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The Green Revolution for Wheat in Developing Countries

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ABSTRACT

The green revolution has greatly increased the wheat supply in the developing world. The experiences of Mexico, India, Pakistan, Turkey, and Argentina are reviewed here. Governments of these countries, except Argentina, used procurement programs and input subsidies to maintain high profits for wheat production as long as domestic production substituted for imports. As these countries achieved wheat self-sufficiency, incentives for wheat production versus other crops were reduced. In contrast, Argentina taxed wheat exports and protected its high-cost fertilizer industry. Argentina increased wheat output by adopting semi-dwarf varieties double-cropped with soybeans using a small amount of fertilizer.

Keywords: Green revolution, wheat, developing countries, agricultural policy, high-yielding varieties.

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PREFACE

Wheat is the king of food grains in international trade. U.S. farmers produce a major share of that market, but their share has diminished since 1981.

This report is part of a comprehensive Wheat Competitiveness Study being conducted by the Economic Research Service. The study will help us to better understand competitiveness and how we compete in world agricultural markets.

The study focuses on factors that relate to the competitiveness of U.S. wheat in world markets ranging from natural endowments to technology to farm and trade policies. Major exporting countries (United States, Canada, Argentina, Australia, and France) are included, as are major importing countries and regions (North Africa, China, USSR, Eastern Europe, Mexico, and Brazil).

Other information related to the competitiveness of U.S. wheat exports is summarized in ERS Wheat Competitiveness Conference: A Proceedings. Copies are available from Velmar Davis, Room 732, Economic Research Service, 1301 New York Ave., N.W., Washington, DC 20005-4788; telephone (202) 786-1699.

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SUMMARY

The green revolution has greatly increased the wheat supply in the developing world and, through import substitution programs, has substantially altered the role of some countries in the international wheat market. Government policy has influenced the progress of this revolution, principally through price supports and farmer subsidies of inputs. This report reviews the experience of five developing countries: Mexico, India, Pakistan, Turkey, and Argentina. Those countries encompass about 70 percent of the total area in the noncommunist developing world planted to the semi-dwarf wheat varieties. The feasibility of wheat production in tropical areas is also discussed.

The key elements of the green revolutions in Mexico, India, and Pakistan were new semi-dwarf wheat strains, irrigation, and increased fertilizer use. Mexico briefly became an exporter, but is once again an importer because consumption is increasing even faster than production. Increased output in India and Pakistan allowed imports to trend downward.

The semi-dwarf varieties were quickly adopted in Mexico, India, and Pakistan because of their high yield response to fertilizer under irrigation. These higher yields created incentives to shift resources from other crops to irrigated wheat production. The competitiveness of irrigated wheat for agricultural resources was enhanced by government-supported prices and subsidized inputs. For example, the high yields of the semi-dwarf varieties in India financed tubewells to bring additional lands into irrigated wheat production. Land was shifted from rain-fed crops, such as coarse grains, to irrigated wheat production. Thus, the semi-dwarf varieties also increased output through expanded area sown to wheat.

The green revolution for wheat in Turkey was initially limited to the irrigated, spring wheat regions on the coast because the semi-dwarf varieties were spring wheats. The green revolution was later extended to the dryland, winter wheat regions with the development of improved management practices and suitable varieties. The increased output allowed Turkey to export wheat for several years. Recently, however, production has stagnated and the country is again a net importer.

Governments of these four countries used procurement programs and input subsidies to maintain the high profitability for wheat as long as domestic production substituted for imports. As these countries achieved wheat self-sufficiency, incentives for wheat production versus other crops were reduced. The sacrifices of other national objectives became too great to continue favoring wheat so heavily. By lowering procurement prices and input subsidies for wheat relative to other crops, governments reduced the expenditures from their national budgets and provided incentives for farmers to shift land to crops in deficit.

Wheat output is expected to continue increasing in these countries due to expanded irrigation and increased fertilizer use. However, these countries are not expected to become competitors for U.S. wheat exports because they are modifying their policies to avoid creating subsidized surpluses that would be exported at a loss to their national economies.

Argentina did not follow the typical green revolution strategy. Unlike the other countries discussed here, wheat yields did not rise rapidly in Argentina because the country's industrial development strategy kept the farm wheat

price low and the price of fertilizer high, thus discouraging fertilizer use. Argentina increased its output of wheat by adopting semi-dwarf varieties and improved tillage practices, not increased fertilizer use. This allowed Argentina to maintain its share of world wheat exports.

Increased fertilizer use can substantially increase yields. Thus, changes in Argentine policy to favor fertilizer use could significantly increase the country's wheat production and exports.

The introduction of wheat production on a large scale in many developing countries is limited by the adverse effects of high temperatures on wheat growth, and sometimes unfavorable soil conditions, for example, acid soils in Brazil and hardpans in the rice paddies of Asia caused by puddling the soil for rice. The prospects for nonproducing countries to begin growing substantial quantities of wheat depend upon solving these problems. Wheat production is being successfully introduced on a large scale in Bangladesh because suitable varieties and practices were developed for wheat to be multiple cropped with rice.

