of late 1979, four semi-dwarf progeny of hybrid crosses had been released for commercial use. (A short variety with a semi-dwarf parent had also been introduced.) Two of the semi-dwarf varieties have well-known semi-dwarfs in their parentage, and two have a variety developed from irradiation (Calrose 76). One was developed in Louisiana and three were developed in California. All are medium-grain.

We turn first to the two varieties with tropical parentage: LA 110 and M-9.

• LA 110[19] (C.I. 9962). This was the first semi-dwarf variety developed by hybridization to be released in the United States. It was produced as a result of cooperative (Federal-State) research conducted at the Rice Experiment Station at Crowley, La. LA 110 was developed from a cross (strain 110) between Taichung Native 1 and H4 from Sri Lanka. The original cross was made in the 1960's. LA 110 is a medium-grain variety averaging 84 to 86 centimeters (33 to 34 inches) in height. It has very high yielding capacity and is resistant to all the races of the blast disease fungus to which it has been subjected. It does not, however, meet U.S. milling quality standards due to extreme chalkiness of kernel endosperm that results in a low milling percentage; in addition, its cooking characteristics are atypical. LA 110 was released expressly as an industrial variety to help fill the starch requirement of breweries preferring to use rice.[20] As of the early 1970's when acreage restrictions were in force, substantial quantities of rice were imported for this purpose. In 1972, it was suggested that the experimental TN-1/H4 cross be developed for this purpose. The seed supply was expanded and the first commercial planting stock, consisting of 240 hundredweight of foundation seed, was distributed to seed growers in 1974. They in turn contracted with a brewing company for production of registered seed.

• M-9[21] (C.I. 9968). This variety was developed at the California Rice Experiment Station, Biggs, from a cross involving IR-8 (IR8/CS-M3^2//10-7^2). The first and second crosses were made in 1968, the variety was approved for certification by the California Crop Improvement Association in 1977, and foundation seed was allocated to growers in the same year. M-9 is a medium-grain type. The plant averages 90 centimeters (35.4 inches) in height. It is highly responsive to high levels of nitrogen fertility. Yield levels were about 11 percent higher than Earlirose in experimental trials. It is adaptable to all but the coldest growing areas in California. M-9 was released jointly by the California Cooperative Rice Research Foundation, Inc., the California Agricultural Experiment Station (AES), and USDA/ARS.

Two semi-dwarf varieties have been, as noted, developed in California from crosses using an irradiated variety (Calrose 76) as one parent: M7 and M-101.

• M7[22] (C.I. 9967). This variety originated from a cross of Calrose 76 and CS-M3 made at the California Rice Experiment Station in Biggs during the winter of 1972/73. It was approved for certification by the California Crop Improvement Association in 1977. M7 is a medium-grain type. The plant is of

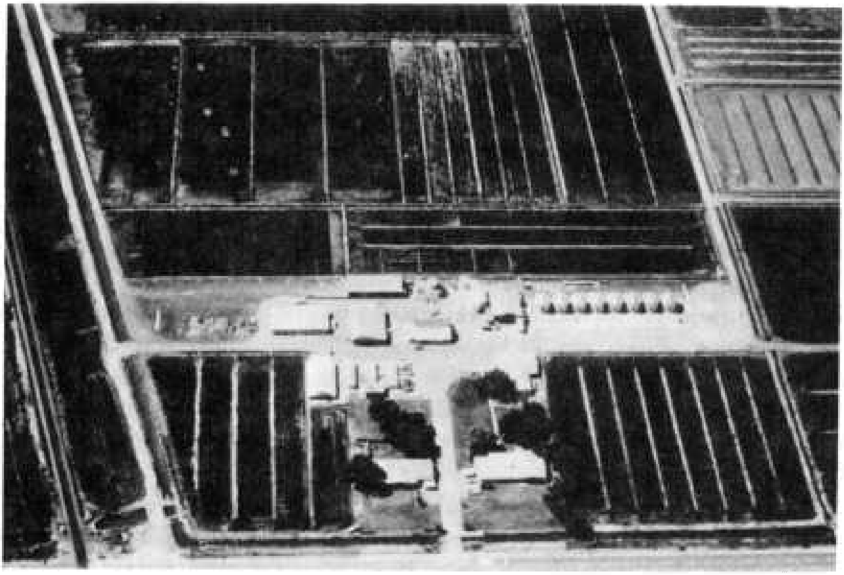


Plate 9. Rice Experiment Station, California Cooperative Rice Research Foundation, Inc., Biggs, Calif.

short stature, averaging 90 centimeters (35.4 inches) in height. It is highly responsive to nitrogen fertilization and yields about 17 percent more than CS-M3 (see figure 7 on p. 85). As was the case with M-9, M7 was released jointly by the California Cooperative Rice Research Foundation, Inc., the California AES, and USDA/ARS.

• M-101[23] (C.I. 9970). This variety originated from the cross CS-M3/ Calrose 76//D31 made at the University of California Rice Research Facility, Davis, in 1974 and was released on April 1, 1979. D31, like Calrose 76, was derived by irradiation of Calrose. M-101 is an early-maturing, medium-grain variety. It is responsive to high levels of fertilization. In tests conducted in 1977 and 1978 it averaged 89 centimeters (35 inches) in height and yielded 10 percent more than Earlirose (the same yield advantage as M-9). It does not have a yield advantage over M-9 in the warmer portions of California, but does have greater cold tolerance. The variety was released jointly by the USDA/SEA/AR, the California AES, and the California Cooperative Rice Research Foundation, Inc.

In addition to the four varieties noted above, another, L-201, has been released.[24] It has IR-8 parentage but is not a semi-dwarf. L-201 is the first long-grain variety to be released for commercial production in California. It is early maturing and has good straw strength. Its height is 96 centimeters (38.6 inches) versus about 116 centimeters (45.7 inches) for another long-grain variety released in germplasm in 1977 and grown in a small area in California, and 90 centimeters (35.4 inches) for M-9. Lodging in 1977 and

1978 tests was less than for M-9, and yields were 1.3 percent higher. IR-8 is one of the grandparents of L-201 but it is not thought to be the source of shortness. L-201 is not tolerant of low temperatures or of zinc deficiency. It was released jointly by the California Cooperative Rice Research Foundation, the California AES, and USDA/SEA/AR in April 1979.

VARIETIES UNDER DEVELOPMENT. In addition to these varieties, work is underway on several others. In California, two other semi-dwarfs are expected to be released in 1980: one is a medium-grain and the other is a short-grain (pearl).[25] In Texas, work is well along on a long-grain semi-dwarf. Promising new strains are 30 centimeters (12 inches) shorter than Labelle and are very resistant to lodging. The dwarfing gene comes from Taichung Native 1. The selections have excellent grain size, shape, appearance, and milling and cooking quality. The first variety is expected to be released in 1981.[26]

Several private firms also are working on the development of semi-dwarf varieties. Two varieties, one in Texas and the other in Louisiana, have principally utilized TN-1 and IR-8. Work is at an advanced stage, but no varieties have yet been released. The Louisiana firm has met quality standards, but the present lines are hard to thresh. The California firm produces for a specialized ethnic market and the semi-dwarfs do not yet meet special taste and quality standards. Both research programs are sponsored by firms which either grow rice or have it grown under contract; only the Louisiana firm sells seed to the public. Another California firm is also using short stature in its breeding program.[27]

Some Technical Notes

Cultivation of the semi-dwarf varieties involves a few changes in cultural practices. In California, growers are advised to apply 20 to 40 pounds more nitrogen per acre than with traditional varieties for maximum yields. In Texas, it has been observed that the semi-dwarfs are slower in emerging and seem to be less vigorous during the first weeks of growth; therefore, water will have to be managed more closely in the early stages of growth or there could be serious weed problems.[28]

There has been virtually no interchange of varieties between California and the South in terms of farm use because of climatic differences. The California varieties are developed for semi-arid conditions and are quite susceptible to diseases, particularly blast, in the more humid conditions of the South. Conversely, southern varieties do not usually have sufficient cold resistance for California (one of the parents of L-201, however, was developed in Arkansas).

Several other technical points might be mentioned relating to the California work discussed in the previous sections.

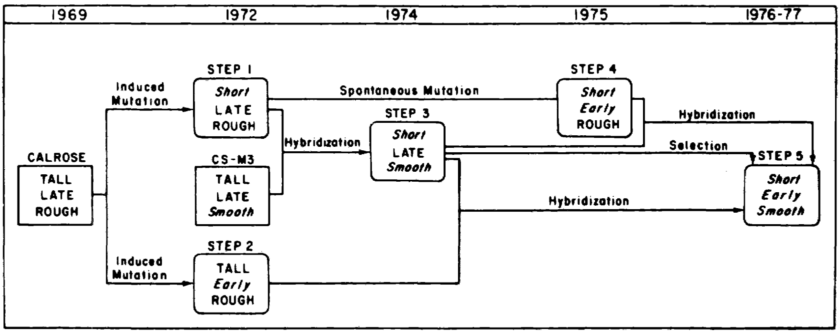
First, the gene for short stature in Calrose 76, developed as a result of induced mutation, is "similar" (the technical term is "allelic," meaning at the same location on the chromosome) to the gene for short stature in TN-1 and IR-8. The major difference is that Calrose 76 is a japonica type of rice, whereas TN-1 and IR-8 are indica types. This means that it is easier to transfer the dwarfing gene from Calrose 76 to other japonica varieties than it is to transfer it from TN-1 and IR-8. Yet, as we have seen, all three have been used. Had Calrose 76 not been available, greater use would probably have been made of IR-8.[29]

Second, the steps involved in developing Calrose 76 and its progeny are outlined in graphic form in figure 6. Step 1 produced Calrose 76, Step 3 produced M7, and Step 5 produced M-101. Rough and smooth refer to the pubescence on the hulls. Smooth hulls are now desired, which may limit Calrose 76 largely to a breeding role.

Third, since the initial work, which led to Calrose 76, two other differing sources of short stature genes have been identified in California: D-66 and D-24. Both are products of the original irradiation that led to the development of Calrose 76.[30]

Figure 6

Derivation of California Semi-Dwarf Rice Varieties Utilizing Induced Mutations



Source: J. N. Rutger and M. L. Peterson, "Improved Short Stature Rice," *California Agriculture*, June 1976 (Vol. 30, No. 6), p. 5.

Estimated Area Planted

The relatively recent arrival of the semi-dwarf rice varieties, and then largely in California, would suggest that their overall area was limited as of 1979. And while this is undoubtedly the case, it is not possible to document officially because USDA and the States do not conduct varietal surveys of rice.

On the other hand, the Rice Millers' Association does make annual varietal estimates for each State that should be quite reliable. The major problem in the semi-dwarf context is that the Association has only reported three "varieties" (types) for California: Pearl, Calrose, and No. 37 Long Grain (a germplasm release). Presumably, the semi-dwarfs planted through 1978 have been listed under Calrose. Some other estimates, however, are available for California. The area of LA 110 in the South also is not reported, but this is not surprising because the area for this variety is very limited since it is raised only under contract.

Overall Rice Area

Because of the relatively limited data on the semi-dwarfs, it is useful to check the official estimates of overall rice production by type and State. Such data for 1978 are summarized in table 8.

Table 8. Estimated Area of Harvested Rice in United States, 1978

State	Length of Grain			Total
	Short	Medium	Long	
		Acres		
AREA				
Missouri	400	1,600	28,000	30,000
Mississippi	–	2,000	213,000	215,000
Arkansas	33,000	161,000	976,000	1,170,000
Louisiana	–	349,000	238,000	587,000
Texas	–	20,000	538,000	558,000
California	200,000	299,000	–	499,000
Total	233,400	832,600	1,993,000	3,059,000
		1,000 cwt.[1]		
PRODUCTION				
Missouri	18	76	1,204	1,298
Mississippi	–	86	9,052	9,138
Arkansas	1,675	7,607	43,188	52,470
Louisiana	–	13,262	9,163	22,425
Texas	–	805	25,421	26,226
California	10,550	15,698	–	26,248
Total	12,243	37,534	88,028	137,805

[1] Cwt. =1 Hundredweight = 100 pounds = 45.36 kilograms.

Source: *Crop Production, 1978 Annual Summary, Acreage, Yield, Production*, USDA, Crop Reporting Board, Jan. 16, 1979, p. B-25.

In terms of type of rice, the breakdown was as follows:

	Short	Medium	Long	Total
		Percent		
Area	7.6	27.2	65.2	100
Production	8.9	27.2	63.9	100

Long-grain rice represented nearly two-thirds of the total area and production; it was grown only in the South. Production of medium-grain rice was divided between the South and California, and short-grain rice was principally grown in California. Altogether, the Southern States represented 83.7 percent of total area and 81.0 percent of production; California accounted for the remaining 16.3 percent of the area and 19.0 percent of production.

If the semi-dwarf varieties are going to have any significant impact on U.S. production, they clearly have to be adopted on a major level in the South and have to move from medium-grain types into long-grain types. As noted in the previous section, some long-grain varieties are under development in Texas.

Semi-Dwarf Area

Estimates of the area planted to LA 110 and the semi-dwarf varieties in California have kindly been provided by two groups involved: the brewery contracting for LA 110 and the California Cooperative Rice Research Foundation.

The first semi-dwarf to be commercially planted in the United States was LA 110, which was raised under contract in Mississippi with a brewing firm. It was first grown in 1974. TN-1 also was raised for the same purpose. The area of both expanded in 1975, reaching about 1,000 acres of LA 110 and about 500 acres of TN-1. The respective areas were about the same in 1976, but have declined in subsequent years. With the easing of acreage restrictions for rice in 1973, the domestic supply of broken rice grain (which can be used equally well for brewing) increased and the price dropped to the point where it became cheaper to use. The firm continues to have a small area of LA 110 and TN-1 grown under contract and would increase the area if economic conditions warranted.[31] Another brewery is reportedly investigating the possible use of LA 110.

The California medium-grain semi-dwarfs first came into commercial use in 1978 when the area of Calrose 76, M7, and M-9 was about 50,000 acres. In 1979, the area is estimated to be about 265,000 acres. The total semi-dwarf area was broken down roughly as follows:[32]

Variety	1978	1979
	Percent	
M-9[1]	45	60
M7	45	30
Calrose 76	10	10
Total	100	100

[1] IR-8 parent.

The proportion of M7 is expected to rise in 1980.

On the basis of USDA estimates of the total rice area in California–490,000 acres in 1978 and 522,000 acres in 1979[33]–the semi-dwarf area represented about 10 percent of the total state area in 1978 and about 50 percent in 1979. These figures are equivalent to about 1.7 percent of the total United States rice area in 1978 and 8.9 percent in 1979. The semi-dwarfs would represent a higher proportion of both California and U.S. production because of their higher yields.

California does not as yet have a commercial short-grain semi-dwarf, but as indicated earlier, one is to be released in 1980. And as also noted, a short stature long-grain variety was released in early 1979. Production is quite interchangeable; and growers could easily switch from short- to medium- to long-grain varieties. The controlling factor is demand; as of 1979, there was a strong market for short-grain rice in Puerto Rico.[34]

Substantial expansion in the development and use of short-strawed and semi-dwarf varieties may be expected in California and the Southern States within the next several years.

References and Notes

*P. R. Jennings, W. R. Coffman, and H. E. Kauffman, *Rice Improvement*, IRRI, 1979, p. 7.

[1] Based, except as noted, on: T. H. Johnston, N. E. Jodon, C. N. Bollich, and J. N. Rutger, "The Development of Early-Maturing and Nitrogen-Responsive Rice Varieties in the United States," *Rice Breeding*, IRRI, 1972, pp. 61-76, particularly pp. 66-73; C. R. Adair, et al., "A Summary of Rice Production Investigations in the U.S. Department of Agriculture, 1898-1972," *The Rice Journal*, March 1975 (Vol. 78, No. 3), pp. 26-29, April 1975 (Vol. 78, No. 4), pp. 24-26; C. Roy Adair, et al., "Rice Breeding and Testing Methods in the United States," *Rice in the United States: Varieties and Production*, USDA, Agricultural Research Service, Agriculture Handbook No. 289, June 1975, pp. 34-36; and C. N. Bollich and J. E. Scott, "Past, Present and Future Varieties of Rice," *Six Decades of Rice Research in Texas*, Texas Agricultural Experiment Station, Research Monograph 4, June 1975, pp. 39-41.

[2] Charles E. Chambliss and J. Mitchell Jenkins, *Some New Varieties of Rice*, USDA, Department Bulletin No. 1127, January 1923, pp. 14-16 (emphasis added; also noted by Bollich and Scott, *op. cit.*, p. 38). Shinriki is also briefly described by Jenkin W. Jones, "Improvement in Rice," *Yearbook of Agriculture, 1936*, USDA, p. 442. If Shinriki were fertilized at today's levels, it would probably be taller.

[3] J. E. Miller, "Foreward" in *Six Decades . . . , op. cit.*, p. iv.

[4] H. M. Beachell, "Varietal Improvements and Cultural Practices in Rice," *1953 Rice Annual* (published by the Rice Journal), pp. 53-54.

[5] D. S. Athwal, "Semidwarf Rice and Wheat in Global Food Needs," *The Quarterly Review of Biology*, March 1971 (Vol. 46, No. 1), pp. 5, 11. The publication referred to is H. M. Beachell and J. E. Scott, "Breeding Rice for Desired Plant Type," *Rice Technical Working Group, Proc.* (Tenth Meeting, Feb. 21-23, 1962, Houston, Texas), Arkansas Agricultural Experiment Station, 1963, pp. 15-16.

[6] T. H. Johnston, "SSS and Other Long-Grain Sources of Short Stature in Rice," Proceedings, *Fourteenth Rice Technical Working Group*, (Davis, California, June 20-22, 1972), Texas Agricultural Experiment Station, p. 22. Details on Bluebelle are provided by C. N. Bollich, et al., in "Registration of Bluebelle Rice," *Crop Science*, May-June 1968 (Vol. 8, No. 3), pp. 399-400. Details on Starbonnet are provided by T. H. Johnston, et al., in "Registration of Starbonnet Rice," *Ibid*, p. 399.

[7] This work is summarized in the references listed in footnote 1. Also see Appendix B.

[8] Details on these varieties are provided in T. H. Johnston, et al.: "Registration of Nortai Rice," *Crop Science*, Nov.-Dec. 1973 (Vol. 15, No. 6), p. 774; C. N. Bollich, et al., "Registration of Brazos Rice," *Crop Science*, Nov.-Dec. 1975 (Vol. 15, No. 6), p. 887; and T. H. Johnston, et al., "Registration of Mars Rice," *Crop Science*, Sept.-Oct. 1979 (Vol. 19, No. 5), pp. 743-744.

[9] "Relative Performance of Rice Varieties in Arkansas," Rice Information, Arkansas Cooperative Extension Service, No. 17, Feb. 16, 1976, p. 2. Maximum experimental yields have been substantially higher: in the case of Nortai a yield of 8,537 lbs/acre was obtained in Arkansas in 1972 (W. F. Faw and T. H. Johnston, *Effect of Seeding Date on Growth and Performance of Rice Varieties in Arkansas*, Arkansas Agricultural Experiment Station, Report Series 224, November 1975, p. 25). (Maximum yield levels for other varieties are reported by B. R. Wells, T. H. Johnston, and P. A. Shockley, *Response of Seven Rice Varieties to Rate and Timing of Nitrogen Fertilizer in Arkansas*, Arkansas Agricultural Experiment Station, Report Series 235, May 1977, pp. 6-11.)

[10] J. L. Sims, V. L. Hall, and T. H. Johnston, "Timing of N Fertilization of Rice. I. Effect of Applications Near Midseason on Varietal Performance," *Agronomy Journal*, Jan.-Feb. 1967 (Vol. 59, No. 1), pp. 63-66; Johnston, et al., *op cit.* (1972), p. 72.

[11] The early season application is made either before planting or during the first three weeks of growth just prior to the first permanent flooding. The first midseason application is made when the internodes are at the correct length for the variety (2 mm. panicle stage); the second midseason application is made 10 to 14 days later. A climatic measurement known as Growing Degree Days (DD) is a useful complementary measure for determining the proper time to apply midseason nitrogen. For details, see B. A. Huey, *Nitrogen Fertilization of Rice in Arkansas*, Arkansas Cooperative Extension Service, Leaflet 405, 1978.

[12] Telephone conversations with T. H. Johnston, AR/SEA, USDA, Stuttgart, Arkansas, Dec. 4 and 5, 1979.

[13] Dana G. Dalrymple, *Development and Spread of High-Yielding Varieties of Wheat and Rice in the Less Developed Nations*, USDA/OICD, FAER 95, September 1978 (6th edition), pp. 25-26; T. R. Hargrove, W. R. Coffman, and V. L. Cabanilla, *Genetic Interrelationships of Improved Rice Varieties in Asia*, IRRI, Research Paper Series No. 23, January 1979, pp. 2-3.

[14] C. N. Bollich, et al., "Performance of New Asian Rice Varieties in the United States," *Rice Journal*, April 1969 (Vol. 72, No. 4), pp. 9, 12, 13.

[15] *Ibid.*

[16] J. N. Rutger and W. F. Lehman, "Rice Introduction and Germplasm Development," *California Agriculture*, September 1977 (Vol. 31, No. 9), pp. 28-29.

[17] Based on J. N. Rutger, M. L. Peterson, C. H. Hu, and W. F. Lehman, "Introduction of Useful Short Stature and Early Maturing Mutants in Two Japonica Rice Cultivars,"

Crop Science, Sept.-Oct. 1976 (Vol. 16, No. 5), pp. 631-635; Rutger & Lehman, *op. cit.*; J. N. Rutger, M. L. Peterson and C. H. Hu, "Registration of Calrose 76 Rice," *Crop Science*, Nov.-Dec. 1977 (Vol. 17, No. 6), p. 978; letters from Rutger, January 25, 1979, August 17, 1979. Calrose is described by T. H. Johnston in "Registration of Rice Varieties," *Agronomy Journal*, November 1958 (Vol. 50, No. 11), p. 696; it is from a Calero and Calady cross.

[18] CS-M3 is described by J. J. Mastenbrock and C. Roy Adair in "Registration of 'CS-M3' Rice," *Crop Science*, Nov.-Dec. 1970 (Vol. 10, No. 6), p. 728; ancestors include Calady 40 and Calrose.

[19] Based, except as noted, on: W. O. McIlrath, N. E. Joden, E. A. Sonnier and G. I. Trahan, "LA 110: A New Industrial Rice Makes Its Debut," *The Rice Journal*, October 1977 (Vol. 80, No. 9) pp. 16-19; T. H. Johnston et al., *op. cit.* (1972), p. 68; McIlrath, et al., "Registration of LA 110 Rice," *Crop Science*, Sept.-Oct. 1979 (Vol. 19, No. 5), pp. 744-745; and phone conversations with Dr. McIlrath, April 3, 4, 1979.

[20] For background information, see Y. Pomeranz, "Rice in Brewing," in D. F. Houston (ed.), *Rice Chemistry and Technology*, American Association of Cereal Chemists, St. Paul, 1972, pp. 433-448.

[21] H. L. Carnahan, C. W. Johnson, S. T. Tseng, and J. J. Mastenbrock, "Registration of 'M9' Rice," *Crop Science*, Mar.-Apr. 1978 (Vol. 18, No. 2), pp. 357-358; letter from Rutger, Jan. 25, 1979.

[22] H. L. Carnahan, C. W. Johnson, and S. T. Tseng, "Registration of 'M7' Rice," *Crop Science*, Mar.-Apr. 1978, (Vol. 18, No. 2), pp. 356-357; letter from Rutger, Jan. 25, 1979.

[23] J. Rutger, M. L. Peterson, H. L. Carnahan, and D. M. Brandon, "Registration of 'M-101' Rice," *Crop Science*, Nov.-Dec. 1979 (Vol. 19, No. 6), p. 929; letter from Rutger, Jan. 25, 1979.

[24] S. T. Tseng, H. L. Carnahan, C. W. Johnson, and D. M. Brandon, "Registration of 'L-201' Rice," *Crop Science*, Sept.-Oct. 1979, pp. 745-746; phone conversation with Carnahan, Director of Plant Breeding, California Cooperative Rice Research Foundation, Inc., Biggs, California, May 2, 1979.

[25] The varieties were subsequently released as M-301 and S-201 respectively. Both have Calrose 76 ancestry.

[26] Letter from Charles N. Bollich, Research Agronomist, AR/SEA, USDA, Beaumont, Texas, May 4, 1979; "Now: Short-Statured Rice," *The Furrow* (Deere & Co.), March 1979, pp. 22-23.

[27] Based on telephone conversations with: Dr. L. E. Crane, Chocolate Bayou Co., Alvin, Texas; and Dr. Lorenzo Pope, Rice Researchers Inc., Glenn, California (Aug. 27, 1979). The Chocolate Bayou Co. is affiliated with the Texas Rice Production Co. of Alvin which markets a long-grain basmati rice. The second California firm is the Davis Dryer and Elevator Co. in Firebaugh.

[28] "Now: . . . ," *op. cit.*, p. 23. This has not been a problem in California where both semi-dwarf and regular varieties are grown in shallow water (3 to 10 cm.) (letter from D. Marlin Brandon, former Extension Agronomist, University of California, Davis, Sept. 14, 1979).

[29] Rutger and Peterson, *op. cit.* (1976), p. 6; Rutger and Lehman, *op. cit.* (1977), p. 28; and conversation with Rutger, April 4, 1979.

[30] Rutger and Lehman, *op. cit.* (1977), p. 28; K. W. Foster and J. N. Rutger, "Inheritance of Semidwarfism in Rice, *Oryza sativa* L.," *Genetics*, Mar. 1978 (Vol. 88), pp. 559-574; conversation with Rutger, Apr. 4, 1979. Also see J. N. Rutger, et al., "Registration of Six Germplasm Lines of Rice," *Crop Science*, Mar.-Apr., 1979 (Vol. 19, No. 2), pp. 299-300.

[31] Telephone conversation with the manager of agricultural operations of the brewery, Apr. 9, 1979.

[32] Based on estimates provided to the Rice Millers' Association by D. Marlin Brandon, Extension Agronomist, University of California, Davis, May 31, 1979. Estimates con-

firmed with Brandon Sept. 17, 1979. Based on rice seed production estimates.

[33] *Small Grains, 1979 Annual Summary*, USDA, Crop Reporting Board, Dec. 21, 1979, p. B-10. The Rice Millers Association placed the total area in 1978 at 503,725 acres, of which 185,632 acres were short-grain, 316,436 medium-grain, and 1,657 acres long-grain ("Rice Acreage in the United States, 1978," Rice Millers' Association).

[34] Telephone conversation with Carnahan, *op. cit.*

V. ASSOCIATED TECHNOLOGICAL FACTORS

> *. . . major technologies are synergistic—that is, their combined use stimulates greater productivity than the sum of the productivity of each used separately.*
>
> **—Lu, Cline, and Quance, 1979***

The use of semi-dwarf varieties of wheat and rice in the United States is part of a closely linked package of practices and inputs. In the United States, as in other developed countries, this package has evolved in an evolutionary manner; the semi-dwarfs are simply an added step. For these reasons, it is difficult to separate the effects of the varieties from those of their associated factors.

In thinking of the package of technologies, one naturally turns first to production inputs. But there is also a group of related agricultural problems stemming from the special nature of the varieties and of their yield levels. And there are a number of related technological developments that could modify the varieties and their relationship to the other inputs as well as to the related production factors.[1] All will be briefly reviewed in this chapter.

Use of Production Inputs

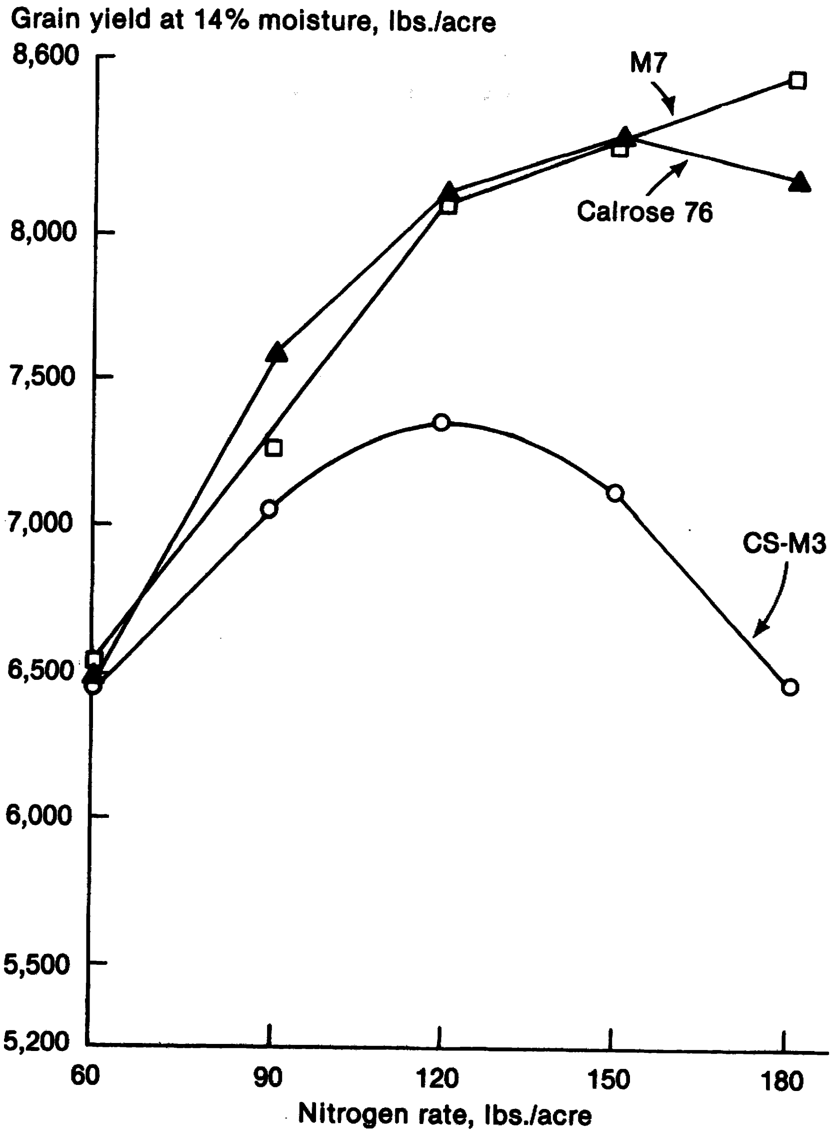
Two of the most important production inputs are nitrogen fertilizer and water. Other production inputs are also needed—weed control, for instance, is a vital matter for semi-dwarfs[2]—but they will not be reviewed here. The extent and degree of use of any input is strongly influenced by economic factors—their cost and the price of the final product (matters which will be briefly discussed in Chapter VII). As we shall see, wheat is generally raised under less intensive conditions and practices than rice.

Fertilizer

The main purpose of developing the semi-dwarf varieties was, as stated earlier, to develop resistance to lodging and to make the plants more yield-responsive to higher levels of nitrogen fertilizer use. This is illustrated by data for rice in California (fig. 7). Grain yields for two semi-dwarf varieties (Calrose 76 and M7) are similar to the tall check variety at low levels of nitrogen and

Figure 7

Yield Response to Nitrogen Fertilization, Three California Rice Varieties



Note: The difference between M7 and Calrose 76 at 180 lbs./acre is not significant.

Source: *Eighth Annual Report to the California Rice Growers,* Rice Research Board, Yuba City, California, April 1977, p. 3 (from *Comprehensive Rice Reseach Report,* University of California and USDA, Davis).

continue to climb at high levels of fertilizer application, while those for the tall variety (CS-M3) drop off. Thus the degree to which the semi-dwarf varieties are high-yielding is strongly influenced by the amount of nitrogen applied.

Unfortunately, however, no data appear to be available on the level of application of nitrogen on semi-dwarf varieties at the farm level. The best that can be done is to identify all fertilizer use on all wheat and rice varieties. Presumably the semi-dwarfs will be fertilized and will generally receive more than average amounts. However, this is not necessarily always the case since some farmers may not be aware of the fertilizer-responsive nature of the varieties or may not be in a position to capitalize on it.

WHEAT. Two sources of data are available on fertilizer use on wheat. One is the U.S. Census of Agriculture held every 5 years. Recent data may be summarized as follows:[3]

Year	Proportion of Harvested Area Fertilized	Amount of Fertilizer Used per Acre
	Percent	*Pounds*
1954	29.0	191
1959	42.1	161
1964	54.2	148
1969	54.9	157
1974	62.0	169

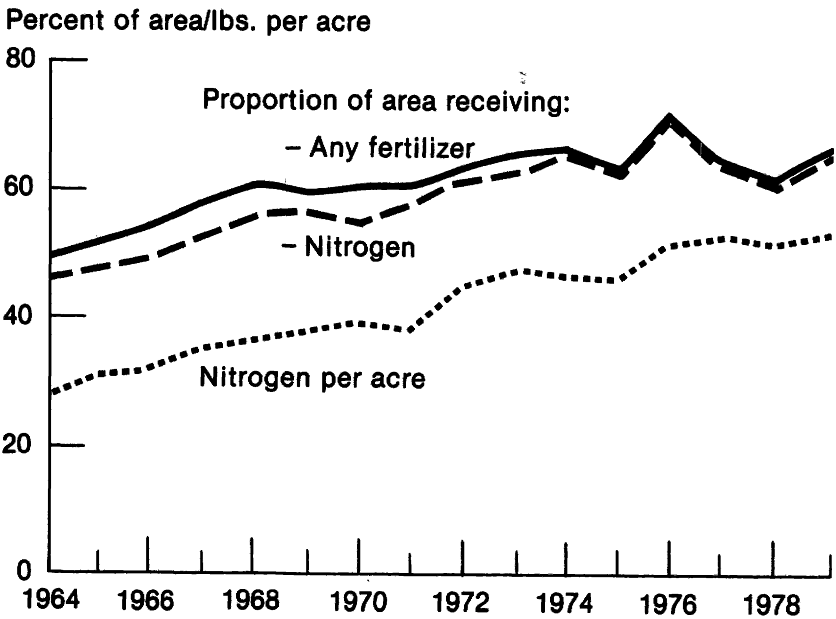
The proportion of area fertilized rose steadily until 1964, leveled off in 1969, and then rose somewhat in 1974. Still, by 1974, some 38 percent of the wheat was not fertilized. Where unfertilized wheat is grown in rotations, however, it may receive some residual benefits if the other crops are fertilized or if they are legumes. In 1974, the proportion of wheat area fertilized was higher on fully irrigated land (87 percent) than on nonirrigated land (61 percent). In regional terms in 1974, the proportion of area fertilized was highest (in percent) in the Northeast (81.7), followed by the South (66.2), the North Central States (62.3), and the West (57.2). By comparison, the proportion of area of selected other crops, which was fertilized in 1974, was as follows (in percent): rice, 99.6; tobacco, 99.5; sugar beets (for sugar), 99.5; white potatoes, 99.1; field corn, 86.2; and barley, 68.0. Of 23 commodity groups listed, 12 ranked higher than wheat and 10 ranked lower.

The expansion of area fertilized from 1954 to 1964 coincided with an evident drop in the amount of fertilizer used per acre (perhaps partly offset by the use of higher analysis fertilizer). The amount utilized, however, rose in 1969 and 1974. The 1974 figure of 169 pounds per acre, compared, as follows, with average levels for selected other crops: tobacco, 1,874; white potatoes, 1,057; sugar beets, 473; rice, 403; field corn, 385; all crops, 318; and barley, 175. Wheat fertilization levels were the lowest of any of 23 commodity groups listed.

In addition to the Census, USDA has gathered time series data on the use of fertilizer from sample farms in 17 States from 1964 to the present (fig. 8).[4]

Figure 8

Estimated Use of All Fertilizer and Nitrogen Fertilizer in Wheat Production, United States, 1964-79 (Based on a 17-State Survey)



Source: *Cropping Practices; Corn, Cotton, Soybeans, Wheat, 1964-70,* USDA, Statistical Reporting Service, SRS-17, June 1971, pp. 23-25; annual issues of the *Fertilizer Situation,* USDA, 1971 to 1979.

The proportion of farms using any fertilizer increased steadily from 50.0 percent in 1964 to a high of 71.1 percent in 1976, then dropped in 1977 and 1978, and increased again (to 66.1) in 1979. Farms using nitrogen showed a similar trend. The quantity of nitrogen applied per acre increased steadily from 27.3 pounds in 1964 to a peak of 53.9 pounds in 1979.[5] By comparison in 1979, 96 percent of corn farmers used any fertilizer or nitrogen and applied an average of 135 pounds of nitrogen per acre, while the comparable figures for cotton were 71 percent and 71 pounds, respectively.

The nitrogen figures for wheat may be placed in sharper relief by noting that in Kansas a low rate of nitrogen application is about 25 pounds/acre and a high rate ranges from 80 to 100 pounds/acre. The latter level would seem appropriate for high protein semi-dwarfs in Kansas.[6]

The data clearly show that more than a third of the wheat area is not fertilized on an annual basis and that the average quantity of nitrogen fertilizer applied is not high. This is probably because water is a greater limiting factor than is soil nitrogen in many regions (this matter will be discussed at greater length in a subsequent section on nitrogen-water interactions). But the result is that there is a substantial portion of the U.S. wheat area where the nitrogen responsiveness of the semi-dwarfs would not appear to be of special value at the moment. The story might be expected to be quite different in the more heavily fertilized areas where water is not a limiting factor.

RICE. In contrast to wheat, virtually all of the rice area is fertilized. According to the 1974 Census of Agriculture,[7] fertilizer was applied to 99.6 percent of the harvested rice area. This was the highest proportion, by a slight margin, of any crop category. As noted in part in the previous section, the next highest categories were (in percent), tobacco, 99.5; sugar beets (for sugar), 99.5; and white potatoes, 99.1.

The amount of fertilizer applied per acre, however, was not exceptionally high—403 pounds. Comparable figures, as reported in the previous section, were (in pounds): tobacco, 1,874; white potatoes, 1,057; sugar beets, 473; field corn, 385; all crops, 318; barley, 175; and wheat, 169.

Comparable figures on fertilizer use on rice for prior census are:

Year	Proportion of Harvested Area Fertilized	Amount of Fertilizer Per Acre
	Percent	*Pounds*
1964	95.2	260
1969	99.6	395
1974	99.6	403

While the proportion of harvested area fertilized went up only slightly from 1964 to 1969, reaching nearly 100 percent, the amount of fertilizer increased more substantially (+ 52 percent). The proportion of area fertilized did not increase from 1969 to 1974, and the amount of fertilizer applied increased only 2 percent. There was, however, a pronounced shift toward the use of higher analysis nitrogen fertilizer during the latter period.

As noted, California growers have been advised to apply 20 to 40 pounds more nitrogen per acre on semi-dwarfs than on traditional varieties.[8]

Water

The realization of higher yields in semi-dwarf varieties, particularly wheat, requires relatively favorable water supplies. On the other hand, where water supplies are unusually abundant, as in a year of high rainfall, the semi-dwarf varieties are less likely to lodge than taller varieties. The water requirements of wheat and rice differ rather sharply, as do their normal growing conditions.

WHEAT. Wheat requires less water than many plants and, thus, production tends to be concentrated in the more arid sections of the country, particularly in the Great Plains. To the east of the Plains, the natural rainfall is generally adequate; in fact, it may be too high in that high moisture conditions can exacerbate disease problems. On the other hand, natural rainfall in some areas is too low or unreliable, and irrigation is needed. Semi-dwarfs are particularly likely to be grown on irrigated land.

According to the last four censuses of agriculture, the harvested wheat area raised under irrigation was as follows:[9]

Year	Irrigated Area	Irrigated as Proportion of Total Wheat Area
	Acres	*Percent*
1959	1,761,108	3.6
1964	1,963,525	4.1
1969	1,993,688	4.5
1974	3,235,662	5.2

The irrigated wheat area represented a small, but gradually growing proportion of the total wheat area. The largest jump in irrigated area took place between 1969 and 1974, a period of high wheat prices.

Irrigated wheat in the United States is rather heavily concentrated in a few areas—in the Panhandle area of Texas, Oklahoma, and Kansas, and in the Mountain States and the Western States. For the United States as a whole, 95.6 percent of the irrigated wheat was in 12 States in 1974. More specific data are provided in table 9. In terms of proportion of total wheat area irri-

Table 9. Irrigated Wheat Area in the United States, 1974

Rank	State	Irrigated Area	Irrigated as Part of Total
		Acres	*Percent*
1	Texas	881,598	25.5
2	Idaho	436,406	31.0
3	Kansas	381,696	3.4
4	California	374,096	53.4
5	Washington	298,686	9.9
6	Arizona	171,055	100.0
7	Colorado	126,779	4.5
8	Oregon	124,377	10.0
9	Oklahoma	119,004	2.0
10	New Mexico	90,196	44.5
11	Montana	67,356	1.4
12	Utah	53,546	20.9
Subtotal 12 States		3,124,795	13.1
Other States		110,867	0.3
United States		3,235,662	5.2

Source: Compiled from *1974 Census of Agriculture, United States Summary and State Data,* Vol. I, Part 51, December, 1977, p. II-37, Table 21.

gated, Arizona was at the top with 100 percent, California followed with 53.4 percent, New Mexico 44.5, Idaho 31.0, Texas 25.5, and Utah 20.9. In Nevada, a minor wheat State, all of the area was irrigated. Irrigation in the Panhandle is of a relatively extensive type and is used to supplement rainfall.

Yields in the irrigated areas in 1974 were, as might be expected, considerably higher than in the nonirrigated areas—45.6 bushels/acre, compared with 26.1 bushels/acre—or 74.7 percent higher. Relative yields will be taken up in greater detail in the next chapter.

RICE. The story on rice is brief: all of the rice area is irrigated, no matter what the natural rainfall situation.

Virtually all of the irrigated wheat and rice is west of the Mississippi River. The future of irrigation in parts of this region is clouded because of increasing competition for urban use (particularly in the Southwest), declining levels of ground water (especially in the Panhandle area of the Great Plains), cost of fuel, and salinization.[10] Analysis of this matter is well beyond the scope of this report, but there could be a decline rather than an increase in irrigated area planted to crops in some regions in the future.

Fertilizer-Water Interactions

As is well known, increased water supplies will normally increase the response to nitrogen fertilizer. The degree of response is greatly influenced by water supplies. Response ranges from none (or negative) in dry, semiarid, nonirrigated wheat areas to a positive response—even with rather high rates of fertilization—under subhumid, nonirrigated or under irrigated conditions.[11]

Within these categories, the response to increased nitrogen also varies somewhat by region. As L. M. Thompson has noted: "Wheat grown in the Great Plains responds with higher yields to greater than normal rainfall, whereas wheat grown in the Corn Belt, particularly in Illinois and Indiana, yields more when rainfall is normal or slightly below normal."[12] The problem in the Corn Belt, where rainfall is higher, is one of disease.

Other natural factors, such as growth habit, also may be involved. Thompson states, for instance, that "spring wheat yield is so highly related to weather that heavy fertilization with nitrogen is less profitable than the same rates applied to winter wheat."[13]

Within these limits, the semi-dwarfs are more responsive to higher rates of applied nitrogen.

Related Production Factors

There are a number of varietal characteristics related to the use of associated inputs that influence the adoption and use of semi-dwarf varieties in the United States. To date, these have almost entirely related to wheat; semi-dwarf rice is so new that it has not yet had time to build up a comparable list.

General Cultural Problems

When the early semi-dwarfs were first tried in the Hard Red Spring and Hard Red Winter wheat areas of the Plains States in the early 1950's, it was found that they did well under high rainfall or irrigated conditions, but not under dryland conditions. The major difficulties were straw breakage under moisture stress and high temperature, along with poor grain quality (shriveled kernels and low test weight). Disease susceptibility of the semi-dwarf germplasm was also a problem.[14] Some thought that the roots of the semi-dwarfs did not go deeply enough into the soil for dryland wheat production. Others were concerned that the short coleoptiles (the sheath covering the first foliage leaf of a young seedling) could lead to slow or poor emergence from deep seeding, particularly in dryland agriculture. It was recognized, however, that many of these problems could be solved through further breeding and selection.[15]

It is not certain that rooting depth was or is a special problem. One set of studies of winter wheat in Colorado "failed to establish any relationship between rooting patterns and semi-dwarf height genes."[16] Still, as with tall plants, there is considerable variation between varieties, and perhaps between locations. And since much wheat is grown in areas subject to moisture stress, the development of drought-resistant varieties is an important breeding objective.[17]

The problem of lower kernel test weight has persisted for some time. The individual kernels, and hence a given volume of grain, from the semi-dwarfs may not weigh quite as much as traditional varieties. Heyne and Campbell stated in 1971 that "test weight as a grading factor for marketing has little value."[18] The millers may see the situation differently if the lower test weight results in lower milling yields. This depends on what causes low weight; if, for example, it is due to shriveling or weathering brought on by moisture stress, lower milling yields are apt to result than if it is due simply to the shape of the grain.[19]

It is not entirely clear how much overall improvement has been made in overcoming the problem of coleoptile length. This is not an issue where seeds are not planted deeply, but may be a difficulty where deep plantings are necessary because of soil moisture, temperature, or crusting conditions. The answer may depend on finding new sources of dwarfism.[20]

There are some regions of the United States where the climate is so harsh that semi-dwarfs still are not grown to any extent and may not be for some time. The high plains area of the Great Plains, with elevations above 600 meters and rainfall below 600 millimeters, is a particular case in point; so far it has been found that "types with superior performance over these highly variable environments tend to be intermediate (in height)."[21]

Protein Levels

A related and rather important matter concerns protein levels in the wheat grain. This is a significant issue for two major reasons: the relationship to nutrition and to end-use requirements. As noted in Chapter I, various products made from wheat have requisite protein levels. Some of these, as for the products made from soft wheat, are rather low. Others, as for the products made from hard wheat, are higher. A wheat protein level of at least 12 percent is required for bread making.[22]

For many years, the protein levels in the hard wheats reportedly have been declining as growers have sought higher grain yields and as soil nitrogen levels have declined.[23] Some of the early semi-dwarfs, and indeed some of the more recent varieties, have lower protein levels than traditional varieties and could accelerate this trend.

Fortunately, protein levels may be raised in two ways—through breeding and through heavier nitrogen applications.

BREEDING. It is possible to develop wheat varieties which produce grain of higher protein level. It fact, this has been done. Consider a progression of semi-dwarf varieties developed by the Minnesota Agricultural Experiment Station. Era was introduced in 1970; it was "significantly lower in protein content and bake absorption than Chris." It was followed by Kitt in 1975 which had a significantly higher protein level, but which was still not up to Chris. Angus, released in 1978, is stated to be comparable to Chris in bake absorption.[24] An induced mutation of Chris was found to have a single gene for height reduction, while maintaining its high protein level.[25]

Future advances in the improvement of protein quality in semi-dwarfs could draw on a longstanding project on genetic methods for improving the nutritional quality of wheat conducted at the University of Nebraska in cooperation with the U. S. Department of Agriculture and funded by the Agency for International Development. A vast number of wheat varieties from around the world have been evaluated for nutritional value. The more promising varieties, including a number of lines from CIMMYT, have been crossed to produce experimental lines with high levels of protein and lysine. More than 100 lines grown under irrigated test conditions at Yuma, Ariz., have averaged 17 percent protein and 3.5 percent lysine—about a 40-percent increase in protein and a 20-percent increase in lysine. These and many other lines have been distributed on a worldwide basis for testing and use in breeding programs. A new variety of normal height, Lancota (C.I. 17389), was released in Nebraska in 1975. As yet these materials have not appeared in the pedigree of semi-dwarfs released in the United States, but they might well do so in the future.[26]

A quite different, and evidently effective, approach has been taken by a private seed firm in Kansas.[27] It has attained high protein levels in Hard Red Winter wheat by introducing alien germplasm (particularly goat grass, *Aegilops ovata*) into the breeding process.[28] A number of high protein semi-dwarf varieties are in use and others are under development, including White wheats. Among the varieties in commercial use in Kansas, the firm estimates that the average protein levels of their Class I (highest protein) varieties is about 16.5 percent, while the average for Class II varieties is about 13.5 percent. In both cases, soil fertilization levels are probably above average. Chemical tests of 240 experimental lines revealed that 26 percent of the varieties had less than 17 percent protein, while 74 percent had more than this level (7 percent of the varieties had more than 20 percent protein). The firm estimates that varieties with 25 percent protein are possible.