The Green Revolution for Wheat in Developing Countries

Gary Vocke

INTRODUCTION

The green revolution has greatly increased the wheat supply in the major wheat-producing countries in the developing world, substantially altering their role in the international wheat trade. Government policy has influenced the progress of this green revolution. This report reviews the history of the interaction between policy and the progress of the green revolution in major wheat-producing countries and the consequences for international wheat trade. Wheat production potential in tropical climates is also reviewed.

Semi-dwarf varieties increased wheat production in developing countries because those varieties respond to increased use of fertilizer, water, and pesticides. The green revolution is the term used to refer to replacing traditional wheat varieties with semi-dwarf varieties and using more inputs beginning in the sixties.

The research that created these wheat varieties began as a cooperative venture between Mexico and the Rockefeller Foundation at what is now called CIMMYT (The International Maize and Wheat Improvement Center) (18).1/ Researchers developed short-stemmed, high-yielding wheat varieties in the fifties by crossing rust-resistant Mexican varieties with American semi-dwarf varieties. (These American semi-dwarf varieties were developed in the forties at Washington State University using varieties from Japan.) By the sixties, the Mexican and American varieties had been successfully crossed and the seed distributed to the farmers, greatly increasing Mexican wheat yields through the seventies.

The development of the semi-dwarf varieties is important because they respond to increased fertilizer application with higher yields. The traditional varieties grew taller and leafier and tended to lodge, thus lowering yields, when fertilizer was applied. Excessive vegetative growth and lodging was solved by the short-stemmed (semi-dwarf) varieties. Fertilizer is essential for these semi-dwarf varieties; without it they may do no better than the traditional varieties. Weed control and water management are also necessary. The added cost of growing the crop caused by these requirements is repaid by increased yields (21).

1/ Numbers in parentheses refer to sources listed in References section.

These semi-dwarf varieties proved well adapted to the major wheat-growing regions of the developing countries (18). India and Pakistan began importing seed from Mexico in 1965. Turkey began importing seed from Mexico in 1967. When grown under recommended practices, including irrigation and fertilization, the semi-dwarf varieties increased yields two and three times above the native varieties. The rapid expansion of the area planted to these varieties during the sixties started the green revolution and has steadily increased production, particularly in the major wheat-producing countries of the developing world.

The semi-dwarf varieties used more fertilizer, water, and pesticides to substitute for land expansion as the primary basis for increased output. Before the green revolution, the proportion of the increase in production attributed to expanded areas exceeded the contribution of higher yields (fig. 1). By the end of the sixties, yields were improving rapidly and were making the larger contribution. By the eighties, most of the increase in output was due to yield increases.

The impact of the green revolution is further shown by comparing wheat with other cereals. Wheat production increased more rapidly than that of other cereals because of both higher yields and expanded harvest areas (table 1). This expansion of area reflects higher profits from the high-yielding semi-dwarf varieties compared with other crops. Higher profits encouraged farmers to shift land from other crops, for example, dryland sorghum, to irrigated wheat in India. Thus, wheat area as a proportion of total harvested area increased relative to other cereals.