The firm claims that the varieties are also capable of high grain yields. In a 4-year replicated test on an unirrigated plot near Haven, Kans., that received less than a maintenance level of fertilizer, grain yields of nine varieties averaged 47.3 bushels per acre, or 33.6 percent above the check variety (Triumph 64). Protein levels, due to relatively low fertilizer levels, were only 9.6 percent higher. The result of higher yield and protein levels was an increase in protein production per acre of nearly 53.5 percent. As yet, these yield levels have not been verified over a wide range of cultural conditions. The firm's materials have only recently found their way into more general testing programs sponsored by public institutions. It will be interesting to see how they compare.

For the moment, the potential to supply high protein seems to have run ahead of the demand for it. In many years a premium is paid for more than 14 percent protein on the open market.[29] Several of the varieties developed by the above firm are being grown under contract with mills for use in blending with varieties with low protein levels; growers are paid a premium for up to 16 percent protein. The overall protein level varies from year to year and this influences the mills' interest in paying a premium.

NITROGEN FERTILIZATION.[30] It has long been known that a crop that has been supplied ample nitrogen will have a higher protein level than a nitrogen-deficient crop. Data collected in Kansas as early as 1932 indicated that fertilized wheat could have protein levels some 2 percentage points above unfertilized wheat.

The amount of increase in protein level is in part a function of the amount of fertilizer applied. In Kansas, it is a general rule of thumb that a low rate of nitrogen application (25 pounds/acre) will not raise the protein level, a medium rate of application (50 pounds/acre) will raise it slightly, and a high rate of application (75 to 100 pounds/acre) will raise it significantly if rainfall is adequate. In Nebraska, experimental data gathered from 1968 to 1970 for two wheat varieties showed that grain protein levels rose in a linear fashion as nitrogen applications were increased from 0 to 135 kilograms/hectare (120 pounds/acre).[31]

Other factors influencing protein level include variety and time of fertilizer application. Some varieties, as noted in the previous section, have a greater ability to accumulate more protein from a given amount of available soil and/or fertilizer nitrogen. While nitrogen is generally applied to spring wheat at (or prior to) seeding, in the case of winter wheat, nitrogen applied later in the spring of the growing season will promote higher protein contents than will applications in the fall or early spring.

Current Developments in Breeding

Considerable research on breeding techniques is currently underway in the United States by both public organizations and private firms. Among the many lines of work, three might represent some of the major thrusts: development of new sources of dwarfism, development of hybrid varieties, and spring and winter crosses.

New Sources of Dwarfism[32]

Virtually all of the semi-dwarf varieties grown in the world derive their stature from a similar set of genes (wheat, back to Daruma or Akahomugi; rice, back to Dee-geo-woo-gen). There are hazards in relying on too narrow a genetic base, and problems and limitations in the use of the present base.

It would clearly be desirable to broaden the genetic base of dwarfism. This can be done in two ways: either through the identification of additional natural sources of dwarfism, or the induction of mutations. Both have been utilized.

Plant breeders are constantly on the alert for possible new sources of germplasm. To date, however, only a few naturally occurring sources of dwarfism have been identified. The two wheat sources are Tom Thumb and Olesen's Dwarf and both are being used in research work. The standard-height variety Ramona 50 has been found to carry a distinct dwarfing gene which is independent of the Norin 10 genes; it has, however, only been used in experimental work.[33] It was hoped that some of the semi-dwarf varieties produced with the People's Republic of China (PRC) would produce new sources of dwarfism but so far they seem to have the same or "similar" (allelic) genes.

It is possible to modify the genetic structure of plants through chemical means or irradiation; sometimes this process produces dwarfism. Induced mutation has been used to produce shorter varieties of both wheat and rice in the United States.

Much of the work on **wheat** has been done at the Washington Agricultural Experiment Station, starting in 1966. Konzak described the program as follows in 1976:

. . . our genetic resource collection includes over 200 reduced-height mutants induced by gamma and neutron radiations or various chemical mutagens in several spring and winter wheats. Only a small number of these mutants have been studied genetically and several have been used to introduce additional genetic diversity for reduced height into our spring and facultative (cold-hardy) spring wheat breeding program. We are still inducing short culm mutants (mainly in promising tall breeding lines) and have become as interested in these as gene sources for cross-breeding as in their possible direct application as varieties.[34]

A radiation-induced semi-dwarf mutant, Burt M937 (C.I. 15076), was used as a parent for a number of lines of wheat germplasm, which have been released and registered.[35] There are some difficulties in using induced mutants in breeding programs, but they are not considered to be any more difficult than those encountered with many natural sources.[36]

Some work has been done with wheat in other States. In studies conducted in Minnesota, Chris was treated with a mutagen to produce a variety with a single gene for height reduction while retaining the high protein levels of Chris; it was used as a parent in experimental crosses.[37] A short-statured wheat variety developed from irradiated stock was released under the name of Lewis in 1964 by the Missouri Agricultural Experiment Station. While Lewis represented a reduction in plant height, it was very susceptible to disease and had low test weight. It was grown on 1,248 acres in 1974.[38]

Induced mutations in **rice** have, as noted in the previous chapter, been made in California. One, Calrose 76, resulted from irradiation of Calrose. Calrose 76 was in turn one of the parents of two other varieties: M7 and M-101. Induced mutations have been the subject of much study elsewhere.[39]

The difficulty in finding different natural sources of dwarfism in wheat and rice may lead in the future to increased interest in induced mutations.

Hybrids

The development of hybrid corn has long stimulated interest in developing hybrid wheat and rice varieties. Typically, the first generation (F_1) of a cross exhibits greater vigor than subsequent generations. But this is difficult to achieve on an economic scale with wheat and rice because they are self-pollinated crops.

To obtain the F_1 hybrid vigor on a commercial scale, a complex process must be followed. Three lines must be developed for seed production: the cytoplasmic male-sterile or A-line, the maintainer or B-line, and the fertility restorer or R-line. Commercial success depends on the ability to multiply the male-sterile line and to be able to mass produce seed. Also, the resulting F_1 generation is not necessarily higher yielding than varieties in commercial use.

Writing about wheat in 1963, Briggle stated that while the technical requirements could be met, the big question was: "Can hybrid seed be produced commercially on an economic basis?"[40]

Observations of hybrid vigor (heterosis) in **wheat** date back to 1919. Significant yield increases were found at the experimental level but there seemed to be no way of achieving this at a commercial level. Following some discoveries during the 1950's, the process seemed technically possible by the early 1960's. A number of commercial firms and public research agencies took up research. Semi-dwarfs were heavily involved. But by the late 1970's, hybrid wheat had still not become a commercial reality and most of the public research agencies dropped work on it. Hybrid seed is much more expensive than regular wheat seed and a higher yield is necessary to pay for the extra seed costs. It is still uncertain when and if hybrid wheat varieties will become a commercial reality. But if they do, they will generally be semi-dwarfs.[41]

Relatively little research work on hybrid **rice** seems to have been done in the United States. Perhaps the first work was reported by Jones in California in 1926.[42] Some further research has been done in the same State, the most recent of which confirms the problems with using F_1 hybrids.[43] The only place where hybrid rice has been grown commercially on a large scale is in the People's Republic of China.[44]

Spring x Winter Crosses[45]

Spring and winter wheat varieties each have certain advantages which they might contribute to each other. Spring wheats may contribute better stem and leaf rust resistance, and better baking quality. Winter wheat may contribute greater drought tolerance and greater resistance to diseases, such as septoria, powdery mildew, and stripe rust. Intercrossing could also produce yield increases and provide a wider range of maturities.

The concept of utilizing spring x winter crosses for varietal improvement is not new or unusual. A number of such crosses have been made to incorporate specific genes for disease resistance or for some other agronomic trait. Early well-known spring x winter crosses included Hybrid 128 (1907), Ridit (1924), Thatcher (1934), and Federation 41 (1942). Norin 10-Brevor was a winter type that was crossed with many spring types.

But little was done in the way of developing a large-scale systematic crossing program until the 1960's. The idea of such a program originated with Dr. Joseph A. Rupert of the Rockefeller Foundation when he was working in Chile. Work was shifted to the University of California at Davis in 1968 and subsequently became a cooperative program between CIMMYT and the Oregon Agricultural Experiment Station with AID financial support. Further details are provided in Chapter VIII.

* * *

We have so far spoken only of traditional breeding techniques. There are also a number of other more advanced breeding techniques undergoing development which may be of considerable significance in the future. These involve cell biology and include cell culture systems, protoplast fusion, and recombinant DNA. Other related areas of plant physiology include increasing photosynthetic efficiency, biological nitrogen fixation, and plant adaptability to stress conditions.[46] These and other developments could well lead to modifications in the semi-dwarfs and in their relationship with current production inputs and agricultural practices.

References and Notes

*Yao-chi Lu, Philip Cline, and Leroy Quance, *Prospects for Productivity Growth in U.S. Agriculture*, USDA, Agricultural Economic Report No. 435, September 1979, p. i.

[1] For a much more detailed analysis of technical factors affecting wheat production, see J. J. Bond and D. E. Umberger, *Technical and Economic Causes of Productivity Changes in U.S. Wheat Production, 1949-76*, USDA, Science and Education Administration, Technical Bulletin No. 1598, May 1979, pp. 17-94. Fertilizer is discussed on pp. 44-59, 79-82, and irrigation on pp. 28-32, 84-86.

[2] Several wheat breeders mentioned the importance of weed control for semi-dwarfs, but no mention of it was found in the literature reviewed. There are doubtless some references to the matter in the *Agronomy Journal* or *Weed Science*, but I have not pursued the subject. In the case of rice, several references were noted; see R. J. Smith, Jr., W. T. Flinchum, and D. E. Seaman, *Weed Control in U.S. Rice Production,* USDA, Agricultural Research Service, Agriculture Handbook No. 497, March 1977, p. 5.

[3] Derived from *U.S. Census of Agriculture* reports as follows:

–1974, Vol. II, Part 4 (September 1978), pp. IV-7, IV-11 to IV-13, IV-23.

–1969, Vol. II, Part 4 (July 1973), p. 155.

–1964, Vol. II, Ch. 9 (June 1968), pp. 934, 935.

–1959, Vol. II, Ch. IV (1962), p. 324.

–1954, Vol. III, Part 10 (December 1956), p. xxi.

One limitation of these data is that the percentage of fertilizer elements has increased over time. Thus fertilizer use on an elemental basis may be greater than indicated in recent years.

[4] The *1979 Fertilizer Situation* (USDA) indicates that the 17 States surveyed in 1978 accounted for 92 percent of total U.S. area harvested (December 1978, p. 15). It also indicated that of the total area fertilized, 75.5 percent was done at or before seeding, 8.8 percent after seeding, and 15.7 percent both at or before seeding and after seeding (p. 17).

[5] The decline in 1978 was related to uncertainty about wheat prices in the southern winter wheat areas (*Ibid.*, p. 17).

[6] Based on a general rule of thumb used by Dr. Floyd W. Smith, Director of the Kansas Agricultural Experiment Station. Kenneth L. Goertzen of Seed Research Inc. (Scott City, Kansas) calculates that in central Kansas to produce 50 bu./acre with 15 percent protein should take about 85 pounds of nitrogen. ("Semi-Dwarf Wheat," 79/4, p. 3).

[7] *Census of Agriculture, op cit.* (same as fn. 3).

[8] "Now: Short-Statured Rice," *The Furrow* (Deere & Co.), March 1979, p. 23.

[9] Derived from *U.S. Census of Agriculture* reports as follows:

–1974, Vol. I, Part 51 (December 1977), pp. 11-37, IV-5; Vol. II, Part 9 (June 1978), pp. 1-31, 35, 41, 47.

–1969, Vol. IV (July 1973), pp. xvii, xv, xix, 27.

–1964, Vol. II, Ch. 9 (June 1968), p. 920 (contains data for 1959).

[10] See, for example: Bond and Umberger, *op. cit.*, pp. 85-86; Joel Kotkin, "Agriculture Losing Contest for Western Water," *Washington Post*, June 18, 1979, pp. A1, A10; Daniel J. Balz, "Panhandle Plight, Even in a Good Year, Costs Squeeze Texans' Style," *Washington Post*, July 2, 1979, pp. A1, A4.

[11] See, for example, Bond and Umberger, *op. cit.*, p. 48. Empirical data on production functions for wheat under irrigation are provided by Roger W. Hexem and Earl O. Heady, *Water Production Functions for Irrigated Agriculture*, Iowa State University Press, Ames, 1978, pp. 106-119, particularly the figures on pp. 108-109.

[12] Louis M. Thompson, "Weather Variability, Climatic Change, and Grain Production," *Science*, May 9, 1975 (Vol. 188), p. 535.

[13] *Ibid.*, p. 536. Due largely to a longer growing season, winter wheat usually has a higher yield potential than spring wheat. Consequently, in those areas where water supply is adequate and both spring and winter wheat are adapted, winter wheat has a greater response to nitrogen fertilizer than does spring wheat.

[14] L. W. Briggle and O. A. Vogel, "Breeding Short-Stature Disease-Resistant Wheat in the United States," *Euphytica*, Supplement No. 1, 1968, pp. 107-108, 120-121; E. G. Heyne and Larry C. Campbell, "Experiments with Semidwarf Wheats in Kansas," *Transactions of the Kansas Academy of Science*, Summer 1971 (Vol. 74, No. 2), pp. 147-148, 154-155; K. B. Porter et al., "Evaluation of Short Stature Winter Wheats . . . for Production Under Texas Conditions," *Agronomy Journal*, July-Aug. 1964 (Vol. 56, No. 4), pp. 393-396.

[15] Heyne and Campbell, *op. cit.*, pp. 154-155; Porter, et al., *op. cit.*, p. 396; A. R. Chowdhry and R. E. Allan, "Inheritance of Coleoptile Length and Seedling Height and Their Relation to Plant Height of Four Winter Wheat Crosses," *Crop Science*, Jan.-Feb. 1963 (Vol. 3, No. 1), pp. 53-58.

[16] J. R. Welsh, et al., "Root Studies of Semi-Dwarf and Tall Winter Wheats," *Proceedings, 2nd International Winter Wheat Conference*, Zagreb, Yugoslavia, June 1975, University of Nebraska, Agricultural Experiment Station, MP, pp. 206-220 (source of quotation); J. R. Welsh, "Semidwarf Wheats; Their Strengths, Weaknesses," *Crops and Soils Magazine*, March 1976, p. 10; and J. F. Pepe and J. R. Welsh, "Soil Water Depletion Patterns Under Dryland Field Conditions of Closely Related Height Lines of Winter Wheat," *Crop Science*, Sept.-Oct. 1979 (Vol. 19, No. 5), pp. 677-680.

[17] D. L. Keim and W. E. Kronstad, "Drought Resistance and Dryland Adaptation in Winter Wheat," *Crop Science*, Sept.-Oct. 1979 (Vol. 19, No. 5), pp. 574-576.

[18] Heyne and Campbell, *op. cit.*, p. 154.

[19] Telephone conversation with Kenneth L. Goertzen, Seed Research Inc. (Scott City, Kansas), May 4, 1979.

[20] There is considerable literature on this subject. See, for example: J. T. Feather, C. O. Qualset, and H. E. Voght, "Planting Depth Critical for Short-Strawed Wheat Varieties," *California Agriculture*, September 1968 (Vol. 22, No. 9), pp. 12-14; R. E. Allan, O. A. Vogel, and C. J. Peterson, "Seedling Emergence Rate of Fall-Sown Wheat and Its Association With Plant Height and Coleoptile Length," *Agronomy Journal*, July-Aug. 1962, (Vol. 54, No. 4), pp. 347-350; J. C. Hoff, B. J. Kolp and K. E. Bohnenblast, "Inheritance of Coleptile Length and Culm Length in Crosses Involving Oleson's Dwarf Spring Wheat," *Crop Science*, Mar.-Apr. 1973 (Vol. 13, No. 2), pp. 181-184; G. N. Fick and C. O. Qualset, "Seedling Emergence, Coleoptile Length, and Plant Height Relationships in Crosses of Dwarf and Standard-Height Wheats," *Euphytica*, November 1976 (Vol. 25, No. 3), pp. 679-684; and G. M. Bhatt and C. O. Qualset, "Genotype-Environment Interactions in Wheat: Effects of Temperature on Coleoptile Length," *Experimental Agriculture*, January 1976 (Vol. 12, No. 1), pp. 17-22.

[21] John M. Schmidt, "Development of Winter Varieties for Low Rainfall, Non-Irrigated Areas," *Proceedings, 2nd International . .*, *op. cit.*, pp. 65-73; quote from pp. 71-72.

[22] The reason for this is that the lower protein levels result in lower water absorption capacity of the flour, which reduces the loaf volume of the dough.

[23] *Summary Progress Report—1978; U.S. Grain Marketing Research Laboratory*, USDA, Science and Education Administration, ARNA-NC-1, February 1979, p. 7.

[24] R. E. Heiner and D. V. McVey, "Registration of Era Wheat," *Crop Science*, July-Aug. 1971 (Vol. 11, No. 4), p. 604; R. E. Heiner, D. V. McVey, and F. A. Elsayed, "Registration of Kitt Wheat," *Crop Science*, Sept.-Oct. 1976 (Vol. 16, No. 5), p. 744; F. A. Elsayed, et al., "Registration of Angus Wheat," *Crop Science*, Sept.-Oct. 1979 (Vol. 19, No. 5), pp. 749-750.

[25] John F. Pepe and Robert E. Heiner: "Influence of Two Different Dwarfing Sources on Yield and Protein Percentages in Semi-Dwarf Wheat," *Crop Science*, Sept.-Oct. 1975 (Vol. 15, No. 5), pp. 637-639; "Plant Height, Protein Percentage, and Yield Relationships in Spring Wheat," *Crop Science*, Nov.-Dec. 1975 (Vol. 15, No. 6), pp. 793-797.

[26] Derived from project papers and annual reports on file in AID/DS/AGR. The principal investigators have been Drs. P. J. Mattern and V. A. Johnson (USDA). The project was begun in 1966 and will conclude in 1979. This work was summarized, as of 1976, by Johnson in "Wheat Protein" in *Genetic Diversity in Plants* (ed. by Amir Muhammed, et al.), Plenum Press, New York and London, 1977, pp. 371-385. Several recent summaries will soon be published in conference proceedings. Also see J. W. Schmidt, et al., "Registration of Lancota Wheat," *Crop Science*, Sept.-Oct. 1979 (Vol. 19, No. 5), p. 749.

[27] This section is based on a wide variety of materials provided by Kenneth L. Goertzen of Seed Research Inc. of Scott City, Kansas. The packet included talks, articles, some from the *Annual Wheat Newsletter* and the following article: George L. Smith, "High Protein . . . Good Yielding . . . Wheats Are Here," *Kansas Farmer*, Feb. 3, 1979. I have also benefited from several telephone discussions with Mr. Goertzen and with Betty L. Goertzen.

[28] The use of alien germplasm for this purpose emerged as a byproduct of research on wheat hybrids.

[29] For further information, see Malcolm D. Bale and Mary E. Ryan, "Wheat Protein Premiums and Price Differentials," *American Journal of Agricultural Economics*, August 1977 (Vol. 59, No. 3), pp. 530-532.

[30] This section is, except as noted, based on Welsh, *op. cit.* (1966), p. 10, and on various talks and papers prepared by Floyd W. Smith, Director, Kansas Agricultural Experiment Station.

[31] V. A. Johnson, A. F. Drier and P. H. Grabouski, "Yield and Protein Responses to Nitrogen Fertilizer of Two Winter Wheat Varieties Differing in Inherent Protein Content of Their Grain," *Agronomy Journal*, Mar.-Apr. 1973 (Vol. 65, No. 2), pp. 259-263.

[32] This section is based, except as otherwise noted, on Dana G. Dalrymple, *Development and Spread of High-Yielding Varieties of Wheat and Rice in the Less Developed Nations*, USDA/OICD, FAER 95, September 1978 (6th edition), pp. 22-23, 34.

[33] G. N. Fick and C. O. Qualset, "Genes for Dwarfness in Wheat, *Triticum Aestivum L*," *Genetics*, November 1973 (Vol. 75, No. 3), pp. 531, 535, 536; M. A. Khalifa and C. O. Qualset, "Intergenetype Competition Between Tall and Dwarf Wheats. II. In Hybrid Bulks," *Crop Science*, Sept.-Oct. 1975 (Vol. 15, No. 5), pp. 640-644. Ramona 50 was derived from a series of backcrosses involving Ramona (and Martin). The parents of Ramona (Bunyip and White Federation) were secured from the New South Wales exhibit at the Panama Pacific International Exposition in San Francisco in 1915 (J. Allen Clark and B. B. Bayles, *Classification of Wheat Varieties Grown in the United States in 1939*, USDA, Technical Bulletin No. 795, June 1942, p. 81). It is possible that some of the short wheat varieties such as those originating from the Purdue AES, might have a similar gene, but this has evidently not been studied (letter from Qualset, Sept. 19, 1979).

[34] C. F. Konzak, "A Review of Semidwarfing Gene Sources and a Description of Some New Mutants Useful for Breeding Short-Stature Wheats," *Induced Mutations in Cross-Breeding*, International Atomic Energy Agency, Vienna, 1976, pp. 79-93; quote from p. 80.

[35] C. F. Konzak, N. I. Hashmi, and M. L. Hu, "Registration of Seven Lines of Wheat Germplasm," *Crop Science*, in press.

[36] Konzak, *op. cit.*, pp. 89, 92.

[37] Pepe and Heiner, *op. cit.*

[38] Briggle and Vogel, *op. cit.*, p. 125; Charles Hayward and J. M. Poehlman, "Registration of Lewis Wheat," *Crop Science*, Mar.-Apr. 1967 (Vol. 7, No. 2), p. 169.

[39] See *Rice Breeding With Induced Mutations*, International Atomic Energy Agency, Vienna, Technical Reports Series: (Vol. I) No. 86, 1968, 155 pp.; (Vol. II) No. 102, 1970, 124 pp.; and (Vol. III) No. 131, 1971, 198 pp. The International Institute of Tropical Agriculture (IITA) began screening induced mutations in 1978 for possible sources of dwarfism for upland rice.

[40] L. W. Briggle, "Heterosis in Wheat—A Review," *Crop Science*, Sept.-Oct. 1963 (Vol. 3, No. 5), pp. 407-412. Also see John W. Schmidt, "Breeding and Genetics," in *Wheat: Production and Utilization* (ed. by G. E. Inglett), Avi Publishing Co., Westport, 1974, pp. 16-18.

[41] This section is based on: Briggle, *op. cit.*; James A. Wilson, "Hybrid Wheat Breeding," *Rice Breeding*, IRRI, 1972, pp. 593-602; Homer E. Socolofsky, "The World Food Crisis and Progress in Wheat Breeding," *Agricultural History*, October 1969 (Vol. 43, No. 4), pp. 435-436; and discussions with various wheat breeders and specialists. For further discussion of economic matters, see Robert E. Retzlaff, *The Economics of Hybrid Wheat*, Nebraska Cooperative Extension Service, EC 76-864, February 1976, 11 pp.

[42] J. W. Jones: "Hybrid Vigor in Rice," *Journal of the American Society of Agronomy*, May 1926 (Vol. 18, No. 5), pp. 423-428; "Improvement in Rice," *Yearbook of Agriculture, 1936*, USDA, pp. 433, 444-445.

[43] H. L. Carnahan, et al., "Outlook for Hybrid Rice in the USA," *Rice Breeding*, IRRI, 1972, pp. 603-607; M. D. Davis and J. N. Rutger, "Yield of F_1, F_2, and F_3 Hybrids of Rice (*Oryza sativa L*)," *Euphytica*, November 1976 (Vol. 25, No. 3) pp. 587-595.