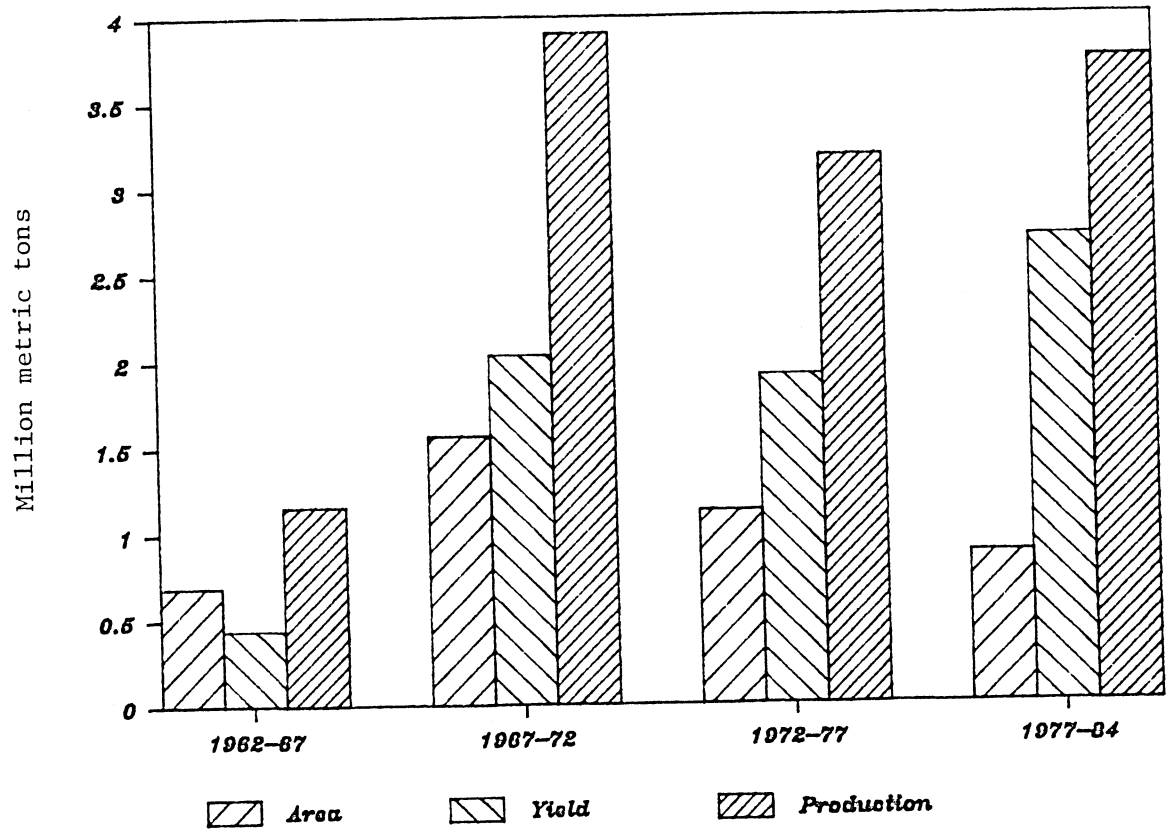
WHEAT IN THE DEVELOPING WORLD

Wheat now provides about one-eighth of the calories consumed in the developing countries and its use is increasing (fig. 2). Wheat production in the developing countries has increased more than 150 percent since the early sixties (fig. 3). Wheat imports by these countries doubled during these years.

This rapid increase in imports by the developing countries has increased their role in international wheat trade in the past 20 years (5). Wheat trade was dominated by the industrialized countries following World War II, with the United States, Canada, and Australia exporting wheat primarily to Western Europe and Japan. But during the sixties, and especially in the seventies, the developing countries, Eastern Europe, and the Soviet Union began importing increasingly large amounts of wheat. During this time too, Western Europe became a net exporter of wheat. The result of these shifts in trade was that the net import share of the developing countries rose from a fourth of the total in 1955 to two-thirds in 1982 (5).

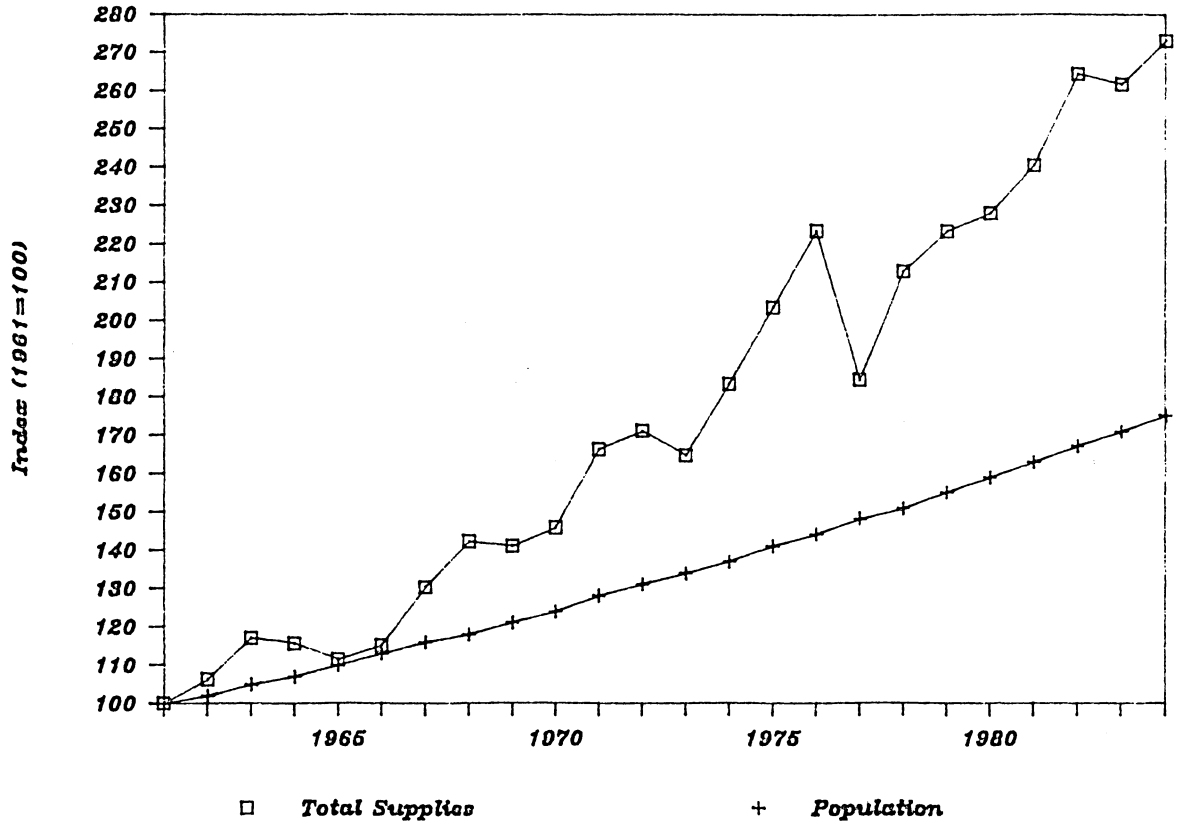
Wheat consumption and imports have expanded rapidly in the developing countries because of increasing populations, and the substitution of preferred grains, primarily wheat and rice, for coarse grains, roots, and tubers in the diet in many countries (2, 3). This substitution is occurring because of rising incomes and urbanization (and, in some cases, food aid). Some countries have been able to meet the increased demand by increasing domestic production. In the major wheat-producing countries, wheat production increased so rapidly because of the green revolution that imports declined in India, Pakistan, and Turkey. In the tropics, where little wheat is grown, increased consumption has been supplied by ever larger imports. Thus, the