[44] See: T. T. Chang, "Hybrid Rice," in *Plant Breeding Perspectives* (ed. by J. Sneep and A. J. T. Hendriksen), PUDOC, Wageningen, 1979, pp. 173-174; and Dalrymple, *op. cit.* (1978), pp. 88-89.

[45] This section is based on W. Kronstad, et al., "Spring x Winter Crosses for Winter and Spring Wheat Improvement," *Proceedings, 2nd . . . , op cit.*, pp. 105-107; *CIMMYT Review, 1978*, pp. 67-68.

[46] See, for example, *World Food and Nutrition Study; The Potential Contributions of Research*, National Academy of Sciences, Washington, D.C., 1977, pp. 69-80; P. R. Day, "Plant Genetics: Increasing Crop Yield," *Science*, Sept. 30, 1977 (Vol. 197), pp. 1334-1339; and S. W. Wittwer, "Future Technological Advances in Agriculture and Their Impact on the Regulatory Environment," *Bioscience*, October 1979 (Vol. 29, No. 10), pp. 603-605.

VI. CHANGES IN YIELDS

It is almost certain that within a generation the ever increasing population of the United States will consume all the wheat grown within its borders, and will be driven to import, and, like ourselves, will scramble for a lion's share of the wheat crop of the world.

—Sir William Crookes, 1898*

The purpose of utilizing semi-dwarf varieties, in association with other inputs, is to increase yields per unit of land. To what extent has this been accomplished? This is a key question, yet is one which is very difficult to answer at present because of a lack of evidence. Nevertheless, some pieces of information exist which provide a partial background. Hopefully these fragments will encourage others to give the matter the more detailed study it deserves.

General Trends

Compared with earlier performance, the rate of growth of yield of all crops in the United States has slowed appreciably in recent years. The yield index has dropped as follows:[1]

Period	Annual Percentage Increase
1950-52 to 1960-62	2.7
1960-62 to 1970-72	1.8
1970-72 to 1975-76	0.1

Crosson notes that:

> While bad weather and high fertilizer prices may account for some of the slowdown in the growth of yields and total productivity since the early 1970's, it is likely that the experience also reflects the using up of the productivity potential of the technologies on which U.S. farmers have relied since the end of World War II.[2]

A similar point of view was expressed in another recent study of the trend in yields of 12 crops in the United States. The study covered the years from 1961 to 1977 and concluded that average yields in recent years were stationary, an indication of a yield plateau. Wheat and rice yields were oscillatory (a trendless series dominated by cycles) while the rest were random fluctuations. In the authors' words:

> This finding may imply that since the 1960's prevailing technology in producing these crops has been adopted to the largest extent possible.
>
> Two possible developments could prevent continued plateauing. One is new technical breakthroughs such as high yield, pest- or drought-resistant varieties. The other is dramatic changes in the cost-price structure, such as a marked reduction in the cost of fertilizer, which would make it possible for farmers to increase production investment . . . because of increasing production costs (both fixed and variable) producers are becoming more concerned about net return per dollar investment than increased yield.[3]

Similar concerns about yield plateaus were expressed in a report published in 1975 by the National Academy of Sciences. The study notes that crop yields have risen over the years as fertilizer use per acre has increased, but that the rate of increase has been at a declining rate as applications reached higher levels. With respect to the future, the Academy study suggests that:

> . . . a definite leveling off of crop yield response to fertilizer application is in prospect. Should this occur and not be offset by other technologies, the practice of more fertilizer usage as a way of increasing crop output will not be applicable.[4]

Resource and environmental constraints could exacerbate the problem.

Could semi-dwarf varieties be the type of technology which could help offset the declining yield response to fertilizer? Some insights may be gained by examining available yield data for wheat and rice.

Wheat

Semi-dwarf varieties are not released unless they show some superiority—particularly with respect to yields—over existing varieties. This superiority is normally documented in extensive testing and field trials. The results at the farm level, however, have been far less thoroughly documented.

Experimental-Level Yields

New wheat varieties released by public agencies in the United States receive exhaustive testing before they are released. They are grown first at the experiment station, tested in trials in the State, and then at the regional level in combination with other varieties. Trials are designed to test many plant characteristics, including disease resistance, but yield is of primary importance. As a result of this process, breeders have quite a good idea of the productive characteristics of the variety before it is released.

The yield levels as recorded in trials are usually noted in the release announcement or in the *Crop Science* registration. The advantage is often expressed in terms of some leading traditional variety or in comparison with some recent release. This process produces many figures, but they are not highly standardized and are not easily compared or summarized. In some cases, only a nonquantitative general statement is given, such as "greater than" or "superior to." And as might be expected, the yields are for widely different periods and growing conditions.

Review of the available data for each of the semi-dwarfs reported in Chapter III underlined the difficulties of making any summary statement. Where yield advantages were reported, they ranged from 0 to 40 percent, with most in the 5- to 25-percent range. When the comparison was with traditional varieties, the advantage tended to run in the higher end of this range; when the comparison was with other semi-dwarfs, the advantage was generally in the lower end. The advantage was considerably higher under irrigation or high rainfall conditions than under dryland conditions. If one had to pick an overall average, a conservative estimate of the yield advantage of the semi-dwarfs compared with traditional varieties might be about 15 percent. This figure, however, is subject to so many qualifications that it is of doubtful value.

One particularly useful, though limited, source of information on relative yields is the wheat "living museum nursery" of the New York State Agricultural Experiment Station at Cornell University.[5] The "museum" contains all of the varieties developed at Cornell and is grown annually. The nursery "demonstrates visually the changes that have taken place in wheat varieties through breeding." Data were recently summarized for 12 varieties over a 10-year period (table 10). Plant height of the newer varieties gradually declined, with a particular drop when Yorkstar was introduced. At the same time, the yields of the newer varieties gradually rose. Yorkstar was 12 percent shorter than its predecessor, and had yields which were 9.3 percent higher. Ticonderoga, the newest variety listed, was 26.7 percent shorter than the oldest variety, and had yields which were 46.7 percent higher. The yield potential has been increased further with the subsequent release of two more semi-dwarfs: Houser (1977) and Purcell (1979). Compared with Ticonderoga over a 10-year period, Houser yielded 7.7 percent more while Purcell yielded 14.1 percent more.[6] Thus the average yields of the Cornell varieties increased by about 67 percent in about 60 years, with much of this increase coming with the intro-

Table 10. Average Height and Yields of Cornell Wheat Varieties in Living Museum Nursery, Ithaca, N. Y., 1966 to 1975.

Variety	Year of Release	Height	Yield
		Cm.	*Bu./acre*
Honor	1920	116	44.1
Forward	1920	112	47.8
Valprize	1930	116	44.2
Yorkwin	1936	115	48.4
Nured	1938	114	46.0
Cornell 595	1942	112	52.1
Genesee	1950	111	52.5
Avon	1959	108	53.8
Yorkstar[1]	1968	95	58.8
Arrow[2]	1971	94	57.3
Ticonderoga[1]	1973	85	64.7

[1] Norin 10-based semi-dwarf. Yorkstar is tall for a semi-dwarf.

[2] Arrow is a short variety which does not contain Norin-10 in its pedigree.

Source: Neal F. Jensen, "Limits to Growth in World Food Production," *Science*, July 28, 1978 (Vol. 201), p. 201.

duction of semi-dwarfs. These increases are of particular potential significance in New York because the total area is normally very heavily planted to the new varieties (fig. 4 on p. 20).

Somewhat similar date gathered in Minnesota in 1974 at three locations showed the following yield levels.[7]

Variety	Year Released	Yield
		Kg./ha.
Marquis	1926	2,028
Thatcher	1935	2,230
Lee	1958	2,425
Chris	1967	2,735
Era	1971	3,623

The yield of Era, a semi-dwarf, was 32.5 percent higher than Chris, and 78.6 percent higher than Marquis. The yield advantage over Chris was somewhat lower in another test (24.6 percent). On the other hand, two experimental lines yielded 4 and 8 percent higher, respectively, than Era.[8]

A quite different procedure was followed in part of a recent study in Idaho. Wheat breeders in the western region agricultural stations were asked to compare yields of new varieties (those available in the early 1970's) with those available to the farmer prior to 1939. They indicated that varieties developed between 1939 and 1974 increased potential wheat yields by 41 percent.[9]

The relative yield levels obtained in experimental tests, however, may not be repeated at the farm level. The experimental test data measure potential; the reality of actual farm level yields can be quite different.

Farm-Level Yields

The virtually complete lack of data on relative yields of wheat varieties at the farm level provides a fundamental stumbling block in directly assessing the actual performance of the semi-dwarf varieties. About all that can be done at this point is to examine some historical trends in yields, particularly in States where the semi-dwarfs have been widely adopted. This procedure is not very precise, but perhaps it will provide some preliminary insights.

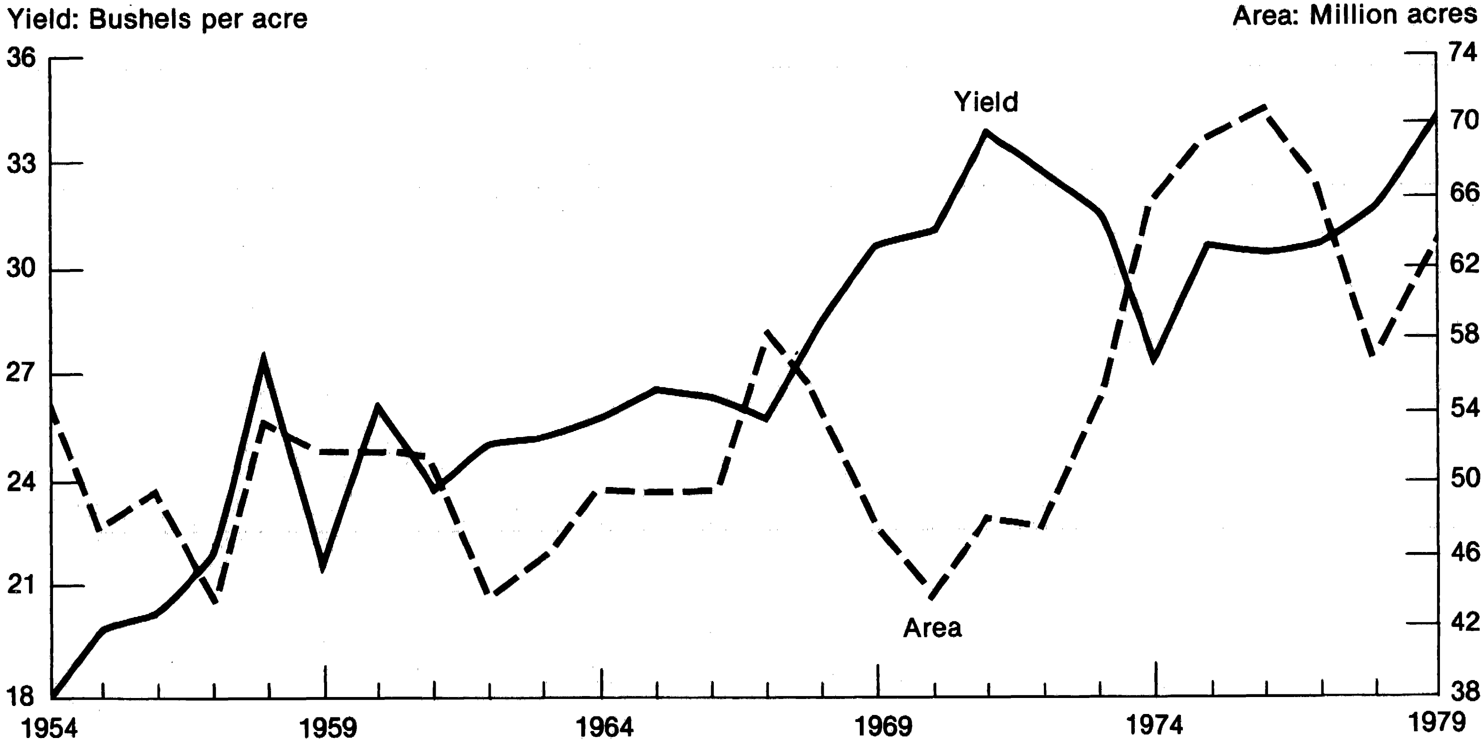
LONG-TERM U.S. TRENDS. Data are available on U.S. wheat yields since 1866.[10] Yields increased only slightly from 1866 to about 1940, when they moved to a higher plateau which held to the mid-1950's.[11] Yields then rose sharply to 1971. Thereafter they dropped somewhat, particularly in 1974. Average yields for 1977 and 1978 (31.1 bushels/acre) were about the same as in 1969 and 1970 (30.8 bushels/acre). Preliminary estimates indicate a record yield in 1979 (34.2 bushels/acre). Data for the 26-year period from 1954 to 1979 are summarized in graphic form in figure 9.

In examining the trends in wheat yields, it is important to keep concurrent changes in area in mind (fig. 9). This is because as area contracts, the most productive land may be kept in wheat, bringing about higher yields. Conversely, as the area expands, less productive land may be brought into use, thus lowering average yield levels.[12] Starting in 1967, the area planted dropped to a low point in 1970 (a period when yields were rising), then rose sharply through 1976 (a period when yields were declining), and then dropped sharply in 1977 and 1978 (a period when yields rose slightly). Thus, there appears to have been an inverse relationship between area and yield from 1967 to 1978. In 1979, however, preliminary data suggest that both area and yield rose.

The proportion of area planted to semi-dwarf varieties, as reported in Chapter III, was (in percent): 1959, 0; 1964, 2.9; 1969, 7.0; and 1974, 22.1. Thus the increase in the semi-dwarf proportion coincided with an increase in yields in 1964 and 1969, and with a rather sharp drop in 1974. Preliminary estimates suggest an increase in both yields and in the semi-dwarf proportion in 1979. The semi-dwarf proportion in 1964 and 1969 was likely too low to have had much of an impact on yields; the increases were probably largely due to the introduction of other improved varieties, increased use of fertilizer and other practices, and perhaps weather. By 1974, the semi-dwarf proportion

Figure 9

Wheat: Average Yields and Area Harvested, United States, 1954-79



reached the level where it might have had some measurable impact on U.S. yields. Yet in that year, yields were lower than at any point since 1967. But as noted above, there was a sharp increase in the overall wheat area in 1974, which may have brought less productive land into use. Fertilizer applications on wheat on farms surveyed by USDA (as seen in figure 8 on p. 87) rose gradually through 1978, although there was a drop in the proportion of wheat area receiving fertilizer in 1977 and 1978.

Hence, wheat yields leveled out through 1978, despite a substantial increase in the semi-dwarf area in 1974, and a gradual increase in fertilizer use on sample farms. As noted in the opening section of this chapter, the yield levels of all crops also leveled out during this period. The reasons for this were thought to be a combination of (a) weather, (b) economic factors, and (c) exhaustion of technology. All three may have played some role in the case of wheat. In particular, economic forces should have stimulated the area under cultivation as wheat prices received by farmers rose sharply in 1973. From 1973 to 1975 they averaged $3.87 per bushel, compared with an average of $1.45 per bushel during 1963-72.[13] (It should be recalled that the Russian wheat purchase was made in the summer of 1972 and that some of the developing nations in Asia experienced shortfalls in grain production in the early 1970's.)

As noted earlier, record yields were obtained in 1979. Were these an aberration due to good weather, or do they mark a more permanent shift? In either case, did the semi-dwarfs play a significant role? It is too soon for an answer; the question must be left to future analysts. Some insights, however, may be gleaned from a closer look at yield changes at the State level.

STATE-LEVEL STATISTICS. The large number of States for which yield data are available, 42 in all, makes analysis a bit cumbersome. The process may be simplified by examining data for 15 States with either large semi-dwarf areas or relatively high proportions of semi-dwarfs. Both time series and cross-sectional data will be considered.

Time series data for the 15 States are summarized in table 11. Yield levels have been averaged for two 5-year periods to help even out the effect of weather (even so, the weather may not be fully comparable in each State for each period). Easily the largest increases in yields were obtained in three Western States (California, Arizona, and Nevada) with high proportions of semi-dwarfs. In California—unlike other States—yields steadily increased during the 1970's. The next group of seven States had yield increases above the national average; all but one (Montana) had semi-dwarf proportions at or above the national average. A final group of five States had yield increases below the national average. Three States (Oregon, Washington, and New York[14]) with fairly high semi-dwarf proportions did not show very sharp changes in yield. This may indicate that these States, which were among the first to use semi-dwarfs, were operating at a relatively high proportion of their potential at an earlier date than were some of the other States.

Table 11. Changes in Wheat Yield and Semi-Dwarf Area In Selected States

State	Increase in Yield[1] 1959-63 to 1974-78	Average Yield[1] 1974-78	Proportion of Area Planted to Semi-Dwarfs, 1974[2]
	Percent	*Bu./acre*	*Percent*
California	122.3	60.7	90.5
Arizona	70.0	70.4	98.8
Nevada	58.8	55.9	88.8
Montana	42.3[3]	28.6	6.4
Idaho	35.7	47.1	61.4
Minnesota	33.1	33.0	84.3
South Dakota	29.8	19.6	24.9
North Dakota	28.1	25.1	20.7
Oregon	27.8	42.8	72.4
North Carolina	25.7	31.8	22.2
Washington	20.4	42.5	64.0
Kansas	20.3	29.0	9.4
New York	17.5	39.0	77.3
Texas	9.8	21.2	28.4
Wisconsin	3.5	35.5	26.6
United States	23.5	30.1	22.1

[1] Calculated from USDA estimates.

[2] From table 6 (p. 62).

[3] This figure is unusually high because of a particularly bad year in 1961. Excluding 1961, the number would have been 33.0

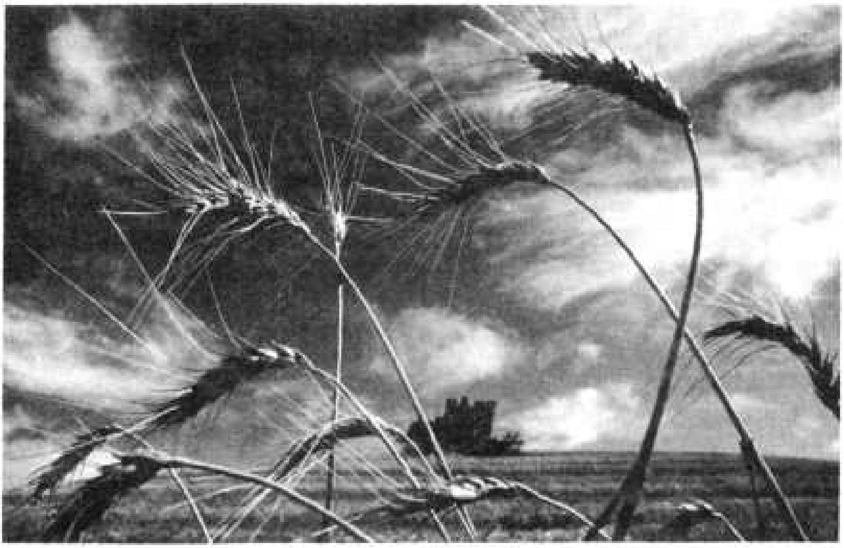


Plate 10. Combining wheat (background), Palouse, Wash.

In evaluating yields, fertilizer use and irrigation should also be examined. A close relationship should be expected between yields and fertilization, and between yields and irrigation in semi-arid areas. There should also be a similar, though perhaps not so close, relationship between the use of semi-dwarfs and the above factors. Cross-sectional data for 1974 (table 12) would seem to bear out these general expectations, with some exceptions. (The fertilizer data do not, of course, reflect the actual amount of fertilizer applied per unit of land.)

Since even 15 States are awkward to discuss briefly when several variables are involved, data in table 12 may be further condensed into three yield groups as follows:

Yield Group	Number of States	Weighted Proportion of Area		
		Semi-Dwarf	Fertilized	Irrigated
			Percent	
Top 3	3[1]	92.0	81.6	64.3
Above U.S. Avg.	6[2]	69.7	83.5	9.9
U.S. Avg. & Below	6[3]	16.5	57.2	5.9
U.S. Average	49	22.1	62.0	5.2

[1] Ariz., Calif., Nev.
[2] Minn., N.Y., Oreg., Wash., Idaho, N.C.
[3] Texas, S. Dak., N. Dak., Okla., Kans., Mont.

The three States, all in the Southwest, with the top yields had relatively high proportions of semi-dwarfs, area fertilized, and area irrigated. By comparison, the next group of six States with lower (but still above-average) yields, had a lower proportion of semi-dwarfs and a much lower proportion of irrigated area, but had a higher proportion of land fertilized. The third group, composed of Plains States, was considerably lower on all three counts, and below the U.S. average on two of them.

The difference in yields between irrigated and unirrigated areas in 1974 (table 12) was striking. For the United States as a whole, irrigated yields were nearly 75 percent higher than unirrigated yields. In States where 10 percent or more of the area was irrigated, the differentials were widest in (decreasing order): California, Washington, Idaho, Oregon, and Texas. Irrigated yields in Washington were the highest in the country. Semi-dwarfs would be expected to represent a high proportion of the irrigated area planted to wheat. It is not known, however, what the actual figure is. But even if all the irrigated area (5.2 percent) were planted to semi-dwarfs in 1974, this would have represented only 23.5 percent of the total semi-dwarf area; the remaining 76.5 percent of the semi-dwarf area would have been on unirrigated land, a large portion of which has adequate natural rainfall. Prospects for irrigation in some portions of the Great Plains and the Southwest are, as noted in the previous chapter, clouded. On the other hand, gradual improvements in water management practices could help increase yields.

Table 12. Comparison of Wheat Cultural Practices and Yields, 15 States, 1974

State	Proportion of Wheat Area			Average Wheat Yields[3]		
	Semi-Dwarfs[1]	Fertilized[2]	Irrigated[2]	Wholly Irrigated	Unirrigated	Total
	Percent			*Bu./acre*		
Arizona	98.8	94.9	100.0	63.6	–	63.6
California	90.5	78.1	53.4	64.0	33.5	49.3
Nevada	88.8	81.9	100.0	43.7	–	43.7
Minnesota	84.3	82.5	([4])	28.1	28.9	28.9
New York	77.3	84.2	0.1	48.1	43.1	43.1
Oregon	72.4	79.6	10.0	59.7	38.0	40.1
Washington	64.0	91.1	9.9	67.1	36.9	39.4
Idaho	61.4	72.9	31.0	59.8	33.8	40.8
Texas	28.4	56.4	25.5	24.2	15.6	17.5
South Dakota	24.9	39.4	0.2	23.1	18.4	18.4
North Carolina	22.2	81.7	0.1	37.8	35.2	35.2
North Dakota	20.7	58.5	0.1	39.1	20.5	20.5
Oklahoma	16.5	66.2	2.0	24.8	21.6	21.5
Kansas	9.4	59.9	3.4	34.9	26.8	27.1
Montana	6.4	47.9	1.4	38.0	22.9	23.1
United States	22.1	62.0	5.2	45.6	26.1	26.9

[1] From table 6 (p. 62).
[2] *1974 Census of Agriculture*: Vol. I, Part 51, p. II-37; Vol. II, Part 4, p. IV-23
[3] *1974 Census of Agriculture*: Vol. II, Part 9, pp. I-35, I-41, I-47. Some of the State average yields differ slightly from those reported by USDA.
[4] Less than 0.1 percent.

CONTRIBUTIONS OF IMPROVED VARIETIES. The semi-dwarf varieties would seem to be associated, along with other inputs, with substantial increases in yield in some States, and less closely associated with yield changes in others. We cannot say much more specifically about the semi-dwarfs until additional data are available. But it may be of interest to review briefly the results of several other studies that have attempted to delineate the contributions of a wider group of improved varieties at the farm level.