Figure 1. Average annual area and yield contributions to wheat production.1/



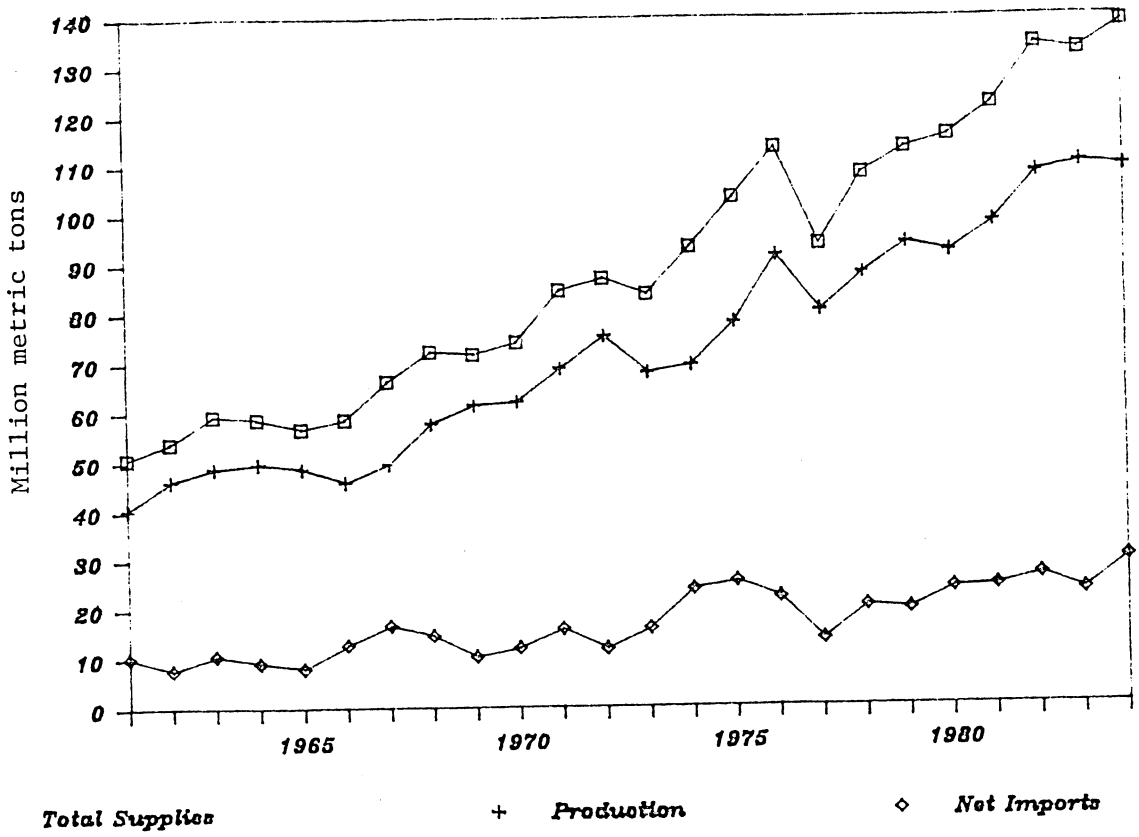
1/ The area contribution to increased output is calculated by multiplying the change in area over the period by the yield at the start of the period. The yield contribution is the change in yield over the period times the area at the start of the period. The area and yield contributions and the change in production are converted to an annual basis.

Figure 2. Wheat availability growing faster than population 1/



1/ Total supplies equals the sum of domestic production and net imports.

Figure 3. Wheat production and net imports, 1961-84 1/



1/ Total supplies equal the sum of domestic production and net imports.

Table 1--Indices for wheat and other cereals in developing countries, 1982-84

Item	Wheat	Other cereals 2/
	Index (1961-63 = 100) 1/	
Production	241	163
Area	142	118
Yield	170	138
Proportion of total area	113	87

1/ Based on data from FAO computer tapes on production.
2/ Other cereals includes rice, corn, sorghum, barley, and millet.

pattern of wheat imports in the developing countries has shifted. In particular, South Asia's share of world wheat imports has declined compared with the rest of the developing world.

THE GREEN REVOLUTION IN THE MAJOR WHEAT-PRODUCING COUNTRIES

Mexico, India, Pakistan, Turkey, and Argentina are the leaders in area planted to semi-dwarf varieties (table 2). Those countries account for 70 percent of the total area in noncommunist developing countries planted to these new varieties (11).

The key elements of the green revolutions in Mexico, India, and Pakistan were semi-dwarf varieties, irrigation, and increased fertilizer use. Mexico briefly became an exporter, but is once again importing because consumption is increasing faster than production. Increased wheat output in India and Pakistan allowed imports to trend downward.

Turkey's green revolution in wheat was initially limited to the irrigated, spring wheat regions on the coast because the semi-dwarf varieties were spring wheats. The green revolution was later extended to the dryland, winter wheat regions with the development of improved management practices and suitable varieties. The increased output allowed Turkey to become a wheat exporter for several years. Recently, however, production slowed and the country is again a net importer.

Argentina's wheat yields did not rise rapidly because its industrial development strategy kept the price of wheat low and the price of fertilizer high, thus discouraging fertilizer use. Argentina increased its wheat output by adopting semi-dwarf varieties and improved tillage practices, not increased fertilizer use. This allowed Argentina to maintain its share of world wheat exports.

Table 2--Estimated area planted to high-yielding varieties of wheat in selected developing countries, 1982-83

Country	Wheat area in high-yielding varieties		Country's area in high-yielding varieties as percent of total area in developing countries planted to high-yielding varieties
	Total	Share of country's total wheat area	
	Million hectares	Percent	Percent
India	18.1	79.0	43.2
Argentina	6.5	91.5	15.6
Pakistan	6.4	87.7	15.2
Turkey	3.3	35.8	8.0
Mexico	.8	80.0	1.9

Source (10).

Mexico

Mexico's wheat-breeding research, begun in the forties, produced the varieties that began the green revolution in the developing countries (18). The initial success of this program was the development of rust resistance in the native Mexican varieties. Production and average yields improved when these rust-resistant varieties were distributed to Mexican farmers in the fifties. During the fifties, researchers developed the semi-dwarf varieties that dramatically increased yields and production in the early sixties.

This wheat-breeding program's goal was to achieve wheat self-sufficiency by expanding the producing area and improving yields (13, 22, 43). The strategy to expand harvested area focused on public investment in large-scale irrigation projects in northwest Mexico. The yield improvement strategy was to develop semi-dwarf varieties suited for the irrigated areas in northwest Mexico. To promote the use of these varieties with water and fertilizer, the Mexican Government subsidized the price of inputs and credit and supported the farm price for wheat (22, 39). Irrigated wheat production became very profitable and production increased so rapidly that by the sixties Mexico had surplus wheat. This surplus production was exported at a loss to the Mexican Government because the world price was less than the support price. To avoid stockpiling wheat and to cut down on their export losses, the Government created a two-level price support system with a lower price for the irrigated wheat growers in an attempt to restrain the output from the irrigated wheat areas in the northwest (22).

Since the seventies, wheat production has not increased as rapidly as use, and Mexico is again a wheat-deficit country. Presently, Mexico is importing low-quality wheat as a substitute for sorghum for livestock feed. Because of the decline in Government subsidies, domestic producer prices for wheat are now below world prices. In addition to the decline in subsidies, the increase

in wheat production has slowed because, with the completion of the irrigation projects in the northwest, total wheat area is expanding much less than before. These projects nearly exhausted the opportunities for water development in northwest Mexico, the area best suited to wheat production (39). The slowed expansion of irrigated lands suitable for wheat production (and the Government's efforts to stimulate production of other crops) is reflected in the decline in the proportion of total harvested wheat area relative to other cereals (table 3). Thus, most of the increase in wheat production has been due to improving yields.

Wheat yields now average about 4.1 metric tons per hectare (MT/HA) and are the highest in the developing world. With improved management and additional inputs, wheat yields in Mexico are projected to reach 5.5 MT/HA, and possibly 6.0, by the year 2000 (18).

The possibilities to increase wheat production through area expansion are relatively limited. Yields are low in the areas where wheat is not irrigated. Additionally, farmers have received higher than world prices for competing crops, especially corn and oilseeds (5). Thus, wheat cannot compete with other crops for land. Most of the dryland wheat-growing areas do not have much potential for irrigation development because of a lack of water. Where water is available for irrigation development, the climate is subtropical and present varieties do not yield well because of the high temperatures. If suitable varieties can be developed, perhaps 200,000 additional hectares of irrigated wheat could be grown (current area is about 800,000 hectares) (18). Expanding irrigated wheat production in the northwest will be limited unless wheat can substitute for competing crops, such as cotton. However, cotton probably provides higher economic returns to land than wheat (5).

India

Successive droughts in 1965 and 1966 placed in question India's capacity to feed its people (12). Wheat imports were very large. Increasing food production was assigned a high priority. However, applying additional fertilizer to the native wheat varieties of India resulted mainly in vegetative growth, lodging, and little increase in output. Fortunately, the Mexican semi-dwarf wheat varieties became available at this time.

The Indian Government decided to concentrate available inputs of fertilizer and pesticides in the highly productive irrigated areas (42). India initiated its wheat intensification program by importing seed from Mexico and promoted its widespread use in the irrigated wheat-growing areas with a package of subsidized inputs and high procurement prices (12, 24). With the varieties from Mexico, wheat yields increased immediately. The rapid success was due to the large investments in irrigation facilities made in the past (36). The green revolution package of semi-dwarf varieties, fertilizer, and pesticides depends on irrigation.