In 1953, Salmon and others analyzed a half century of wheat improvement in the United States and estimated that the better varieties available in 1950 yielded 40 percent more grain than did the varieties in use in 1900. The advances occurred mostly in the last decade of the period and were evident in all regions of the country.[15] A subsequent study, however, suggested that the authors "over-attributed" to varietal change. Johnson and Gustafson calculated a varietal contribution of about 40 percent of the figure reported by Salmon, et al. They also found that in the 1928-41 and 1945-54 periods, adoption of new varieties had a major effect on yields in the Western States, but no significant effect in the Eastern States. About 60 percent of the yield increase in the West was attributed to new varieties, while most of the increase in the East was attributed to fertilizer.[16]

A recent study concerned the contribution of all varieties, including semi-dwarfs, developed in the western region of the United States for the 36-year period from 1939 to 1974. The effect of other variables was sorted out in statistical analysis. The results suggested that all wheat research expenditures in the region increased wheat yields in the region by nearly 25.3 percent in one set of calculations, and by about 20.7 percent in another set. Of the latter, perhaps 11.9 percent was contributed by the breeding research, and 8.8 was contributed by other types of research. A comparable procedure suggested that U.S. wheat research expenditures were responsible for a 27.1-percent increase in the U.S. wheat yields during the same period.[17]

In the above study, of the total increase due to research, an estimated 57.4 percent was contributed by breeding research and 42.6 percent by other aspects of research (excluding fertilizer). In the New York study cited earlier, the author suggested that of the increase in State yields from 1936 to 1975, 49 percent was due to breeding and 51 percent to other technological improvements (including fertilizer). In Minnesota from 1940 to 1975, it has been estimated that 45 to 51 percent of the yield increase was due to breeding (26 to 29 percent for yield and 19 to 22 percent for disease resistance), 19 to 26 percent to cultural practices (fertilizer and herbicides), and 26 to 32 percent to mechanization.[18] On the basis of these studies, breeding research appears to have been responsible for about half of the yield increases.[19]

INTERNATIONAL YIELD COMPARISONS. On an international basis, U.S. wheat yields in 1977 were not particularly high. They averaged 2.06 metric tons per hectare (mt/ha.), compared with a global average of 1.67 mt/ha. The highest yields, 5.24 mt/ha., were achieved in the Netherlands and were 2.54 times the U.S. average. All told, 26 countries had higher average yields in 1977. Most of these countries, however, raise wheat under more favorable conditions than the United States, where much is grown in the relatively harsh and dry lands of the Great Plains.[20]

Effect on Production

To the extent that semi-dwarf wheats have higher yields than traditional varieties, it would be expected that they would represent a larger portion of production than the area figure alone would suggest. No production data, however, are available on a national level to document this point.

In the case of the Pacific Northwest, estimates are available of the production by variety for certain years. Comparable area figures are not reported. The estimates refer to eastern Washington (20 counties), Oregon (14 counties), and northern Idaho (9 counties). In 1977, the semi-dwarf varieties identified in this report accounted for 81.2 percent of the production in this region. By comparison, the semi-dwarf proportion of production was at least 75.8 percent in 1975, and 76.4 percent in 1974 (no survey was conducted in 1976).[21] In 1974, the statewide proportions of semi-dwarf varieties were (as noted in table 6 on p. 62): Washington, 64.0 percent; Oregon, 72.4; and Idaho, 61.4. As expected, the semi-dwarfs appear to have contributed more to production than their proportion of area alone would suggest in 1974. The calculation might well be repeated when the 1979 data become available.

While it has been assumed that the effect of semi-dwarfs would be wholly on yields, it is possible that in some areas they might also have some influence on area planted. This would not be through expanding the geographic boundaries of wheat adaptation, because dwarfing itself should have no biological influence of this nature. But the semi-dwarfs might well influence the area planted to wheat through their influence on profitability.

Two examples may be cited. In Arizona, the introduction of semi-dwarf Durum, which yielded well under irrigated conditions and drew relatively high prices, encouraged area expansion through 1976. Some of this expansion represented replacement of other varieties of wheat and some represented replacement of other crops.[22] In 1977, however, the Durum area dropped sharply, largely in response to economic conditions (a drop in the price for Durum and increased profitability of cotton) and to some extent due to grain color. But as of late 1979, in response to higher Durum prices and with improved varieties available, the area was in the process of expansion.[23] The growth in wheat area in California (more than a doubling between 1955-59 and 1975-79) is thought to be a result of the availability of varieties that could be grown with irrigation and high fertilization, e.g., semi-dwarfs.[24]

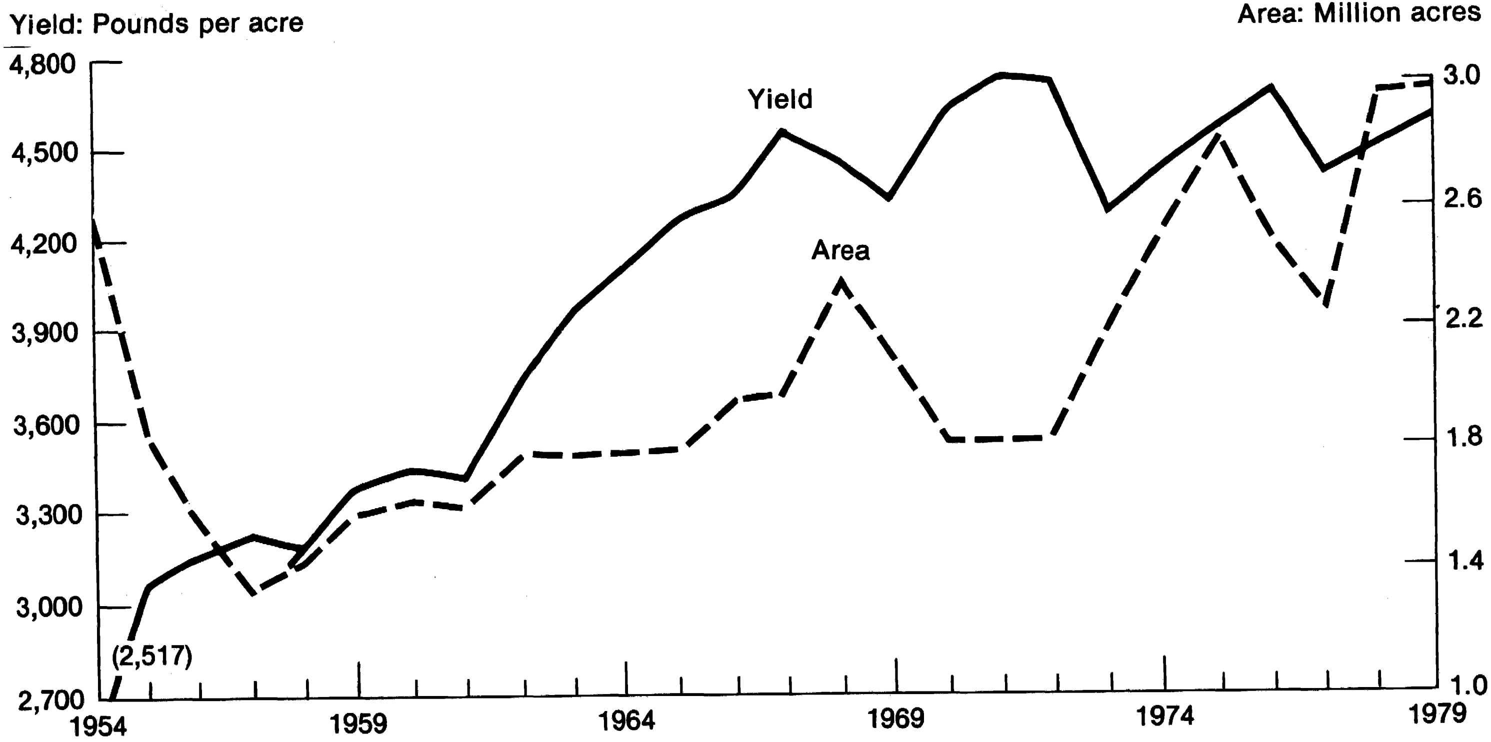
Rice

Since the semi-dwarf varieties only began to be commercially planted in 1978, it is much too early to perceive any effect on yields at the national level. In California, however, they accounted for about 10 percent of the total area in 1978 and 50 percent in 1979. Comparative yield levels in California were (in pounds per acre): 1977, 5,810; 1978, 5,220; and 1979 (preliminary), 6,450.[25] The 1979 yield was a record, and was 11.1 percent above the previous high attained in 1977. While the weather was unusually good in California in 1979, semi-dwarf varieties undoubtedly played a major role in bringing about a rise in yields.

A brief review of trends in U.S. rice yields for the 51-year period from 1929 to 1978 may be of background interest. Average U.S. yield levels were fairly stable from 1929 to 1949, ranging from 1,902 to 2,194 pounds per acre. From 1949 through 1967 they increased sharply, from 2,122 pounds/acre to 4,537 pounds/acre. They then evened out at between 4,274 to 4,718 pounds/acre from 1967 to 1978. The preliminary estimate for 1979 is 4,588 pounds/acre. Data for the 21-year period from 1959 to 1979 are presented graphically in figure 10.[26]

Figure 10

Rice: Average Yields and Area Harvested, United States, 1954-79



Regional trends differ. Yields in California were considerably higher than the national average. They followed roughly the same pattern over time, but increased particularly sharply in 1956. They have continued to rise since then, especially in 1979. Yields in the Southern States have shown little yield increase for the past 11 years, but this was a period of sharp increase in area. Use of the shortest southern varieties—Brazos, Mars, and Nortai—was quite limited (the three accounted for only 3.0 percent of the South's rice area in 1978 and 3.75 percent in 1979[27]).

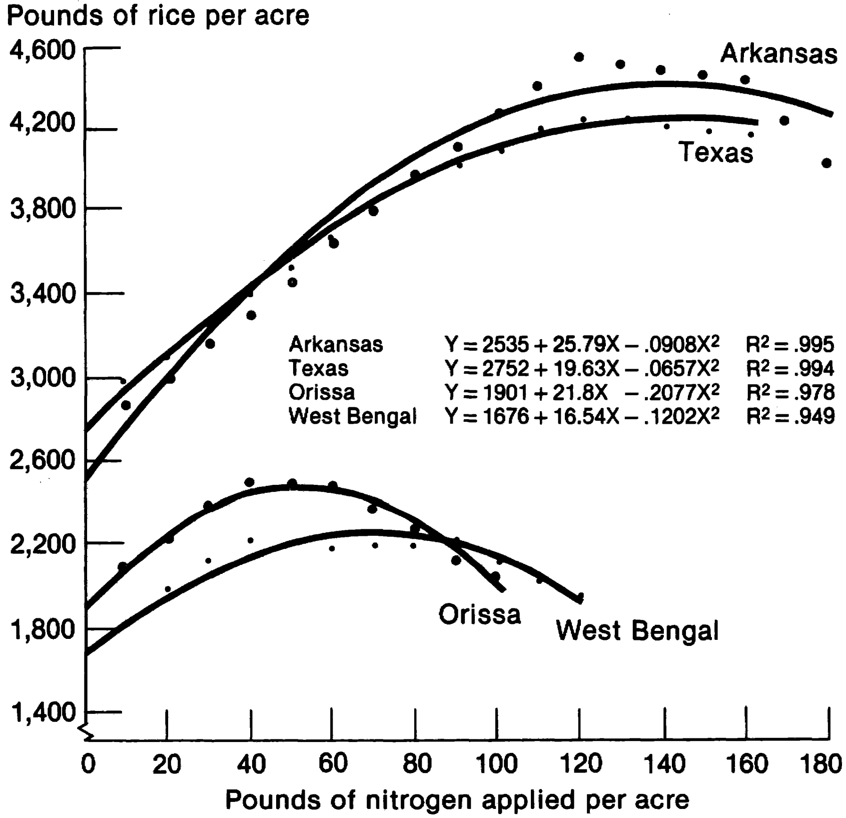
The increase in yields from 1949 to 1967 was probably largely due to improved varieties, increased and better timed fertilizer use, and improved weed control. One study allows us to isolate the fertilizer effect. Yield figures have been reported for the Fortuna variety grown over a 28-year period from 1928 to 1955 at Stuttgart, Ark. Fertilizer was not applied during the first 20 years, but was applied the last 8 years at 40 pounds/acre. During the first 20 years, yields averaged 2,304 pounds/acre; during the last 7 years (excluding 1951 because of exceptionally poor weather) yields averaged 3,467 pounds/acre, a 50-percent increase. Moreover, there was a marked increase in yields over the latter period, from 2,660 pounds per acre in 1948 to 5,260 pounds per acre in 1955.[28] A previous chapter revealed that from 1964 to 1974, the proportion of the rice area fertilized increased slightly, from 95.2 percent to 99.6 percent, and the pounds of fertilizer applied per acre increased substantially, from 260 to 403 (a gain of 55 percent).

Through constant improvement, the standard U.S. varieties as of the late 1950's and early 1960's had a considerably greater ability to respond to heavy application of nitrogen than did varieties in developing nations. A comparison of yield responses for experiment stations in Arkansas and Texas and for Orissa and West Bengal in India is provided in figure 11. Semi-dwarf varieties were

Plate 11. Combining rice, Poinsett County, Ark., 1968.

Figure 11

Comparative Yield Response to Nitrogen Fertilizer at Experiment Stations, United States and India



Source: Robert W. Herdt and John W. Mellor, "The Contrasting Response of Rice to Nitrogen: India and the United States," *Journal of Farm Economics*, February 1964 (Vol. 46, No. 1), p. 152.

released subsequently. The data may not have been fully comparable due to differences in soil fertility and other factors, but they suggest that the standard for comparing the performance of the semi-dwarfs was considerably higher in the United States than in India.

On an international basis, U.S. rice yields are relatively high compared with wheat. In 1977, the average U.S. rice yield was 5.04 metric tons per hectare. The world average was 2.53 mt/ha. Five countries that were substantial producers ranked higher: South Korea, 6.60 mt/ha.; Spain, 6.11; Japan, 5.93; Australia, 5.65; and Egypt, 5.21. In 1976, U.S. yields were above those in Egypt. Thus, the U.S. yield was nearly twice the world average and only 24 percent less than that of the leading country.[29]

In making such comparisons it should be recalled that U.S. rice production is large scale and highly mechanized whereas production in many other countries is much more labor intensive.[30] Also, the gap between the United States and other leading countries has closed over time. In 1936, Jones wrote "yields in this country are relatively low." He cited data for 1934 showing that U.S. yields were less than half those in Spain and 59 percent of those in Japan.[31] The United States has gained a lot of ground since then.

Future Prospects

What are the prospects for further yield increases in wheat and rice? No one can say with certainty. While semi-dwarf varieties and associated inputs raise the yield potential, eventually yields will reach an upper ceiling given existing technology. Yields at experiment stations, as they are higher than farm-level yields, are closer to the present biological maximum. (Both the International Maize and Wheat Improvement Center in Mexico and the International Rice Research Institute in the Philippines have encountered yield ceilings in their experimental work.[32]) Deterioration in, or increased emphasis on, environmental factors could lower the maximum.[33] Economic and other conditions ensure that a point of diminishing returns is reached at a lower level than the physical maximum (some of these economic factors will be noted in the next chapter).

Evaluations of technical potential differ. One of the more pessimistic comes from Neal Jensen, a former Cornell breeder who developed a number of semi-dwarf varieties. He recently wrote of yield levels for wheat in New York:

> . . . we are approaching the end of an epoch of research and of increases in wheat productivity. . . I believe the line [of yield increases] will begin leveling off and this will be evident for the decade ending in 1985. . . productivity will continue to grow, but at a slower rate . . . and will eventually become level . . .[34]

The general nature of the yield curve Jensen discusses is quite likely. The major questions concern applicability to other States, timing, and whether significant new technological developments will create a new curve. Jensen is doubtful that the latter will occur: "It seems unlikely that any future combination of genetics, technology, or unknown factors will be able to generate a sustained rise in productivity . . ."[35]

Others are more optimistic. One is Everett Everson, a wheat breeder in Michigan who was part of the original Vogel group and who has recently developed several semi-dwarf varieties. He believes that breeders, in cooperation with plant physiologists, are on the verge of making significant advances in increasing the tolerance of wheat plants to stress or unfavorable conditions.[36] Such advances could do much to raise the average realized yield (by reducing the dips in yield), and raise the maximum potential yield level. Other technological developments are also possible—such as those noted at the end of the previous chapter—in the longer run, and they could raise the ceiling.

The outlook for wheat will undoubtedly vary by ecological region. To date, as noted, the semi-dwarfs have had their greatest effect on yields in areas with a relatively favorable environment for wheat. They have not made as large a contribution in some higher risk areas where other factors, such as moisture, limit production potential.[37] When and if it is possible to increase plant tolerance to these limiting factors, or ameliorate them in some other way, shorter height may play an increasing role in bringing about increased yields. The semi-dwarfs may also be of increasing importance in the Midwest where they so far have been little utilized.

Views on the prospects for rice would probably also show a similar range, although the general outlook should be considerably more favorable because the crop is entirely irrigated. Prospects will depend, in part, on improvements in related cultural practices, particularly weed control. In the Southern States, control of sheath blight (*Rhizoctonia solani*) will be particularly important in the case of semi-dwarfs.[38]

One of the key factors influencing the course taken in either crop in the future will be the level of investment in research. A recent USDA study has projected the following relationships between research and extension (R&E) investment and productivity growth in agriculture:[39]

Level of Technology	Real (deflated) rate of annual growth of expenditure on R&E	Resulting rate of growth of productivity by the year 2000
	Percent	*Percent*
Low[1]	0[1]	1.0
Baseline[2]	3[2]	1.1
High	7[3]	1.3

[1] Rate of growth of expenditures offset by inflation.

[2] Rate of growth which has existed since the beginning of World War II.

[3] Also assumes that significant new technologies become available for adoption.

It is sobering to note that the average annual rate of productivity growth during the past century was 1.5 percent. Only if the high level of technology is extended to the year 2025 would this rate be attained.

Only time will tell which of those projections, if any, are appropriate, and whether they also apply to wheat and rice. But one cannot evaluate probable future productivity of these two crops without considering the level of investment in research.

References and Notes

*Sir William Crookes, "The World's Wheat Supply" (Presidential Address, British Association for the Advancement of Science), in Crookes, *The Wheat Problem*, G. P. Putnam's Sons, New York, 1900, pp. 17, 18. Crookes, a chemist, emphasized the need to "rely on nitrogenous manures to increase the fertility of the land under wheat" (p. 43). With respect to the U.S., however, he subsequently noted that "neither fertilization nor rotation is practiced in the great American wheat districts to any considerable extent; their general use will imply higher prices, and higher prices imply comparative scarcity" (p. 100).

[1] Pierre Crosson, "U.S. Agricultural Production Capacity: Comment," *American Journal of Agricultural Economics*, February 1978 (Vol. 60, No. 1), p. 146.

[2] *Ibid.*

[3] Kuang-hsing T. Lin and Stanley K. Seaver, "Were U.S. Crop Yields Random in Recent Years?" *Southern Journal of Agricultural Economics*, December 1978 (Vol. 10, No. 2), pp. 139-142.

[4] *Agricultural Production Efficiency*, National Academy of Sciences, 1975, pp. 6-7.

[5] Neal F. Jensen, "Limits to Growth in World Food Production," *Science*, July 28, 1978 (Vol. 201), p. 201.

[6] M. E. Sorrells, "Soft White Winter Wheat Selection NY 61176-19 [Purcell]," Cornell University, Dept. of Plant Breeding and Biometry (prepared for College Seed Committee Meeting, 1/30/79), 1 p.

[7] William F. Hueg, Jr., "Focus and the Future With an Eye to the Past," *Agronomists and Food: Contributions and Challenges*, American Society of Agronomy, Special Publication No. 30, 1977, p. 79 (Table 1).

[8] *Ibid.*, p. 80 (Table 2).

[9] R. J. R. Sim and A. A. Araji, "The Economic Impact of Public Investment in Wheat Research in the Western Region, 1939-1974," Idaho Agricultural Experiment Station, Research Bulletin, in press.

[10] See, *Wheat, Acreage, Yield, Production, by States, 1866-1943*, USDA, Agricultural Marketing Service, Statistical Bulletin No. 158, February 1955, and the following "Statistical Bulletins on Field Crops" of the Crop Reporting Board: No. 108, March 1952; No. 185, June 1956; No. 290, June 1961; No. 384, December 1966; No. 498, November 1962; No. 587, December 1977. 1978 and 1979 estimates are provided in *Small Grains, 1979 Annual Summary . . .*, Dec. 21, 1979, p. B-6. The data are summarized graphically as follows: (a) 1866 to 1972, C. B. Luttrell and R. Alton Gilbert, "Crop Yields, Random, Cyclical, or Bunchy?" *American Journal of Agricultural Economics*, August 1976 (Vol. 58, No. 3), p. 527; (b) 1875 to 1975, J. J. Bond and D. E. Umberger, *Technical and Economic Causes of Productivity Changes in U.S. Wheat Production, 1949-76*, USDA/SEA, Technical Bulletin No. 1598, May 1979, p. 6; and (c) 1910 to 1975, Paul E. Waggoner, "Variability of Annual Wheat Yields Since 1909 Among Nations," *Agricultural Meteorology*, February 1979 (Vol. 20, No. 1), p. 43.

[11] "Wheat yields were generally above the trend line from 1940 to 1948 and below it from 1949 to 1956. In part the higher yields in the 1940-48 period may be attributed to more favorable growing conditions during this period, but weather was not the only factor involved. Other factors include the adoption of a number of new varieties of seed, increased summer fallowing, and rising fertilizer use in the Eastern States. . . . During the 1949-56 period heavy attacks of black stem rust occurred. . . . By 1956 rust-resistant varieties had been developed and average yields rose." (Luttrell and Gilbert, *op cit.*, p. 529.) Heid places the turning point in yields as 1933 (Walter G. Heid, Jr., *U.S. Wheat Industry*, USDA/ESCS, Agricultural Economic Report No. 432, August 1979, p. 24. Also see D. Gale Johnson and Robert L. Gustafson, *Grain Yields and the American Food*

Supply; An Analysis of Yield Changes and Possibilities, University of Chicago Press, 1962, pp. 32-36, 61-91.

[12] The reasons for this, which largely relate to summer fallow in the western Great Plains States, are discussed in detail in: Louis M. Thompson, "Weather and Technology in the Production of Wheat in the United States," *Journal of Soil and Water Conservation*, Nov.-Dec. 1969 (Vol. 24, No. 6), pp. 223-224; E. O. Heady, L. V. Mayer and H. C. Madsen, *Future Farm Programs, Comparative Costs and Consequences*, Iowa State University Press, Ames, 1972, p. 39; and Bond and Umberger, *op cit.*, pp. 18-26. Also see Johnson and Gustafson, *op. cit.*, pp. 98-110, 121.

[13] Calculated from data provided in *Agricultural Statistics, 1978*, USDA, p. 1.

[14] It will be recalled that Gaines was introduced in 1961, which may influence the base figure. When the base period is moved back 2 years, however, to 1957-61, the average yield increases only from 20.4 to 22.8 percent.

[15] S. C. Salmon, O. R. Mathews and R. W. Leukel, "A Half Century of Wheat Improvement in the United States," *Advances in Agronomy*, Vol. V, Academic Press, 1953, pp. 110-111.

[16] Johnson and Gustafson, *op. cit.*, pp. 85, 88-91. When the analysis was extended to the 1957-60 period, the contribution of new varieties in the eastern states became significant (pp. 138, 139, fn. 6).

[17] Sim and Araji, *op. cit.*

[18] Jensen, *op. cit.*, p. 201; Hueg, *op. cit.*, p. 80 (Table 4).

[19] Similar results have been obtained for wheat in the United Kingdom. See "Higher Wheat Yields From Modern Varieties," *Span* (Shell), 1980 (Vol. 23, No. 1), p. 22 (reproduced from *ARC News*, December 1979).

[20] *Agricultural Statistics, 1978*, USDA, pp. 9-10.

[21] *1977 Wheat Production Estimates by Varieties in Certain Pacific Northwest Counties Compared with 1975 and 1974*, Pacific Northwest Crop Improvement Association, Spokane, May 1978, pp. 1-2.

[22] Norman H. Fischer, "Durum Wheat, Growing in Popularity, Is Near to Being Key Crop in Southwest," *The Wall Street Journal*, Jan. 19, 1976, p. 16.

[23] Telephone conversation with Dr. Robert E. Dennis, Dept. of Plant Sciences, University of Arizona, Tucson, Sept. 10, 1979.

[24] Letter from C. O. Qualset, Dept. of Agronomy and Range Sciences, University of California, Davis, Sept. 10, 1979.