With the semi-dwarf varieties, the subsidized inputs, and the higher procurement prices, the profits from wheat production increased dramatically (24, 42). The high profits encouraged farmers to increase fertilizer use and to finance wells from their profits to improve and expand the area for irrigated wheat production (24). Thus, the new varieties increased wheat production through both higher yields and expanded area (table 4).

Table 3--Comparison of Mexico with all developing countries for wheat production 1/

Item	Unit	Mexico	All developing countries
Indices for 1982-84: 2/			
Production	Index	268	241
Area	Index	125	142
Yield	Index	214	170
Proportion of total harvested area	Index	95	113
Ratio of yield to area contributions 3/	Ratio	4.5	1.6
Yield in 1982-84	MT/HA	4.1	1.6

1/ Based on data from FAO computer tapes on production.
2/ Average of 1961-63 = 100.
3/ The yield contribution is calculated as the change in yield from 1961-63 to 1982-84 multiplied by the harvested area in 1961-63. The area contribution is calculated as the change in area from 1961-63 to 1982-84 multiplied by the yield in 1961-63.

Table 4--Comparison of India with all developing countries for wheat production 1/

Item	Unit	India	All developing countries
Indices for 1982-84: 2/			
Production	Index	370	241
Area	Index	175	142
Yield	Index	212	170
Proportion of total harvested area	Index	158	113
Ratio of yield to area contributions 3/	Ratio	1.5	1.6
Yield in 1982-84	MT/HA	1.8	1.6

1/ Based on data from FAO computer tapes on production.
2/ Average of 1961-63 = 100.
3/ The yield contribution is calculated as the change in yield from 1961-63 to 1982-84 multiplied by the harvested area in 1961-63. The area contribution is calculated as the change in area from 1961-63 to 1982-84 multiplied by the yield in 1961-63.

The higher procurement prices under the Government program increased the quantity of domestic wheat acquired for distribution to the urban poor through its fair-price shops (23, 38). The procurement prices before the green revolution were below both the market prices and the cost of production. Average Government purchases in the 15 years before the green revolution were less than 2 percent of domestic production. When wheat procurement prices were raised above production costs in the early years of the green revolution to encourage the adoption of the semi-dwarf varieties, farmers sold as much as 20 percent of their production to the Government. These domestic purchases substituted for wheat imports in supplying the country's fair-price shops.

Recently India has developed large deficits in oilseeds and pulses, in part, because these crops have been less profitable than the high-yielding varieties of wheat and rice (25). To reduce large foreign exchange outlays for vegetable oil imports and to increase pulse production, the Government is now modifying its pricing policies and development programs to shift some agricultural resources from wheat and rice into rain-fed oil crop and pulse production.

Continued increases in wheat output in the irrigated northwest will depend on improving the growing practices for the semi-dwarf varieties. Use of additional fertilizer can raise yields. The expansion of the supply of low-cost fertilizers will help to increase output.

Several activities may extend the green revolution for wheat outside of northwest India. Given the dependence of the semi-dwarf varieties on controlled application of water, the area that can be planted with these varieties is limited. Additional investments are needed to develop water resources. For both central and northeast India, wheat breeders are developing high-yielding varieties that can tolerate the high temperatures. Irrigation systems are being improved and expanded and alternative multiple-cropping patterns are being evaluated (4, 25).

Pakistan

Growth in Pakistan's wheat production before the green revolution was due almost exclusively to expanded area (14). The national average yield was static. Population was increasing faster than wheat production, and imports were steadily increasing. When the Mexican semi-dwarf varieties became available in the midsixties, the Government decided to use these varieties to increase the growth rate for wheat production. Field trials had shown that the yield potential of the wheats developed in Mexico were superior to native varieties. The wheat intensification program was initiated by importing seed wheat from Mexico, subsidizing fertilizer use, and supporting the farm price of wheat.

The wheat intensification program was a quick success because, as in India, the semi-dwarf varieties made wheat production very profitable and there were already large irrigated areas. These areas were irrigated from river diversion dams established during British colonial rule. The use of wells to supplement this irrigation system for the cash crops of cotton, sugarcane, and tobacco had been slowly increasing before the wheat intensification program. Wheat was not irrigated using well water because the cost was too high. With the semi-dwarf varieties and the Government's pricing policies, it became profitable for the farmers to use well water on wheat (14). Farmers rapidly

increased their investments in wells for wheat. Fertilizer use on wheat increased profits and wheat yields (table 5).

The Government used the increased output to reduce its imports of wheat. The country moved so quickly from being a wheat importer to near self-sufficiency that the Government considered promoting wheat as an export crop. However, after realizing that the country would be attempting to export wheat that would meet only the lowest of the international grades, the Government decided that wheat production should be targeted to increase at the same rate as wheat consumption (14). This self-sufficiency objective for wheat has been a guiding principle for the incentives provided to farmers by the Government through price supports and fertilizer subsidies. Wheat production continues to increase and presently exceeds current consumption even though prices are below international levels and subsidies on fertilizer are being reduced. Pakistan is a net importer now only because of concessional wheat imports for the Afghanistan refugees in the country.