[25] *Small Grains, 1979 Annual Summary* . . . , USDA, Crop Reporting Board, Dec. 21, 1979, p. B-10. In 1979, one 54-acre field of M-9 averaged about 10,000 pounds per acre (letter from Howard L. Carnahan, Director of Plant Breeding, California Co-operative Rice Research Foundation, Inc., Biggs, California, Oct. 22, 1979).

[26] Derived from annual data issued by the Crop Reporting Board of the U.S. Department of Agriculture. Estimates are available back to 1866 (see *Rice, Popcorn, and Buckwheat; Acreage, Yield, Production, Price and Value; By States, 1866-1953*, USDA, Statistical Bulletin No. 238, pp. 1-9). Preliminary estimates for 1979 were reported in *Small Grains*, *op cit.* U.S. totals for 1960 to 1979 are summarized in metric terms in *World Grain Situation, Outlook for 1979/80*, USDA, Foreign Agricultural Circular, FG-18-79, Nov. 14, 1979, p. 23.

[27] Calculated from "Rice Acreage in the United States," Rice Millers' Association, 1979. Yields of Brazos, the most widely planted of the three, averaged 4.3 percent above the average yield of all varieties in the south in 1978. In 1979, one Arkansas grower obtained a carefully measured yield of 9,000 pounds per acre on an 18-acre field of Mars (telephone conversation with T. H. Johnston, AR/SEA, USDA, Stuttgart, Arkansas, Dec. 4, 1979).

[28] C. Roy Adair, E. M. Cralley, and T. H. Johnston, "Long-Time Trends in Grain Yields of Five Rice Varieties," *Agronomy Journal*, May 1958 (Vol. 50, No. 5), pp. 233-235.

[29] *Agricultural Statistics, 1978*, USDA, pp. 25, 26.

[30] For some comparisons between California and Asia, see: Roy Bainer, "Science and Technology in Western Agriculture," *Agricultural History*, January 1975 (Vol. 49, No. 1), p. 59; Leon A. Mears, "The Political Economy of Rice in the United States," *Food Research Institute Studies*, 1975 (Vol. XIV, No. 4), p. 323.

[31] Jenkin W. Jones, "Improvement in Rice," *Yearbook of Agriculture, 1936*, USDA, p. 417.

[32] CIMMYT has found this plateau for wheat to be from 8 to 9 mt/ha. (119 to 134 bushels/acre) (*CIMMYT Review, 1979* p. 61). IRRI indicates that maximum practical potential rice yields in the tropics range from 6 to 8 mt/ha. (5,350 to 7,140 pounds/acre) (*Research Highlights for 1977,* IRRI, p. 6). The maximum yield attained at IRRI was 11.0 mt/ha. (9,810 pounds/acre) (*Annual Report for 1976,* IRRI, p. 262).

[33] As noted earlier, groundwater supplies are reportedly shrinking in some irrigated wheat areas in the Great Plains. In some of the dryland areas, such as the highly productive Palouse region of the northwest, soil erosion is a threat ("Learning From the Past," *Agricultural Research*, USDA, October 1979, Vol. 28, No. 4, pp. 4-10).

[34] Jensen, *op. cit.*, p. 319.

[35] *Ibid.*

[36] Based on telephone conversations with Dr. Everett Everson, Dept. of Crop and Soil Sciences, Michigan State University, Nov. 9, 1979.

[37] It will be recalled that only about 5 percent of the wheat area in the U.S. was irrigated in 1974 and that much of the unirrigated wheat is raised under dryland conditions.

[38] The severity of the disease seems to have (a) an inverse relationship with plant height, and (b) a direct relationship with the density of the plant canopy (conversation with Johnston, *op. cit.,* Dec. 5, 1979).

[39] Yao-chi Lu, Philip Cline, and Leroy Quance, *Prospects for Productivity Growth in U.S. Agriculture*, USDA/ESCS, Agricultural Economic Report No. 435, September 1979, pp. i, 34-35.

VII. EVALUATING ECONOMIC IMPACT

> *. . . a technological advance has the effect of lowering the* per unit costs of production *of the farm firm . . . By underwriting a rapid rate of technological advance, society assures itself of a bountiful food supply at relatively low prices.*
>
> —**Willard W. Cochrane, 1958***

The previous chapters have discussed the semi-dwarfs in largely technological terms, although some economic matters have been touched upon. The semi-dwarfs also should be examined from a broader economic and social point of view. This will be done only briefly here, due to a lack of needed data for the United States.[1] But perhaps this short review will help highlight the need and opportunities for further study.

Cost of Production

The use of semi-dwarf varieties can raise production costs per unit of *land*, but should reduce costs per unit of *product.* The higher costs per acre would not arise from the cost of the seed itself (which would not differ significantly from traditional seed), but rather from additional fertilizer or irrigation that might be applied. But the higher yields resulting from this process should normally equal or exceed the additional costs involved. If they do not, there is little reason for farmers to adopt the technology. The expected returns, however, are subject to some uncertainty due to variations in production costs, the price of the final product, and weather-induced variations in yield.[2]

No cost-of-production data are known to have been gathered specifically for semi-dwarfs. But data are available for wheat and rice that give some idea of the role of fertilizer and irrigation in the total cost structure. The data also indicate the role of yields in influencing cost per unit of product. Information for 1976 is briefly summarized in the following sections.

Wheat

In total, fertilizer and irrigation costs averaged $10.54 per acre and represented 15.25 percent of total costs, excluding land (table 13). Fertilizer alone

Table 13. Production Costs for Wheat, United States, 1976

Class	Cost Per Acre (In dollars)						Yield per Acre	Cost per Bushel
	Variable Costs				Other Costs[2]	Total Costs[3]		
	Fertilizer	Irrigation	Other[1]	Total				
							Bu.	*Dol.*
Hard Red Winter	8.10	0.38	31.11	39.59	25.92	65.51	24.3	2.70
Arizona, California	23.93	8.22	72.11	104.26	51.85	156.11	57.9	2.70
Soft Red Winter	23.54	0	37.27	60.81	30.14	90.95	30.4	2.99
Hard Red Spring	7.95	0	28.03	35.98	28.65	64.63	24.8	2.61
White (Pacific N.W.)	15.42	1.25	37.36	54.03	42.42	96.45	45.0	2.14
Durum	6.09	0	28.50	34.59	28.48	63.07	23.9	2.64
All Classes	10.22	0.32	29.05	39.59	29.52	69.11	27.1	2.55

[1] Seed, lime (where used), other chemicals (herbicides, insecticides), custom operations, all labor, fuel and lubrication, repairs, miscellaneous, and interest.
[2] Machinery ownership, general farm overhead, and management.
[3] Excluding land.

Source: *Costs of Producing Selected Crops in the United States, 1976,1977, and Projections for 1978.* Prepared by the Economics, Statistics, and Cooperatives Service, USDA for the Committee on Agriculture, Nutrition, and Forestry, United States Senate, Committee Print 24-607, March 1978, pp. 28-38.

cost $10.22 per acre, representing 14.8 percent of total costs. There was a rather wide range in fertilizer costs, by market class, from lows for Durum, Hard Red Spring, and Hard Red Winter to a high for Soft Red Winter. Irrigation costs for the United States, reflecting the limited irrigated area, were only $0.32 per acre or 0.4 percent of total costs. They were highest for White wheat—and high for Hard Red Winter wheat in the Southwest.

For market classes of Soft Red Winter and White where fertilizer and irrigation were relatively more expensive than the U.S. average, other costs were also higher. On the other hand, yields for these classes were above average. Overall results varied widely: The cost of Soft Red Winter was the highest of any class, while that of White wheat was the lowest. (Within the Hard Red Winter category, total costs were especially high in Arizona and California, but yields were also higher, so the unit cost was the same as for the class.)

Costs must next be balanced against prices received by farmers. These prices vary by market class. In 1976, they averaged as follows: winter wheat, $2.76 per bushel; spring wheat (excluding Durum) $2.68 per bushel; and Durum, $2.95 per bushel.[3]

While the price/cost relationship is an important general factor in influencing fertilization and irrigation, it is not the only one—and sometimes it is not the most important factor. A recent USDA study sheds some light on the role of other factors.

–Fertilizer. In dryland areas of the Great Plains, variable rainfall makes it difficult to tell whether yield responses are from fertilizer or climate. Under these conditions, farmers may require considerable time to acquire evidence of favorable returns and are likely to increase fertilizer use only slowly.

–Irrigation. In most areas where wheat is irrigated it is not the most profitable crop. However, wheat requires water primarily in the spring when the needs of the other crops are minimal. Thus, irrigated wheat is often a companion crop that conveniently fits into rotations and does not compete for water with more responsive and higher value crops. Still, wheat prices influence the area planted within irrigated crop rotations.[4]

Rice

In total, fertilizer cost $29.62 per acre, 10 percent of total production costs–a lower proportion than in the case of wheat (table 14). Irrigation costs

Table 14. Production Costs for Rice, United States, 1976.

Region/State	Costs per Acre (In dollars)						Yield per Acre	Cost per Cwt.[4]
	Variable Costs				Other Costs[2]	Total Costs[3]		
	Fertilizer	Irrigation	Other[1]	Total				
							Cwt.	*Dol.*
Arkansas[5]	26.24	NR[8]	176.06	202.30	84.57	286.87	47.94	5.98
Mississippi Delta[6]	24.00	NR[8]	204.19	228.19	77.53	305.72	43.82	6.98
Gulf Coast[7]	32.06	NR[8]	183.88	215.94	70.49	286.43	43.51	6.58
California	34.47	NR[8]	187.66	222.13	96.82	318.95	55.70	5.73
United States	29.62	NR[8]	185.51	215.13	79.97	295.10	46.79	6.31

[1] Seed, other chemicals (herbicides, insecticides), custom operations, all labor, fuel and lubrication, repairs, drying, miscellaneous, and interest.

[2] Machinery ownership, general farm overhead, and management.

[3] Excluding land.

[4] Cwt. = hundredweight = 100 pounds.

[5] Non-Delta.

[6] Parts of Arkansas, Missouri, Mississippi, and Louisiana (except Southwest).

[7] Southwest Louisiana and the Gulf Coast of Texas.

[8] Not reported separately.

Source: *Costs of Producing Selected Crops in the United States, 1976, 1977, and Projections for 1978.* Prepared by the Economics, Statistics, and Cooperatives Service, USDA for the Committee on Agriculture, Nutrition, and Forestry, United States Senate, Committee Print 24-607, March 1978, p. 46.

were not reported separately. Fertilizer costs were lowest in Arkansas and Mississippi and highest in the Gulf Coast and California. While total costs per acre were highest in California, yields were also the highest, with the result that cost per unit of product was less than the three other regions/States. Data are not reported on prices in these regions or by type.[5]

Semi-Dwarfs

The semi-dwarfs will likely influence the cost structures reported here. The probable effects on fertilizer cost (and on irrigation expenditures for wheat) and on yields have been noted. Some others have not. For example, the reduced lodging of semi-dwarfs could increase the recovered harvest and reduce harvest costs, since severely lodged grain may be difficult to recover mechanically. Combines can cover considerably more ground when harvesting unlodged grain, and the reduced volume of straw could reduce wear and tear on the machinery. (And in California, the reduced volume of rice straw lessens the vexatious problem of straw disposal.) In order to calculate the net effect of these and other factors, it would be useful to have comprehensive cost and yield data broken down by traditional and semi-dwarf types. In either case, added returns from better yields may in time be capitalized into land values, eventually raising fixed and total costs of production.

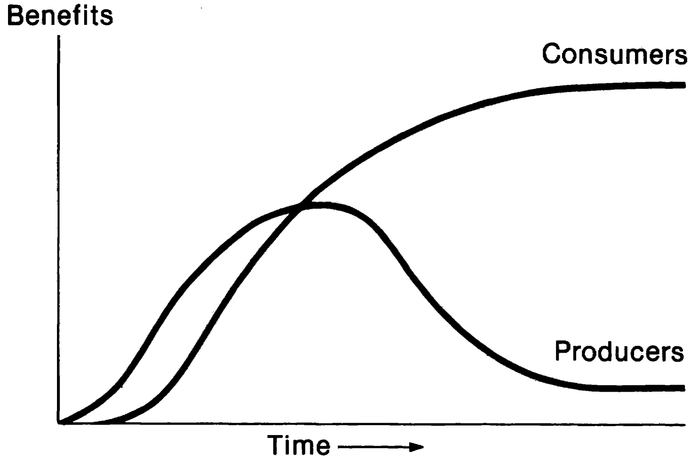
Distribution of Benefits

New technologies must normally reduce the unit cost of production, or keep it below what it otherwise might have been, if they are to be adopted. At the same time they usually increase total output. The result is a reduction in price of the product. Although a price reduction benefits consumers, it may be of concern to producers. To the extent that the technology has lowered costs of production, farmers will be able to bear lower prices. But if the price decline is larger than the decrease in costs, farm income will decrease.[6] The generalized nature of the distribution of benefits from a new agricultural technology over time is illustrated in figure 12.[7]

The relative distribution of these gains and losses between the producers and consumers is influenced by: (1) The degree to which the product is consumed by producers, (2) the elasticities of supply and demand, and (3) the extent to which the product is exported. In the United States, relatively little wheat and rice is consumed by producers. The elasticity of supply is greater than the elasticity of domestic demand. Domestic demand is generally considered quite inelastic, but the elasticity of demand for exports is much greater.[8] In 1976, nearly 56 percent of the wheat crop and 61 percent of the rice production was exported. Government programs accounted for nearly 19 percent of wheat exports and 23 percent of rice exports.[9]

Figure 12

Generalized Nature of the Distribution of Benefits From a New Agricultural Technology Over Time



Source: James Nielson, SEA, USDA.

How these factors add up in the case of semi-dwarf wheat and rice is difficult to say. On the basis of domestic demand alone, most of the benefits of increased supplies would be expected to flow to consumers through lower prices. But the large export markets for the two products should increase the relative benefits to producers.

An added problem in each case is to sort out the effects of Government programs. A number of Government supply controls, farm price supports, and export programs have been in effect since World War II.[10] The United States has also had tariffs on imported rice since 1846.[11]

Thus, analysis of the distribution of the benefits of the semi-dwarf wheat and rice varieties is a very complex matter and well beyond the scope of this review. But it deserves further study.

Measuring Returns to Research

Given the availability of yield data and certain other information, it is possible to utilize some economic tools to measure returns to society for the investment in wheat and rice research.[12] Relatively little work of this nature has been done on these two crops in the United States—with the exception of a recent study of wheat research in the Western States[13]—and none specifically on semi-dwarf varieties.

The Idaho study, referred to earlier, covered wheat research in the Western States from 1939 to 1974. It suggested that the internal rate of return for wheat research ranged from 36 to 44 percent, depending on which assumptions are made and which research tool is utilized. These are quite favorable returns.[14] The study also broke down the time period into three units, producing the following rates of return (in percent): 1939-1950, 43; 1951-1962, 36; and 1963-1974, 57. The authors suggest that the high rate in the first period was due to the development of the short variety Elgin and that "the relatively high return in the 1963-1974 period is due to the development and wide adoption of high-yielding varieties such as Gaines." The study also attempts to consider the value of added foreign exchange received from expanded production. Future analysts may well wish to give much more attention to such questions for semi-dwarfs.

They may also wish to make some division between research done in the United States and that done overseas. The fact that 25.7 percent of the area planted to semi-dwarf wheat, or 5.7 percent of the total wheat area, in the United States in 1974 was made up of introductions from Mexico or selections from Mexican crosses means that calculations of returns to work done in Mexico are higher than may have previously been estimated, and that rates of return for research in the United States should be adjusted correspondingly. The same is true of semi-dwarf rice with IRRI parentage. How much of an adjustment should be made in these cases, however, is uncertain—some domestic expenditures are involved, for example, in developing the selections. On the other side, the United States has paid for about 25 percent of the cost of the research at international centers since 1970, but since this was carried in the foreign aid account, perhaps it should not be counted. Partitioning the benefits to research for an international commodity is a difficult task and will become even more so. Clearly, there is much work awaiting agricultural economists.

References and Notes

*Willard W. Cochrane, *Farm Prices: Myth and Reality*, University of Minnesota Press, 1958, pp. 95, 99.

[1] By contrast, a vast amount of research has been done on these matters in the developing nations. The work of the Agricultural Economics Department at IRRI has been particularly outstanding; two recent examples are: *Economic Consequences of the New Rice Technology*, 1978, 402 pp; *Farm Level Constraints to High Rice Yields in Asia: 1974-77*, 1979, 411 pp. A comprehensive list of the major publications on the economic and social effects of the new varieties in developing nations is provided in Dana G. Dalrymple, *Development and Spread of High-Yielding Varieties of Wheat and Rice in the Less Developed Nations*, USDA/OICD, FAER 95, September 1978 (6th edition), pp. 127-128.

[2] For example (as noted in Chapter V), in 1978: "In the southern winter wheat areas, uncertainty about wheat prices caused farmers to cut back on fertilizer use," (*1979 Fertilizer Situation*, USDA, December 1978, p. 17).

[3] *Agricultural Statistics, 1978*, USDA, p. 2.

[4] J. J. Bond and D. E. Umberger, *Technical and Economic Causes of Productivity Changes in U.S. Wheat Production, 1949-76*, USDA, Science and Education Administration, Technical Bulletin No. 1598, 1979, pp. 81, 82, 85. Also see Clarence A. Moore, "Production," in *Wheat: Production and Utilization* (ed. by G. F. Inglett), Avi Publishing Co., Westport, 1974, pp. 35-46.

[5] Further economic data on rice are summarized by J. B. Hottel, R. Stelly, and W. R. Grant, "Economic Considerations," in *Six Decades of Rice Research in Texas*, Texas Agricultural Experiment Station, Research Monograph 4, June 1975, pp. 107-114; and in the following recent reports issued by the Economics, Statistics, and Cooperatives Service (ESCS) of USDA: S. H. Holder, Jr. and Alberta Smith, *An Analysis of U.S. Rice Distribution Patterns*, Agricultural Economic Report No. 413, November 1978, 47 pp.; Troy Mullins, *Rice Production in Nontraditional Areas*, Agricultural Economic Report No. 423, April 1979, 20 pp.; and W. R. Grant and M. N. Leath, *Factors Affecting Supply, Demand, and Prices of U.S. Rice*, ESCS-47, March 1979, 58 pp. Also see Leon A. Mears, "The Domestic Resource Cost of Rice Production in the United States," *Food Research Institute Studies*, 1976 (Vol. XV, No. 2), pp. 139-176.

[6] This process has been termed the "agricultural treadmill." For further discussion, see the following works by Willard W. Cochrane (all published by the University of Minnesota Press): *Farm Prices; Myth and Reality*, 1958, pp. 94-107; *The City Man's Guide to the Farm Problem*, 1965, pp. 45-57; and *The Development of American Agriculture: A Historical Analysis*, 1979, pp. 201-202, 350-352, and 387-390.

[7] Taken from James Nielson, "Issues and Priorities in Public Funding of Agricultural Research and Extension Education," presented at the 144th Annual Meeting of the American Association for the Advancement of Science, Washington, February 1978 and printed in *Public Support for Agricultural Research and Extension—Investing in the Future*, Mississippi Agricultural Experiment Station, Special Publication, December 1978, p. 5 (figure 1/2).

[8] In one recent note, the elasticity of domestic demand for *wheat* is placed at -0.2 while the implied elasticity of export demand is put at -6.72 (Paul R. Johnson, "The Elasticity of Foreign Demand for U.S. Agricultural Products," *American Journal of Agricultural Economics*, November 1977 (Vol. 59, No. 4), p. 736). The export figure is tentative and appears high. Other elasticity estimates for wheat are summarized by Walter G. Heid, Jr., *The U.S. Wheat Industry*, USDA/ESCS, Agricultural Economic Report No. 432, August 1979, pp. 44, 45. The elasticity appears to vary by market class. A recent analysis of *rice* suggests an elasticity of domestic demand of -0.07 and an elasticity varying from -0.46 to -4.45 for export demand (Grant and Leath, *op. cit.*, p. 43).

[9] *Agricultural Statistics, 1978*, USDA, pp. 4, 11, 20, 23.

[10] For a general introduction to these programs, see: Wayne D. Rasmussen and Gladys L. Baker, *Price Support and Adjustment Programs From 1933 Through 1978: A Short History*, USDA, Agriculture Information Bulletin No. 424, February 1979, 32 pp. More specific details on wheat and rice programs are provided in: Heid, *op. cit.*, pp. 62-80; and S. H. Holder, Jr. and W. R. Grant, *The U.S. Rice Industry*, USDA/ESCS, Agricultural Economic Report No. 433, August 1979, pp. 30-39. Current details are reported in two USDA periodicals: *The Wheat Situation* and *The Rice Situation.* Also see Leon A. Mears, "The Political Economy of Rice in the United States," *Food Research Institute Studies*, 1975 (Vol. XIV, No. 4), pp. 319-357; and James P. Houck, et al., *Analyzing the Impact of Government Programs on Crop Acreage*, USDA/ERS, Technical Bulletin No. 1548, August 1976, 49 pp., esp. pp. 30-38.

[11] See: Arthur H. Cole, "The American Rice-Growing Industry: A Study of Comparative Advantage," *Quarterly Journal of Economics*, August 1927 (Vol. XII, No. 4), pp. 602, 643; Edward Hake Phillips, "The Historical Significance of the Tariff on Rice," *Agricultural History*, July 1952 (Vol. 26, No. 3), pp. 89-92.

[12] Examples of a number of such studies, principally for other nations, are found in

Resource Allocation and Productivity in National and International Agricultural Research (ed. by T. M. Arndt, D. G. Dalrymple, and V. W. Ruttan), University of Minnesota Press, 1977, 617 pp. A recent updating and evaluation of the results of this work is provided by R. E. Evenson, P. E. Waggoner and V. W. Ruttan in "Economic Benefits from Research: An Example from Agriculture," *Science*, Sept. 14, 1979 (Vol. 205), pp. 1101-1107. Also see Yao-chi Lu, Phillip Cline, and Leroy Quance, *Prospects for Productivity Growth in U.S. Agriculture*, USDA/ESCS, Agricultural Economic Report No. 435, September 1979, 87 pp., esp. pp. 28-30.

[13] R. J. R. Sim and A. A. Araji, "The Economic Impact of Public Investment in Wheat Research in the Western Region, 1939-1974," Idaho Agricultural Experiment Station, Research Bulletin, in press. The western region includes Arizona, California, Colorado, Idaho, Montana, Oregon, Washington, Wyoming, and Utah.

[14] For comparative data, see Evenson, et al., *op. cit.*, p. 1103.

VIII. INSTITUTIONAL LINKAGES

The United States will benefit from an expanded flow of technical findings from production research in the developing countries.

–World Food and Nutrition Study, 1977*

Wheat and rice variety improvement is not a solitary activity. The semi-dwarf varieties of wheat and rice that have been introduced, selected, or crossed in the United States have emerged from a well-coordinated national program. National activities are in turn linked with several international programs. Since, as noted earlier, wheat and rice are not native to the United States, new sources of germplasm for varietal improvement have to be acquired from other nations. Thus, the United States is, and must be, a part of an international network.

Domestic Linkages

The institutional network for wheat and rice improvement in the United States differs somewhat.

In the case of wheat, three groups are involved: Federal, State, and private. Most of the Federal (or USDA) wheat researchers are stationed at State agricultural research stations, thus providing the physical proximity needed for a high degree of coordination. The USDA national research program is coordinated by the Staff Scientist for Small Grains on the National Program Staff of the Science and Education Administration. The Cooperative program informally involves four main regions: Eastern, Great Plains Winter Wheat, Great Plains Spring Wheat, and Western. Each region has a USDA technical advisor who, among other duties, supervises the operation of uniform regional nurseries.

Federal, State, and private wheat researchers compose the 17-member National Wheat Improvement Committee, which was organized in 1959 and meets annually. USDA representatives include the national staff scientist, who acts as secretary of the Committee, and the four regional technical advisors.[1] The Committee sponsors an *Annual Wheat Newsletter*, published by Kansas State University and the Canada Department of Agriculture, which provides reports of work by Federal, State, and private industry scientists and by scientists in many foreign nations.[2] In these ways, U.S. wheat breeders are relatively tightly linked and well informed.

Rice breeding research is even more tightly linked because it is largely carried out by public agencies, and virtually all of the work is done in five States: Arkansas, Louisiana, Mississippi, Texas, and California. USDA researchers are stationed in each State except Mississippi, and the one in Arkansas has served as USDA national technical advisor for rice breeding and production since 1973. A "Rice Technical Working Group," concerned with all aspects of rice, meets every 2 years, while a rice improvement planning conference is held annually.

In addition to the usual Federal-State combination, there are several other grower components. In many Great Plains and Western States, wheat growers help provide funds for research. In 1969, California rice growers voted for a State Rice Marketing Order to develop short stature early maturing rice varieties. A Rice Research Board was established which principally supports research conducted by: (1) the California Cooperative Rice Research Foundation Inc., which operates the Rice Experiment Station at Biggs; and (2) the California Agricultural Experiment Station at Davis where research is carried out in cooperation with USDA and the Foundation. During the 1976/77 fiscal year, the Board allocated nearly $817,000 for research, of which nearly $323,000 was for the work at Biggs devoted to varietal improvement.[3] A Texas Rice Improvement Association, composed mainly of rice producers, was established in 1941 to produce and distribute foundation seed of improved varieties and to provide financial support to research.[4] Grower support is also provided in Louisiana and is expected shortly in Arkansas.

In the case of varieties developed by public institutions, essentially all of the seed is multiplied and distributed under the supervision of State crop improvement associations.

International Linkages

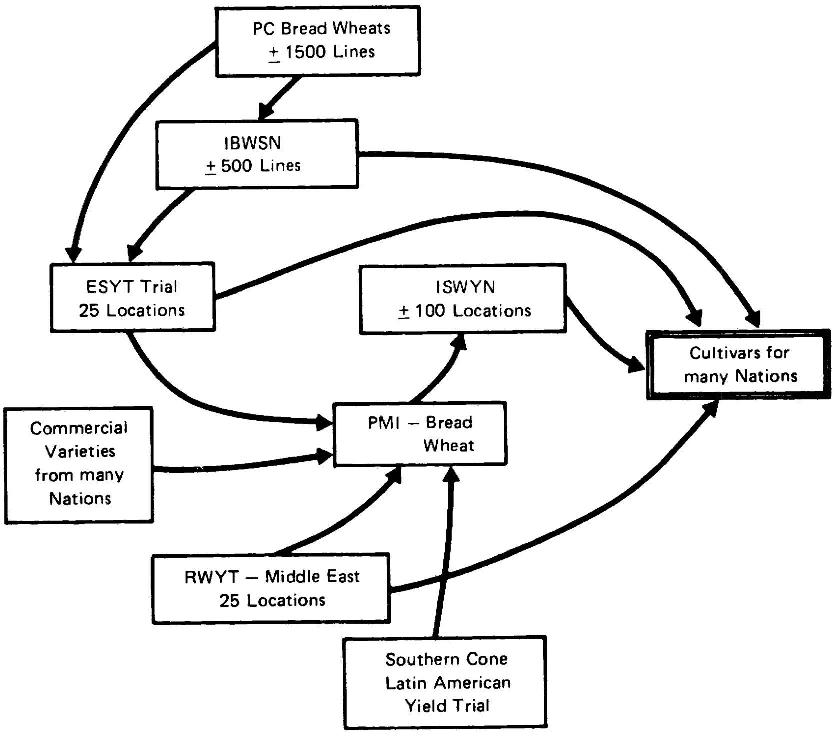
U.S. wheat and rice breeders are linked to a number of international research and variety testing programs.

Among the best known international research efforts are those conducted by the International Maize and Wheat Improvement Center (CIMMYT) in Mexico and the International Rice Research Institute (IRRI) in the Philippines. In addition, wheat research is carried out at the International Center for Agricultural Research in the Dry Areas (ICARDA) in Syria, and rice research is conducted by the International Center for Tropical Agriculture (CIAT) in Colombia and by the International Institute of Tropical Agriculture (IITA) in Nigeria. All are partly supported by the U.S. Agency for International Development (AID's policy has been to provide about 25 percent of the funding of these centers).

Two of the international centers sponsor variety testing programs.[5] CIMMYT sponsors the International Spring Wheat Yield Nursery and the International Bread Wheat Screening Nursery, both of which include some other more specialized nurseries. U.S. institutions' participation in the overall framework is shown in figure 13. IRRI sponsors an International Rice Testing Program; however, U.S. institutions participate on only a very limited basis—principally because of plant quarantine requirements.[6] Beyond these activities, an International Winter Wheat Performance Nursery has been sponsored by AID, USDA, and the Nebraska Agricultural Experiment Station.[7] And an International Spring x Winter Wheat Screening Nursery is sponsored by CIMMYT, the Oregon Agricultural Experiment Station, and AID. Results of these trials are summarized and are readily available to participants and others.

Figure 13

Flow of Germ Plasm Between National and CIMMYT Programs



PC = Small plot multiplication for pure seed
ESYT = Elite Selection Yield Trial (International)
RWYT = Regional Wheat Yield Trial – Middle East
ISWYN = International Spring Wheat Yield Nursery
PMI = International Multiplication Plot
IBWSN = International Bread Wheat Nursery

Source: CIMMYT Report on Wheat Improvement 1975. World Bank—20253

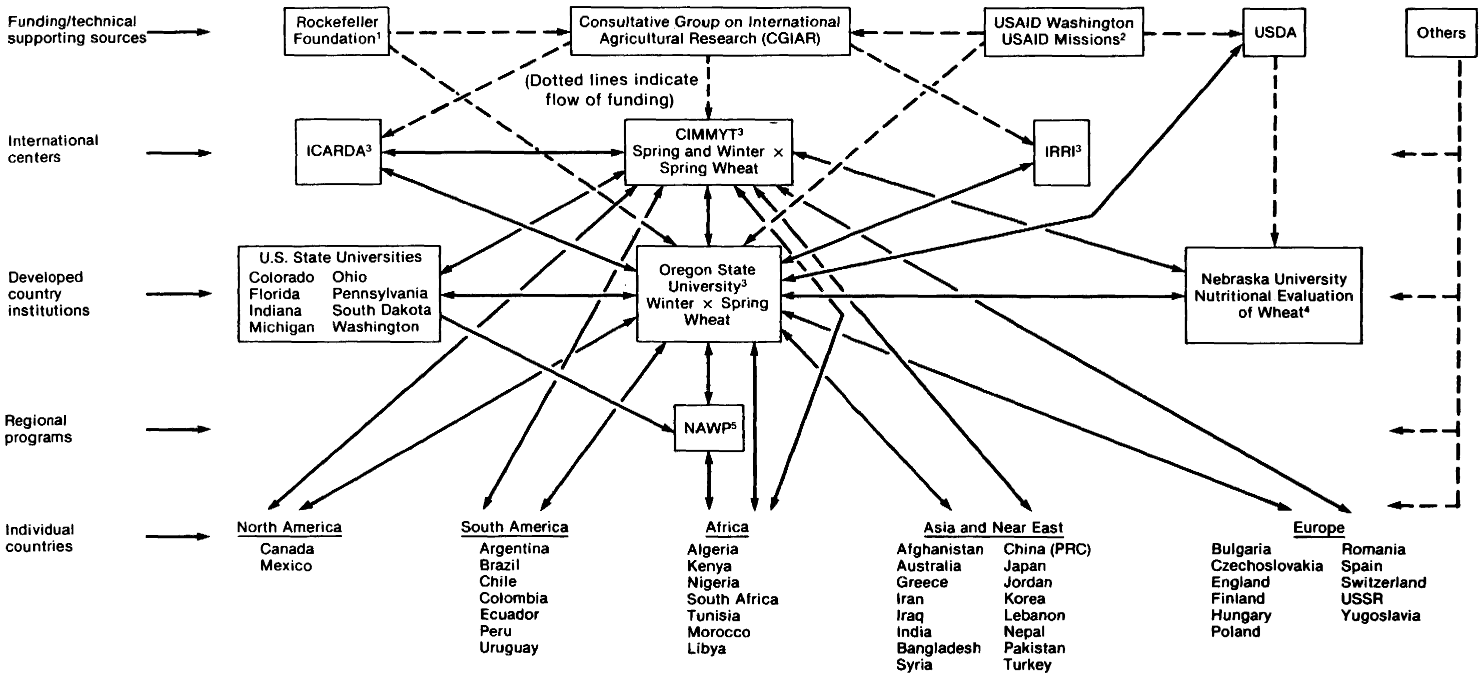
The winter x spring wheat nursery is part of a rather unique cooperative research program involving a particularly strong linkage between domestic and international programs. The purpose of the program, as noted in Chapter V, is to transfer certain desirable qualities of winter wheat to spring wheat and other useful qualities from spring wheat to winter wheat. CIMMYT concentrates on the former and Oregon on the latter. Through the exchange of germplasm the breeding process is speeded up and varieties are tested under a wide range of environmental conditions. Varieties have been screened for nutritional content at the Nebraska Agricultural Experiment Station. Numerous other States as well as institutions in other countries participate in the nursery (comprising a total of 97 breeding programs in 48 countries in 1978/79). The overall network is presented in diagramatic form in figure 14. AID supports the work in Oregon through a research contract and at CIMMYT through its regular contribution. The overall purpose is to develop improved varieties for the less developed nations, but the varieties also should be of considerable interest and potential value to the United States.

As an outgrowth of this and previous work, the cereal breeding program at the Oregon AES has sponsored for the past 10 years an annual 2-day spring tour to the Yaqui Valley and the CIMMYT/INIA research work in Ciudad Obregon in northwest Mexico. The group includes wheat growers and wheat industry representatives from Oregon and Washington, and wheat breeders and administrators from the experiment stations in the two States (plate 12). The tour has proved very popular and a useful educational technique.[8]

Plate 12. Dr. Bent Skovmand of CIMMYT speaks to a group of Oregon and Washington wheat growers, breeders, and administrators visiting research work conducted by CIMMYT in cooperation with INIA at the CIANO station in Cd. Obregon, Mexico, April 1979. Dr. Norman Borlaug is to the right of Dr. Skovmand (looking at paper).

Figure 14

International Winter × Spring Wheat Research Network, 1979



Notes: [1]The Rockefeller Foundation provides funds to Oregon State University for graduate training. [2]USAID missions contribute through bilateral support of individual country programs. [3]The links with individual countries take the form of information and materials exchange, the conduct of seminars and workshops, cooperative research projects, advisory services, and training. [4]USAID funding of nutritional work expired in late 1979. [5]North African Wheat Program. Source: Adapted from figure provided by Department of Crop Science, Oregon State University, Corvallis.

Need for Internationalization

Close linkages are, as we have seen, of vital importance in wheat and rice breeding. Since a vast area of the less developed world is planted to semi-dwarf varieties and since they are becoming of increasing importance in developed nations, there are many lines of potential significance for U.S. breeders that lie outside of U.S. borders. And as the number of semi-dwarf varieties developed in the United States expands, the United States may have more to offer the international centers and other nations in the way of improved varieties. In either case, the primary value of the varieties will be for breeding for local conditions; few varieties can be adopted as is.

A relatively complete network of institutional linkages exists, both within the United States and between the United States and international efforts. The latter, however, could probably be strengthened. In the case of agricultural technology, the United States appears better organized at the public level to "export" than to "import." AID helps support the export of technology, but there is less clear-cut public support for the import of technology. Much of what goes on in terms of U.S. utilization of technology generated by the international centers, for instance, is done by individual scientists on a personal basis.

As the relative amount of wheat and rice research increases in the developing nations and international centers, there will be an expanding body of information of potential interest and value to the United States. The challenge is to develop some way of facilitating the acquisition and use of this technology.

Part of the answer may be increased personal contact. Some travel to the international centers is possible (one USDA representative has, for example, usually attended IRRI's annual rice conference), but is limited. U.S. scientists and graduate students increasingly need to get on the ground overseas. At the same time, the international centers could profit from a closer knowledge of developments in the United States. Periodic visits to the principal U.S. breeding programs by center personnel could be mutually beneficial.

Both the United States and other nations could benefit substantially from a greater internationalization of U.S. agricultural research. AID has done much in this direction, but its emphasis has to be on the developing nations. It now seems the time for domestic research agencies to begin to seek ways to make greater use of what this process has wrought, or is likely to bring forth in the future.

References and Notes

[*] *World Food and Nutrition Study; The Potential Contributions of Research*, National Academy of Sciences, Washington, 1977, p. 50.

[1] Based on discussions with L. W. Briggle, Staff Scientist, Grains Production, National Program Staff, AR/SEA, USDA, Beltsville, Md.

[2] *Newsletter* is a bit of a misnomer in terms of length; the 1978 issue was 156 pages. It is edited by E. G. Heyne, Dept. of Agronomy at Kansas State University and A. B. Campbell of the Canada Department of Agriculture. According to the title page, "The information in this Newsletter is considered as personal communications. Before quoting any information herein obtain the consent of the specific author." Only a limited number of copies are printed (600 in 1978).

[3] *Ninth Annual Report to the California Rice Growers*, Compiled by the Rice Research Board Operating Under the Authority of the Director of Food and Agriculture, State of California, Yuba City, April 1978, 32 pp. (The Biggs Station, as noted in Chapter II, was established in 1912.)

[4] J. P. Craigmiles, "Advances in Rice—Through Research and Application," in *Six Decades of Rice Research in Texas*, Texas Agricultural Experimental Station, Research Monograph 4, June 1975, p. 2.

[5] Details may be found in the annual *CIMMYT Review* or IRRI's annual *Research Highlights.*

[6] Imports of rice seed are normally prohibited, except from Mexico, because of disease problems (*Code of Federal Regulations*, Title 7, Part 319.55). USDA may import seed for experimental purposes, but it has to be grown under detention for one crop cycle before the seed can be distributed. This is done in a specially approved greenhouse at Beltsville, Md., or under field conditions in El Centro, Calif. (about 600 miles south of the rice growing area). U.S. scientists receive the results of the nursery trials from international centers and may request promising seeds through USDA, but they have to go through the detention process, which means an unavoidable delay, especially if the seed also needs to be multiplied. (Based on discussions with F. E. Cooper, Regulatory Support Staff, Animal, Plant and Health Inspection Service, USDA, May 11, 1979; and Albert J. Oakes, Plant Genetics and Germ Plasm Institute, Science and Education Administration, USDA, May 11, 1979.)

[7] The same group has sponsored a periodic winter wheat workers conference; the last was held in Yugoslavia in 1975, the next is scheduled for Spain in 1980.

[8] Based on telephone conversation with Warren Kronstad, Oregon AES, Corvallis, May 21, 1979.

IX. CONCLUDING REMARKS

Better short and sweet than long and lax.
—James Kelly*

Your plainness and your shortness please me well.
—William Shakespeare**

In small proportions we just beauties see;
And in short measures, life may perfect be.
—Ben Jonson***

The focus of this report has been narrow. Even within the confines of wheat and rice variety improvement, the breeder must necessary seek many qualities. Shorter height is only one. As Dr. T. T. Chang of the International Rice Research Institute recently stated, "Semi-dwarfism . . . is only a start on improving plant types, not an end product in itself . . ."[1] However, I have chosen to take a rather limited perspective because of the critical importance of the height factor for improved yields and its relative neglect in the general agricultural literature in the United States.[2]

Clearly a great deal is going on in terms of development of semi-dwarf and other short-strawed varieties in the United States. Short-strawed varieties provide a stern basis of comparison for the semi-dwarfs. Still, the proportion of total wheat areas planted to semi-dwarf wheat varieties expanded from zero in 1959, to 3 percent in 1964, to 7 percent in 1969, and to 22 percent in 1974. The proportion rose further in 1979, perhaps to about 29 percent. Semi-dwarf rice was slower getting started, but began to assume significant proportions in California in 1978 and expanded sharply in 1979. In the latter year, California plantings of semi-dwarfs represented about 9 percent of the U.S. rice area. New semi-dwarf varieties under development promise to raise the semi-dwarf proportions in the future.

The genetic sources of dwarfing for nearly all these varieties are the same as those for the semi-dwarf varieties developed at the international agricultural research centers in the less developed countries (LDC's). The U.S. and LDC varieties have largely been developed independently. However, there has been some overlap in that certain LDC varieties of wheat have been: (1) directly introduced and grown in the United States (5.4 percent of the 1974 semi-dwarf area); (2) used as the basis for selections which are widely grown in the United States (20.1 percent of the semi-dwarf area); or (3) served as one or more parents of recent varieties developed in the United States (14 as of late 1979). In the case of rice, three of the six semi-dwarf varieties have LDC semi-dwarfs as parents and derive their dwarfing characteristics from them. The other three varieties have used an induced mutation as the source of dwarfing. One of the varieties with an IRRI parent occupied about 60 percent of the semi-dwarf area in California in 1979. Thus there has been a modest but clear-cut linkage between varietal developments at the international centers and in the United States.

Direct Effects: Differing Patterns

Although a semi-dwarf wheat variety was developed, released, and in use in the United States before such varieties were released in the LDC's, the use of semi-dwarfs has moved relatively slowly in the United States (outside of a few States) and attracted relatively little general attention and study. By comparison, the use of these varieties has moved very quickly in some LDC's, and has been reported by the press to have brought about a "green revolution." Why such a difference in treatment of what is essentially the same product?

There are, I think, plausible reasons that have to do with the degree of development of agricultural technology and the nature of agricultural production in the two societies.

United States

In the United States, there has been, as we have seen, a long history of varietal improvement in wheat and rice varieties. Growers have been treated to a succession of improved varieties, which they have rather quickly adopted. At the same time, the height of the varieties has gradually decreased. Shorter height has been needed to reduce lodging and to accommodate increasing levels of fertilizer use.

WHEAT. Since World War II, a number of rather short wheat varieties have been developed simply by crossing traditional varieties. Some of these appear to meet current needs in certain regions of the United States. But in other areas of the country, such as the Pacific Northwest (which has long had yields well above the national average), short varieties were developed years ago and the industry was ready to move on to even shorter—to semi-dwarf—varieties at an early stage.[3] Thus, the first semi-dwarf, Gaines, was developed and quickly adopted in the Northwest in the early 1960's.

The prowess of Gaines became well known quickly and it was tried in many other areas of the country where it often was not well adapted to local conditions. Some other semi-dwarfs of the period were perhaps rushed into use, also without being fully adapted to local requirements. But even local breeding efforts with semi-dwarfs did not provide at first many startling results. In other cases, wheat breeders and growers simply did not need, or were slow to accept, semi-dwarfs. The result was that after the first surge in semi-dwarf use in the Pacific Northwest, the ensuing rate of introduction and adoption was relatively slow through the mid-1960's.

The pace began to accelerate during the late 1960's. Still, when the varieties were introduced, not a great deal was made of their semi-dwarf nature. They were often simply represented as being shorter than previous varieties, some of which were already relatively short. Thus, the semi-dwarfs were just another step in the gradual reduction in height. No great changes were needed in cultural factors, other than perhaps somewhat closer attention to seeding depth and to heavier fertilization. Many growers probably did not even realize that they were planting semi-dwarfs. And certainly when grown in areas with low rainfall and where no fertilizer was applied, there was nothing special about their performance. As noted earlier, these areas are substantial. According to the U.S. Census of Agriculture in 1974, 38 percent of the wheat area was not fertilized (and much was raised under dryland conditions in the Great Plains), and only 5.2 percent was irrigated. It was only in the more favored areas where more fertilizer was applied that an inkling or indication of their yield potential could readily be realized.

But the realization of these qualities widened in the 1970's and the semi-dwarf varieties were much more widely used in breeding programs and were much more widely planted.

RICE. The situation has differed in some ways for rice, which is completely fertilized and irrigated. As with wheat, there has been a longstanding emphasis on breeding shorter varieties, and many have been developed which meet current yield and fertilization needs.

The greatest initial push towards semi-dwarf varieties has taken place in California where yields have long been above the national average and where the industry has long relied on only a few varieties (compared with the many varieties in use in the South Central States). Increased emphasis on new varieties in the late 1960's, stimulated by the newly enacted, farmer-financed Rice Research Program,[4] came at a time when the IRRI semi-dwarf varieties were receiving considerable attention. It was only natural to consider using them in an expanded breeding program.

Work on semi-dwarfs has long been under way in the South Central States. The challenge was to develop one which could do better than the several existing short-stature varieties. The first semi-dwarf in the United States was in fact released in Louisiana in 1974 for industrial use; a semi-dwarf long-grain rice—long-grain rice is emphasized in many sections of this region—is expected to be released in 1981.

PRODUCTION. The yield increases for the semi-dwarf varieties at the experimental level in the United States tend to range from 5 to 25 percent for wheat, with perhaps a rough average of 15 percent, and about 10 percent for rice. Farm-level increases are not known but would be expected to be lower.

By comparison, the farm-level yield advantage of hybrid corn when it was introduced in the United States in the 1930's was estimated to be about 15 percent above traditional varieties;[5] that was quite enough to ensure its adoption.

In the case of both wheat or rice, the semi-dwarfs probably had little influence on mechanization, employment, and farm structure. U.S. wheat and rice farms were highly mechanized long before the advent of the semi-dwarf varieties.[6] And it is doubtful that they have led to any detectable changes in employment or farm structure.

Developing Nations[7]

In contrast to their impact in the United States, the semi-dwarfs were more revolutionary in nature in the developing nations. Where adapted, and where the associated inputs were utilized, significant increases in yields and production were realized. These gains drew considerable attention in the public press.

These gains stood out because relatively little had been accomplished in the past and because the semi-dwarfs arrived at a time of severe need in South Asia in the mid-1960's. While a fair amount of research had been done in some nations, relatively few farmers raised improved varieties. Most relied on traditional varieties raised under traditional practices.

Suddenly, with a severe drought in the mid-1960's in South Asia, much more attention was given to increasing output of these two crops. The first improved semi-dwarfs from IRRI and CIMMYT were pressed into use, with a package of improved cultural practices, in the more favored areas. Growers were provided a distinctly shorter variety with distinctly different cultural practices.

The yield advantage of the semi-dwarf package in the developing nations was, and still is, quite substantial. It is very difficult, perhaps impossible, to obtain meaningful averages, but when I attempted to come up with some estimates for the early 1970's a few years ago, farm-level increases of 50 percent for wheat and 25 percent for rice did not seem unreasonable for Asia (much more of the wheat in South Asia is raised under irrigation than is the case in the United States).[8] These increases, if correct, have undoubtedly declined as the area planted has expanded. Still, they were very substantial by developed country standards.

The result of yield increases of such magnitude—though certainly not obtained by all and exceeded by some—was that much happened fast. Agriculture was partly modernized very quickly. Domestic food supplies were expanded and production costs per unit of product (though not per unit of land) were reduced below what they might otherwise have been. These results clearly benefited consumers, particularly poor consumers, but were of more variable benefit to producers. As with any technological advance, some farmers gained and some did not. The differences among producers were not due so much to the seeds as to inequities in the distribution of natural resources and purchased inputs. The effect on employment was strongly influenced by concurrent changes in mechanization. The nature of these and other effects depended heavily on the existing structure of society.

Since the landmark days of the late 1960's and early 1970's, the whole process has quieted down somewhat. The semi-dwarfs have continued to be adopted at a good pace, but the process is now more familiar and more normalized. Both accomplishments and disruptions are less extreme.

One point that becomes clear in comparison with the United States is that the number of semi-dwarf varieties available in most developing countries is quite limited. As noted, for example, 147 semi-dwarf wheat varieties have been introduced and/or released in the United States. Moreover, these varieties are still concentrated on only part of the total wheat area. Developing nations have generally made do with relatively few varieties, which means that much more tailoring to local conditions remains to be done and that these countries have limited reserves in case problems develop.

The challenge now is to expand the number of semi-dwarf varieties available to meet different conditions and to extend the semi-dwarfs into less favored areas that were bypassed on the first round. Increased tolerance to unfavorable climatic or cultural conditions will be of major importance. Such activities do not draw big headlines, but they are a vital step in agricultural development.