The Government is continuing its efforts to improve wheat yields. In the past, most of the effort has been to increase yields of wheat following fallow, the most common cropping pattern. Researchers are now investigating the yield constraints when wheat is double-cropped with cotton or rice. Presently, 70 percent of the cotton and 80 percent of the rice is followed by wheat. This double-cropped wheat is about 30 percent of the area of wheat harvested annually. The principal constraint to higher wheat yields following rice and cotton is the yield reduction due to the delay in the seeding of wheat. Also under investigation is the effect on wheat of the puddling of the soil for rice.

Table 5--Comparison of Pakistan with all developing countries for wheat production 1/

Item	Unit	Pakistan	All developing countries
Indices for 1982-84: 2/			
Production	Index	289	241
Area	Index	148	142
Yield	Index	195	170
Proportion of total harvested area	Index	111	113
Ratio of yield to area contributions 3/	Ratio	2.0	1.6
Yield in 1982-84	MT/HA	1.6	1.6

1/ Based on data from FAO computer tapes on production.
2/ Average of 1961-63 = 100.
3/ The yield contribution is calculated as the change in yield from 1961-63 to 1982-84 multiplied by the harvested area in 1961-63. The area contribution is calculated as the change in area from 1961-63 to 1982-84 multiplied by the yield in 1961-63.

An additional difficulty to increasing wheat production is the management of the old diversion dam irrigation system. There have been problems in the timely delivery of the water among competing crops. This system was not designed to deliver water over large areas with the control required for modern agriculture.

Turkey

The wheat sector of Turkey developed in three phases (18, 37). During the late forties and fifties, production increased by expanding the area of dryland winter wheat on the Anatolian Plateau. (About three-fourths of Turkey's wheat area is on this plateau.) The second phase was the spread of semi-dwarf spring wheat varieties from Mexico in the late sixties through the irrigated areas of the coastal plains. The third phase was the adoption of cropping and farming practices in the midseventies to improve moisture and weed control on the Anatolian Plateau. These management practices raised yields and allowed some reduction in the area in fallow.

These development phases are closely linked to the history of Turkey's wheat trade. Following the rapid area expansion on the Anatolian Plateau, production exceeded consumption and Turkey was able to export wheat. By the early sixties, however, wheat demand was growing faster than production and Turkey again became a net importer of wheat. The Government then initiated a wheat intensification program that led to the second and third phases of the development of its wheat sector. Yields were quickly increased in the irrigated, spring-wheat areas with the Mexican varieties. The Government promoted the widespread use of these varieties and additional fertilizer by supporting wheat prices and subsidizing inputs (42).

The principal constraint to higher wheat yields on the Anatolian Plateau is the lack of moisture (18, 37). Thus, what was needed was a change of agronomic practices for moisture storage and weed control. The package of crop management practices developed by the researchers for the Anatolian Plateau was adopted by the farmers during the midseventies. The resulting yield increases of the winter wheats on the plateau and the increased production from the coastal areas allowed Turkey to become a net exporter of wheat once more. The yield contribution to increased output was 4.5 times larger than the area contribution (table 6).

Continued yield improvement depends upon increased input use, which in turn, is influenced by input prices relative to wheat prices. These prices are controlled by Government policy. In 1980, the Government adopted an austerity budget that removed agricultural subsidies and reduced support prices (44). Consequently, production for some crops, including wheat, has fallen. Turkey was a net importer of wheat in 1985 for the first time in several years.

Argentina

Argentina has long been a wheat exporter because of abundant land resources well suited to dryland wheat production (32). About 35 percent of the wheat is grown in semi-arid regions requiring a fallow rotation. In the more humid areas, wheat is typically double-cropped with soybeans. Double cropping with soybeans is a recent development. Following the introduction of sorghum and of high-yielding hybrid corn in the sixties, the area of these crops increased while wheat area declined to a low in 1970-73 (26). This decline in wheat area was reversed after 1973 because of the introduction of double cropping

with soybeans. This double cropping was feasible because short-season varieties suitable for Argentina were developed from the semi-dwarf Mexican varieties. Soybeans were very profitable and double cropping with these higher yielding wheat varieties gave even higher returns to farmers (40). The spread of this double-cropping practice reversed the decline in wheat area. By the early eighties, the proportion of total harvested area in wheat was slightly larger than in the early sixties (table 7). Now, about 80 percent of the soybeans are double-cropped with wheat.

Argentina's wheat yields are only slightly above average for developing countries because of its dryland growing practices and because little fertilizer is used. Yields have increased somewhat with improved varieties and improved cropping and tillage practices, but Argentine farmers have not used chemical fertilizers to increase yields, as farmers in other countries have (18). Because wheat yields have improved only slightly, the yield contribution to increased output was only 0.7 of the area contribution (table 7).

Fertilizer use is low in Argentina because of the country's macro policies of taxing wheat exports and protecting its inefficient and high-cost domestic fertilizer industry (41). These policies tend to keep the farm-level price of wheat low and the fertilizer price high, making fertilizer use unprofitable.