Indirect Effects: Multiple Cropping

In addition to their well-known direct effect on yields, semi-dwarfs also may have a significant indirect effect on overall output per unit of land per year through their effect on multiple cropping, the growing of more than one crop in sequence on a given land in a year. Breeders have combined early maturity with the semi-dwarf characteristic. This allows farmers more time to plant a second crop.

The effect has probably been greatest in the developing nations where multiple cropping is widely practiced.[9] The semi-dwarf varieties, particularly of rice, have played a significant role in its expansion. In some cases, such as Bangladesh, rice is followed in the winter by semi-dwarf wheat. Rice-based cropping systems, as well as a continuous year-round rice production model, are undergoing intensive study at IRRI.

Because of climatic restraints, multiple cropping is not commonly practiced in the United States, so that earlier maturity is less important for this purpose.[10] Yet there is some multiple cropping of wheat and rice, and earlier maturity plays a role. Double cropping of wheat is primarily carried out in the Southeastern and Southern Corn Belt, where earlier maturity has facilitated the planting of soybeans following wheat. Rotations involving wheat followed by grain sorghums have long been practiced in the South.[11] In the case of rice, there is considerable second crop production in Texas involving the regeneration of ratoons or tillers from the base of crown of the plant after harvest. The practice was encouraged with the release of very early maturing, moderately short-stature (but not semi-dwarf) varieties, such as Belle Patna and Bluebelle, in the 1960's.[12] Rice, however, is often grown on land which is not well suited to many other crops, which may limit multiple cropping prospects to some degree.

There may well be other indirect effects of the semi-dwarfs which should be explored.

Facilitating Varietal Improvement

We have seen that wheat and rice improvement is necessarily an international business. This is particularly true of the efforts to develop semi-dwarf varieties of wheat and rice. The original sources of the dwarfing genes in common use came from Asia. And a large area of semi-dwarf varieties is planted in the less developed nations and probably in other developed nations. (Some references to semi-dwarfs in other developed nations are provided in Appendix A.) It is only sensible that the United States utilize as much of the foreign work and experience as seems helpful.

While some use has been made of foreign semi-dwarfs in the past, it might seem that the amount of "borrowing" has been less than it could have been. Why? Some of the reasons have been alluded to earlier. In part they may be due to technical factors—problems in using the foreign materials due to lack of adaptability of the plant, poor grain quality, etc. In some cases, breeding work has emphasized the development of short-stature varieties which have, or closely approximate, many of the qualities of the semi-dwarfs. And there probably have been differences of opinion among scientists about the value of semi-dwarfism compared with other desired plant qualities, with the result that semi-dwarfism may have sometimes received relatively low priority.

An example of several of these factors is provided for wheat by Borlaug of CIMMYT:

> Nearly everyone in the spring wheat region of the United States was skeptical of semi-dwarfs prior to the mid-1960's. The late Don Fletcher, of the Crop Quality Council, took back with him from our Cd. Obregon nursery in 1956, selected heads of the best F_2 generations of Mexican wheats x Norin 10 semi-dwarf wheats. He distributed seed of these crosses to scientists at the University of Minnesota, North Dakota State University, the University of Manitoba, and the Canadian Department of Agriculture. I doubt that anyone at these locations looked at any of these materials critically.[13]

One Minnesota-based scientist responds that the varieties were examined, but that they did not prove to be adapted.

There are also some other factors. In the case of **rice**, for instance, Coffman of IRRI, who recently spent a sabbatical year in the United States, notes:

> I can not say whether the U.S. breeders have made adequate use of these foreign materials but I would certainly say that they have not had adequate exposure to them. It is very difficult for them to obtain permission to travel to Asia so we have not had much contact. Also, the U.S. quarantine regulations are very strict so it is not very convenient to exchange germplasm . . . I would strongly suggest more liberal travel for your rice breeders and a more efficient, well-funded quarantine system for rice.
>
> In spite of the difficulties there has been some progress. The U.S. breeders arranged to bring in the named IRRI varieties . . . a few breeding lines, and more recently, they have arranged to receive several of the nurseries of the International Rice Testing Program on a regular basis. Thus, they are receiving a good cross-section of international material.[14]

The full utilization of the IRRI materials, however, involves making many crosses with domestic varieties. Most U.S. rice breeding operations consist of only one or two breeders with very limited help. This severely limits the number of crosses they can make in a year and tends to confine them to the best adapted materials. One exception to this staffing pattern occurred in California during the 1970's when the number of breeders was expanded with grower financial support. It is perhaps not accidental that this State has recently made significant progress in the development of semi-dwarf varieties.

What can be done to enhance U.S. access to, and utilization of, international technology developed at the international centers and in other national programs? Increased personal contact is probably part of the answer. But in some ways the matter is easier for **wheat**, because CIMMYT is relatively close and there are no plant quarantine restrictions on nursery stock from CIMMYT. On the other hand, there are many U.S. breeders involved with wheat. Problems are more severe for **rice** because of the great distance to IRRI and the plant quarantine restrictions. On the other hand, rice breeding is done by relatively few groups in the United States. On balance, it should be possible to devise a way to assist U.S. breeders to keep up to date more fully on research at international centers and in some of the leading national programs overseas. A little additional effort in this direction could have a high payoff.

Additional effort is also needed on several domestic fronts if varietal improvement is to be facilitated. As noted earlier, wheat variety information is available for the United States only once every 5 years. This may have been an adequate frequency in 1919 when the series started and when varieties were fairly stable, but it is quite inadequate to keep up with the highly dynamic situation that exists today.

A related need is to initiate economic analyses of the semi-dwarf varieties. None presently are known to exist. Initially, it would be particularly useful to have some farm-level analyses of a farm management and/or production economics nature. Public policy aspects need to be considered in more detail. With such data and analyses in hand, it would be possible to do a far more enlightened job of calculating returns on investment in semi-dwarf research.

*   *   *

As long as there is interest in increasing wheat and rice yields in the United States—and this is inevitable in the long run[15]—there will be interest in plant height and other improvements in plant type. Short varieties will increasingly replace those of traditional height, just as semi-dwarfs will increasingly replace short varieties. But eventually the point may be reached when further shortening of height offers little more in terms of yield response. One of the key determinants will be the role of other limiting factors—be they biological, physical, or economic. The relative importance of these factors, and the degree to which it is possible to overcome them through scientific advances, will sharply influence the future role of the semi-dwarfs. Thus, future prospects for semi-dwarfs depend in large part on changes in the varieties themselves as well as on more general advances in agricultural science and technology.

References and Notes

Scottish Proverbs, 1721, p. 59. [*]

**"The Taming of the Shrew," Act IV, Scene 4.

***"A Pindaric Ode . . . ," from "Underwoods."

[1] T. T. Chang, "The Green Revolution's Second Decade," *Span* (Shell), 1979 (Vol. 22, No. 1), p. 3. Rice breeding objectives in the Southern States of the U.S. are outlined in Appendix B.

[2] The subject has, as should be evident by now, not been neglected in the scientific literature used by plant breeders.

[3] One set of data indicate that yields in the Pacific Northwest (Washington, Oregon, Idaho) over the 93-year period from 1879 to 1972 averaged about 47.4 percent higher than the United States as a whole. (James F. Shepherd, "The Development of New Wheat Varieties in the Pacific Northwest," *Agricultural History*, January 1980 (Vol. 54, No. 1), p. 62.

[4] "In 1969, California rice growers voted overwhelmingly for the Rice Research Program." (*Eighth Annual Report to the California Rice Growers*, Compiled by the Rice Research Board Operating Under the Authority of the Director of Food and Agriculture, State of California, Yuba City, April 1977, p. 1.)

[5] Zvi Griliches, "Research Costs and Social Returns: Hybrid Corn and Related Innovations," *Journal of Political Economy*, October 1958 (Vol. 66, No. 5), p. 421.

[6] For historical statistics on wheat mechanization, see C. W. Nauheim, W. R. Bailey, and D. E. Merrick, *Wheat Production; Trends, Problems, Programs, Opportunities for Adjustment*, USDA, Agricultural Research Service, Agriculture Information Bulletin No. 179, March 1958, pp. 6-9. In the case of rice in California: (1) airplanes were first used for seeding in 1929 and 1930 (Jenkins W. Jones, *How to Grow Rice in the Sacramento*

Valley, USDA, Farmers' Bulletin No. 1240, revised June 1931, pp. 15, 16 (fig. 8); and (2) towed combines were first used in 1927 and/or 1928 and self-propelled combines in 1932, though the latter did not begin to find wide use until about 1939 (*The Rice Journal*, 1944 (Vol. 47): January, p. 12; February, p. 9; March, p. 7; July, pp. 12, 36; November, p. 7).

[7] I have discussed the situation in the developing nations in detail elsewhere. See Dana G. Dalrymple: *Development and Spread of High-Yielding Varieties of Wheat and Rice in the Less Developed Nations.* USDA/OICD, FAER 95, September 1978 (6th edition), 134 pp.; "The Adoption of High-Yielding Grain Varieties in Developing Nations," *Agricultural History*, October 1979 (Vol. 53, No. 4), pp. 704-726.

[8] Dana G. Dalrymple, "Evaluating the Impact of International Research on Wheat and Rice Production in Developing Nations," in T. M. Arndt, D. G. Dalrymple, and V. W. Ruttan (eds.), *Resource Allocation and Productivity in National and International Research*, University of Minnesota Press, St. Paul, 1977, pp. 197-200.

[9] For further information on multiple cropping, see: Dana G. Dalrymple, *Survey of Multiple Cropping in Less Developed Nations*, USDA (in cooperation with AID), Foreign Agricultural Economic Report No. 91, October 1971, 108 pp.; and R. I, Papendick, P. A. Sanchez, and G. B. Triplett (eds.), *Multiple Cropping*, American Society of Agronomy, Special Publication 27, 1977, 378 pp. More recent information on the work at IRRI is provided in their annual *Research Highlights.*

[10] The earlier maturity, however, has made it possible to move up the harvesttime. "This has reduced storm loss risks and saved on water costs by shortening the irrigation time" (J. Norman Efferson, "New Rice Varieties . . . Advantages and Disadvantages," *World Farming*, May 1978 (Vol. 20, No. 5), p. 22).

[11] Dalrymple, *op cit.* (1971), p. 106; L. P. Reitz, *Wheat in the United States*, USDA, Agricultural Research Service, Agriculture Information Bulletin No. 386, February 1976, pp. 11, 15; W. M. Lewis and J. A. Phillips, "Double Cropping in the Eastern United States" in Papendick et al., *op. cit.*, pp. 41-50. Also see F. B. Gomm, F. A. Sneva, and R. J. Lorenz, "Multiple Cropping in the Western United States," in Papendick, et al., *op. cit.*, pp. 103-115.

[12] See *Six Decades of Rice Research in Texas*, Texas Agricultural Experiment Station, Research Monograph 4, June 1975, pp. 3, 34-35, 47, 120. The average period from seeding to harvest for Belle Patna in 18 experiments over 3 years was 108 days. The first IRRI varieties to have this short a growth duration were IR-28 and IR-30, both released in January 1975. For details on the two U.S. varieties, see C. N. Bollich, et al., "Belle Patna Rice," *Crop Science*, May-June 1965 (Vol. 5, No. 3), p. 287; and C. N. Bollich, et al., "Registration of Bluebelle Rice," *Crop Science*, May-June 1968 (Vol. 8, No. 3), pp. 399-400. Labelle has even earlier maturity (C. N. Bollich, et al., "Registration of Labelle Rice," *Crop Science*, Nov.-Dec. 1973 (Vol. 13, No. 6), pp. 773-774).

[13] Letter from Dr. Norman E. Borlaug, International Maize and Wheat Improvement Center, April 17, 1979.

[14] Letter from Dr. W. R. Coffman, Visiting Scientist (from IRRI), Louisiana State University, Baton Rouge, Feb. 27, 1979.

[15] The need to increase yields will be intensified by the loss of farmland to other uses (see, for example, Mary Thornton, "Food Exports Threatened by Loss of Farmland in U.S.," *Washington Star*, Nov. 26, 1979, p. A2).

X. APPENDIX

A. Publications on Semi-Dwarf Varieties of Wheat in Other Developed Nations[1]

Australia

–A. T. Pugsley, "At Last–Semi-Dwarf Wheats for Australia," *Bulk Wheat*, 1974 (Vol. 8), pp. 34-35.

–A. T. Pugsley, "Semi-Dwarf Wheats and Gibberellin," *Annual Wheat Newsletter* (Kansas State University), June 1979 (Vol. XXV), p. 42.

–J. R. Syme, "A High-Yielding Mexican Semi-Dwarf Wheat and the Relationship of Yield to Harvest Index and Other Varietal Characteristics," *Australian Journal of Experimental Agriculture and Animal Husbandry*, 1970 (Vol. 10), pp. 350-353. (Reference section lists several earlier articles on semi-dwarfs.)

–J. R. Syme and A. T. Pugsley, "A Mexican Wheat and Its Application to Australian Wheat Improvement," *SABRAO Journal*, 1975 (Vol. 7, No. 1), pp. 1-5.

–J. R. Syme, et al., "Oxley, a New Wheat Variety for Queensland," *Queensland Agricultural Journal*, 1975 (Vol. 101), pp. 130-133.

Canada

–L. E. Evans, et al., "Glenlea Spring Wheat," *Canadian Journal of Plant Science*, November 1972 (Vol. 52), pp. 1081-1082. (Glenlea has semi-dwarf varieties in its ancestry but is not a semi-dwarf.)

–L. E. Evans, et al., "Noquay Hard White Spring Wheat," *Canadian Journal of Plant Science*, July 1974 (Vol. 54), p. 573. (Variety later withdrawn because of "identification" problems.)

[1] I had originally hoped to include a comparable list for rice but was unable to find any appropriate references, though some undoubtedly exist for Japan. The nearest I came were two articles by Donald J. McDonald: "Rice Breeding in Australia," in *Rice Breeding*, IRRI, 1972, pp. 171-174; and "Rice and Its Adaptation to World Environments," *The Journal of the Australian Institute of Agricultural Science*, March 1978 (Vol. 44, No. 1), pp. 3-20, esp. pp. 10-20.

Czechoslovakia

—P. Bartoš and V. Slovenčikova, "Items from Czechoslovakia: Common Wheat Breeding Problems," *Annual Wheat Newsletter* (Kansas State University), May 1978 (Vol. XXIV), p. 51.

Greece

—Wilford L. Phillipson, "New Seeds Help Greece Double Wheat Yields," *Foreign Agriculture* (USDA), Nov. 20, 1978, pp. 6-7.

Israel

—A. Blum, "Wheat Breeding for the Semi-Arid Region," *Gan Sadeh Vameshek*, June 1979, pp. 11-16 (in Hebrew).

—J. Ephrat, et al., "Studies on Dwarf and Semi-Dwarf Varieties of Wheat in Israel," *Bulletin of the Ecole Nationale Superior Agronomique*, Nancy, 1964 (Vol. 7), pp. 1-23 (in French).

—Yoav Kislev and Michael Hoffman, "Research and Productivity in Wheat in Israel," *The Journal of Development Studies*, January 1978 (Vol. 14, No. 2), pp. 161-181.

New Zealand

—J. M. McEwan, "The Performance of Semi-Dwarf Wheats in New Zealand: Implications for New Zealand Wheat Breeding," *Proceedings of the Fourth International Wheat Genetics Symposium* (ed. by E. R. Sears and L. M. S. Sears), University of Missouri Agricultural Experiment Station, 1973, pp. 557-559.

United Kingdom

—F. G. H. Lupton, "The Potential of Semi Dwarf Winter Wheats," *2nd International Winter Wheat Conference Proceedings*, Zagreb, Yugoslavia, June 1975, University of Nebraska, Agricultural Experiment Station, pp. 60-64.

—M. D. Coale and C. N. Law, "The Identification and Exploitation of Norin 10 Semi-Dwarfing Genes," *Plant Breeding Institute, Annual Report, 1976*, pp. 21-35.

—"Higher Wheat Yields From Modern Varieties," *Span* (Shell), 1980 (Vol. 23, No. 1), p. 22 (reproduced from *ARC News*, December 1979).

B. Goals of Rice Breeding in the Southern United States

Although this report has given primary emphasis to plant height, height is only one of several goals in U.S. plant breeding programs. A broader picture of these goals in the case of rice is provided in a recent statement concerning the cooperative Federal-State breeding program in the Southern States by Charles N. Bollich, B. D. Webb, and J. E. Scott.[1] *Excerpts from this paper are reproduced below. Bollich and Webb are with USDA; Scott is with the Texas AES.*

Primary objectives of the rice breeding programs in the Southern United States are to develop higher yielding, early and very early maturing varieties that have acceptable or improved milling, cooking, and processing qualities for the respective grain types, are resistant to lodging and major diseases, and adapted to highly mechanized cultural practices. All Federal-State programs emphasize improved plant type and in Texas the ratoon or second crop yielding ability of promising advanced selections is routinely determined because of the importance of the ratoon crop.

This report emphasizes the rice breeding work in Texas but objectives and general procedures are essentially the same in Arkansas and Louisiana.

* * *

Grain Quality

In no other country in the world is rice quality given a higher priority in breeding programs than in the United States, particularly the quality of long-grain varieties. The United States produces only about 1.5 percent of the total annual production of rice in the world, but it generally leads the world in the volume of rice exported. With approximately two-thirds of the rice crop exported, U.S. varieties must be of the type and quality desired in export markets. Quality is even more important domestically, and is becoming more refined as parboiling and other processing uses continue to increase.

* * *

To maintain the traditionally high quality standards of U.S. rice and to develop varieties with even better qualities for particular end uses requires a well-organized, closely coordinated quality testing program throughout the period of development of new varieties. This need is filled by the Regional Rice Quality Laboratory at Beaumont, Texas, which serves all public rice breeding programs in the United States. The Laboratory was established over two decades ago and pioneered in the adaptation of quality testing methods to

[1] "Rice Breeding in the Southern States," in Marvin K. Harris (ed.), *Biology and Breeding for Resistance to Arthropods and Pathogens in Agricultural Plants*, Texas Agricultural Experiment Station, Miscellaneous Publication, in press.

practical rice breeding programs to assist in the development of high quality varieties. It has served and continues to serve as a model laboratory for breeding programs in other rice producing countries.

The Quality Laboratory conducts a series of chemical and physical tests that serve as indices of rice cooking and processing behavior.

* * *

As lines are advanced and sufficient quantities of seed become available, milling determinations are conducted. The whole-grain milling yield determines the monetary value of the rice and as such has a strong influence on the acceptance of a new variety in the United States. This is illustrated by the fact that the leading long-grain and medium-grain varieties in the United States today, Labelle and Nato, have the highest milling yields for their respective grain types, although neither is the highest yielding variety grown. By world standards, all U.S. varieties mill well, but within the United States a difference of two or three percentage points in whole-grain yield has a strong influence on the acreage sown to a variety. Acceptable milling, cooking, and processing qualities, and acceptable kernel size, shape, and translucency are all absolute requirements for any new commercial variety of table rice in the United States.

* * *

Plant Type

Next to grain quality, improved plant type receives the most emphasis in the breeding program in Texas. Just as the breeder must have a clear idea of the grain quality, maturity, disease resistance, and other attributes he desires to incorporate in a new variety, he also must have a general concept of the plant type desired in order to plan an effective breeding strategy, since his concept would have a strong influence on his choice of parents for crosses and his selection criteria in segregating generations. Our concept of an improved plant type in rice is one that is relatively short in height, with relatively small leaf dimensions, an upright leaf habit, and a sturdy culm resistant to lodging. This plant type is widely accepted as the "ideal" plant type in rice, usually with high tillering ability included as a component for varieties grown under transplanting culture. While high tillering ability is considered essential in transplanted rices, it has not been shown to be so in direct seeded varieties, and since direct seeding is the universal practice in the United States, we did not include it in our initial concept. While semi-dwarf plants frequently possess the combination of characters desired, our concept encompasses both semi-dwarf and normal plant types.

* * *

Our research to date confirms the importance of plant type in achieving very high grain yields at Beaumont but indicates that, in respect to some characteristics, there is room for flexibility in our concept of an improved plant type. In the period 1967-75, we conducted annually a yield trial that included 24 varieties and selections of diverse plant type, and two nitrogen rates, 90 and 180 kilograms per hectare.

* * *

The two highest mean yields were produced by Taichung Native 1, a semi-dwarf variety, and PI 325893, a selection of normal plant type derived from the cross of Tainan-iku No. 487 and Peta, made at IRRI. [Both, however, have unacceptable grain quality.] . . . These two entries and Brazos have produced the highest grain yields thus far obtained in field plots of the varietal improvement program at Beaumont, about 9,000 kilograms per hectare. This level may be considered the "yield plateau" at Beaumont, under present standard cultural practices.

* * *

As data from these studies became available through the years, we tended to modify our initial concept of a superior plant type (for our environment) and, at the same time, gained increased confidence in our general concept of an improved plant type. We can summarize our general impressions concerning plant type as follows:

(1) Leaf size and habit are the most important attributes of an improved plant type.
(2) Shorter plant stature is important, but there is a lower limit that is partly dependent on cultural practices, that is, whether direct seeded or transplanted, rain fed or flood irrigated, machine or hand-harvested, etc.
(3) Sturdy culms are essential for lodging resistance. Lodging resistance is independent of plant type, i.e., normal or semi-dwarf. For example, IR-28, a semi-dwarf, is more susceptible to lodging, under Beaumont conditions than any of the presently grown U.S. varieties, even though some are relatively tall, e.g., Nato. However, other things being equal, shorter plants are more lodging resistant.
(4) The evidence from our studies suggest that somewhat higher tillering ability (under direct seeding culture) than found in most current U.S. varieties may be needed for further increases in yield.
(5) Both normal and semi-dwarf types can produce very high yields, provided they possess improved plant type characteristics.
(6) Although an improved plant type is required for very high yielding ability, all lines possessing an improved plant type are not high yielding; we have many that produce inferior yields.

* * *

We believe that it is desirable to develop varieties that encompass a range of plant types, all within the general definition of an improved plant type, because of different microenvironments or required cultural practices within a geographical region. For example, a semi-dwarf variety might be adapted to an area where the land surface is relatively level, requiring few contour levees for irrigation; it might not be adapted to fields with numerous contour levees, because combines would tend to miss panicles on the short-statured plants when crossing over levees.

Early Maturity

In the past three decades there has been a consistent tendency for newly released southern U.S. rice varieties to be earlier maturing. Today only one southern variety (Starbonnet) that is of midseason maturity is grown on extensive acreage, all other widely grown varieties being either early or very early maturing. Earlier maturity decreases irrigation costs and the period of time during which the crop is exposed to weather hazards. Early maturity is also necessary for dependable ratoon (second) crop production in Texas and south Louisiana.

Early maturity is among the most readily attainable characteristics desired in new southern U.S. rice varieties because of the relatively large number of early maturing U.S. varieties with good cooking and milling quality that are available for use as parents. The earliest variety presently grown in the United States today is Labelle. It is questionable that varieties much earlier than Labelle can be developed that will produce very high grain yields. With very short season varieties, good management becomes increasingly important because the plants have insufficient time to overcome stresses caused by poor management, e.g., nutritional deficiencies, inadequate weed control, poor water control, etc.

Ratooning Ability

With the release of the very early maturing variety, Belle Patna, in 1962, ratoon (second) crop production became established in Texas and today probably about 50 percent of the annual rice acreage is ratooned. One reason for the popularity of Labelle, which was grown on 88 percent of the Texas rice acreage in 1978, is its superior ratooning ability.

Annually we obtain ratoon yields for all very early and early maturing selections in the Uniform Regional Rice Performance Nurseries at Beaumont. In Texas, the ratooning ability of a selection has an important bearing on the decision to release a new variety.

[Conclusion]

We believe that the breeder must keep an open mind, seek new ideas, be innovative, and constantly strive to develop new screening techniques for all important characteristics to advance his material as efficiently and effectively as possible. He should constantly use the best possible field plot technique, within the limits of available time and resources, to minimize variation and gain the most precision reasonably achievable. The "yield barriers" that appear to be emerging in various regions present formidable challenges that will be difficult to break and further progress in developing higher yielding varieties will become increasingly dependent on intensive studies of constraints to higher yields.

☆ U. S. GOVERNMENT PRINTING OFFICE : 1980 625-118/1861