Yet, Argentine wheat yields can be increased substantially with proper fertilization (6, 31). For example, fertilizer trials in the humid region using 30 kg of nitrogen and 20 kg of phosphorus per hectare raised yields an average of 1.0 MT in 1982 and 0.6 MT in 1983 (a dry year). It is estimated

Table 6--Comparison of Turkey with all developing countries for wheat production 1/

Item	Unit	Turkey	All developing countries
Indices for 1982-84: 2/			
Production	Index	198	241
Area	Index	114	142
Yield	Index	175	170
Proportion of total harvested area	Index	102	113
Ratio of yield to area contributions 3/	Ratio	5.6	1.6
Yield in 1982-84	MT/HA	1.9	1.6

1/ Based on data from FAO computer tapes on production.
2/ Average of 1961-63 = 100.
3/ The yield contribution is calculated as the change in yield from 1961-63 to 1982-84 multiplied by the harvested area in 1961-63. The area contribution is calculated as the change in area from 1961-63 to 1982-84 multiplied by the yield in 1961-63.

Table 7--Comparison of Argentina with all developing countries for wheat production 1/

Item	Unit	Argentina	All developing countries
Indices for 1982-84: 2/			
Production	Index	186	241
Area	Index	144	142
Yield	Index	129	170
Proportion of total harvested area	Index	101	113
Ratio of yield to area contributions 3/	Ratio	0.7	1.6
Yield in 1982-84	MT/HA	1.9	1.6

1/ Based on data from FAO computer tapes on production.
2/ Average of 1961-63 = 100.
3/ The yield contribution is calculated as the change in yield from 1961-63 to 1982-84 multiplied by the harvested area in 1961-63. The area contribution is calculated as the change in area from 1961-63 to 1982-84 multiplied by the yield in 1961-63.

that 50 percent of the wheat area in Argentina needs fertilization (33). Presently, only 17 percent of the wheat area is fertilized. Thus, changes in Government policy to favor fertilizer use could substantially increase wheat production in Argentina.

WHEAT PRODUCTION IN TROPICAL CLIMATES

Wheat production on a large scale in tropical countries is presently limited by the adverse effects of high temperatures on wheat growth and sometimes unfavorable soil and climate conditions. Many countries are investing in research and development on the feasibility of growing wheat on a large scale in their countries (27).

Acid Soils

Acid soils contain free aluminum, which inhibits root growth, and phosphorus is not freely available (18, 29). Brazil is an example where intensive research efforts are underway to develop wheat varieties and cropping practices suitable for acid soils. Brazil has 50 million hectares of acid soils of which 12 million might be suitable for wheat. Similar soils are in Africa (Zaire, Zimbabwe, Kenya, Tanzania, Zambia, and Mozambique) and in Southeast Asia (Burma, Thailand, Malaysia, and Indonesia). The work with acid soils is focused on tolerance to aluminum, ability to extract phosphorus, multiple cropping patterns, and supplemental irrigation.

Rice Paddies

Millions of hectares of land in Asia lie idle during the dry season. Research and development on growing wheat on this idle paddy land focus on breeding suitable varieties, multiple cropping patterns, and soil management practices, including the effects on wheat of the hardpans resulting from the puddling of the soil for rice (4, 20). Bangladesh is an example where wheat production is being successfully introduced. Wheat area rose from an average of 61,000 hectares in 1961-65 to 567,000 hectares in 1982-83.

Hot, Arid Climates

Sudan and Nigeria are examples of countries with hot, arid climates where wheat production is being developed to reduce imports (1, 34). The principal constraints to wheat production in these countries are high temperatures and lack of water. Wheat production in these countries is being developed on large-scale public irrigation projects requiring large capital investments.

CONCLUSION

Wheat consumption in the developing countries has increased rapidly over the last two decades. The green revolution has allowed the major wheat-producing countries to meet this increased consumption from domestic production. In other countries, especially the tropics where little wheat is grown, increased consumption was possible only because of imports. Thus, there has been a shift in the pattern of wheat imports in the developing countries. In particular, the level of imports and import share for India and Pakistan have declined.

The green revolution spread rapidly in the major wheat-producing countries, in part because these countries typically subsidized inputs and supported wheat prices to encourage farmers to use the new technology. As production increased and countries were able to reduce their imports, they reduced their incentives to wheat farmers. These countries modified their pricing policies to avoid surpluses, which would have to be exported in competition with the traditional exporters of the international wheat market. Generally, these major wheat-producing developing countries are following a strategy of self-sufficiency.

Wheat production will increase in the major wheat-growing regions as farmers improve their management practices and wheat breeders continue developing higher yielding varieties. Expansion of the area planted to semi-dwarf varieties will require substantial investments in irrigation facilities in many of these countries. Because wheat is usually part of a multiple cropping sequence, the financial feasibility of this expansion of irrigated land will depend on the profits of the whole crop sequence, not just wheat. Wheat production on a significant scale in regions with tropical climates, and sometimes unfavorable soil conditions, will require further improvement in varieties. There must be improvement in the yield potential of the varieties tolerant of high temperatures.

The major wheat-growing areas of the developing world have adopted the semi-dwarf varieties that are responsive to fertilizer. This phase of the green revolution has been nearly completed (10). The succeeding phase, that of further improvement in varieties and management, is proceeding rapidly.

Improving yields now make a large contribution to the growth of wheat production in developing countries. This trend can continue because average yields are below their potential.

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