TECHNOLOGIES FOR INCREASING FOOD PRODUCTION

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Keywords: Food Production, Hybridization, Heterosis, Pest Resistance, Insect Resistance, Disease Resistance, Weed Control, Crop Cultivars, Breeding for Higher Biological Nitrogen Fixation (BNF), Biopesticides, Marketing Infrastructure.

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Summary

The present world population of 6.1 billion is likely to reach 7 billion in 2010 and 8 billion in 2025. Per capita food intake will increase due to improved living standards. It is estimated we will have to produce 50% more food by 2025. This increased demand will have to be met from less land, with less water, less labor and less pesticides. Several biotic and abiotic stresses and unfavorable post-harvest conditions take a serious toll of crop production. Therefore crop varieties with higher yield potential and yield stability, and better management practices are needed to meet the twin goals of increased crop productivity and sustainability. At the same time public policies favorable for maximum crop output must be introduced.

Genetic enhancement strategies should focus on increasing the yield potential of crops through: 1) conventional breeding and selection procedures; 2) redesigning the crop ideotypes for higher harvest index; 3) exploitation of heterosis; 4) widening the gene pools through intraspecific and interspecific hybridization; 5) modification of physiological processes such as photosynthetic efficiency, increased rubisco per unit of leaf protein and increased starch biosynthesis.

Similarly, yield stability should be enhanced through: 1) incorporation of multiple resistance to diseases and insects; and 2) tolerance to abiotic stresses such as drought, salinity, submergence and poor soils.

Crop productivity can also be increased by developing crop varieties with: 1) shorter growth duration for increased cropping intensity; 2) better nutrient uptake and utilization ability; 3) ability to enhance biological nitrogen fixation; and 4) superior post-harvest qualities.
Improved management practices will play vital role in increasing crop productivity. Emphasis should be laid on: 1) integrated pest management; 2) integrated nutrient management; 3) weed management; 4) proper control and management of water; 5) care of soil health; and 6) benign crop rotations.

Public investment in improved water control (irrigation and drainage), marketing infrastructure (roads and markets), supply of credit to subsistence farmers, property rights, land reform, agricultural extension and farmer friendly price structure for farm inputs and produce, will go a long way in meeting world needs for food and fiber.

1. Introduction

Food is the most basic human need. At low levels of income the utmost concern for human beings is to meet the energy needs to overcome hunger, and cereals provide the cheapest source of energy. Thus per capita intake of cereals as human food is often high at low levels of income, and increase further with rising incomes. The cereal intake, however, starts declining when the basic energy needs are met (at a middle income level), when people can afford to have a more diversified diet that provides balanced nutrition with adequate consumption of vegetables, meat and livestock products that are rich in protein, vitamins and micro-nutrients. But as the demand for livestock products increases with economic prosperity, so does the indirect demand for some cereals, such as maize and other coarse grains that are used as livestock feed. The indirect demand for cereals as livestock feed to have the same amount of calories from livestock products is many times higher than from direct consumption of cereals. The decline in per capita consumption of cereals for human food is over compensated by the increase in per capita demand for cereals as livestock feed. So the per capita consumption increases monotonically with the growth of incomes.

Regions	**Population (billions)**		**Projected per capita Consumption of Cereals (kg)**		**Food grain Requirements (million ton)**		**Percent Increase 2000 to**
	2000	2025	2000	2025	2000	2025	2025
East Asia	1.48	1.70	284	332	420	564	34
South-central Asia	1.50	2.10	167	187	250	392	57
Southeast Asia	0.52	0.69	210	242	109	167	53
Western Asia and North Africa	0.36	0.55	405	469	146	258	77
Sub-Saharan Africa	0.65	1.20	138	156	90	187	108
Latin America	0.52	0.69	273	301	142	208	46
Developing countries	4.90	6.82	258	280	1265	1910	51
Developed countries	1.19	1.22	626	680	745	830	11

Table 1: Population growth and food grain requirements for different regions in of the world 2000 to 2025

The most important factor determining the demand for cereals is however, population growth. The world population has doubled over the last 40 years, from 3.0 billions in 1960 to 6.1 billion in 2000, and is not expected to stabilize before 2100, when the number may reach between 9.4 (with faster progress in fertility decline) to 11 billions (with standard fertility decline). Most of the increase in population will be in developing countries. Over the next 25 years the world population is projected to increase by 1.95 billion; nearly 31 percent of the increase will come from south Asia and another 28 percent from sub-Saharan Africa (Table 1). These are the regions in the world where poverty and hunger are widespread and per capita cereal consumption is less than half of that for the developed countries.

The developed countries may not need further increase in cereal production to meet their internal demand. Most of these countries have reached a stationary population and many, particularly in Europe, will experience an absolute decline in population very soon. Only in North America and Australia, is population still growing mostly due to inmigration of people from low income countries. In Europe, North America and Japan, the per capita consumption of cereals has also started declining because of the sluggish internal demand for livestock products and growing consumers' preference for low-calorie diets with dominance of vegetables and fruits. With further increase in yields these countries are now facing problems of disposal of surplus and a downward pressure on the prices of cereals in the world market that reduce farmers' incomes. Many countries have adopted a policy of direct payment to farmers to reduce land under cereal crops to lower production and maintain prices. In Japan, for example, the area under rice has declined from 3.3 million ha in 1960 to about 2.0 million ha in 1999, in response to the declining domestic demand for rice. Many farmers in developed countries now find it profitable to go for organic farming that reduces crop yield but the produce fetch higher price in the market, because of the affluent consumers' preference for organic food.

The situation in developing countries is completely opposite because of the continuing high growth of population. It will take a longtime for many developing countries to reach the present level of per capita cereal consumption of the developed world (Table 1). So, it is expected that cereal intake will follow an increasing trend for a long time to come, the rate of increase will depend on the growth of incomes. Ironically, it is in the poverty-stricken regions, such as in sub-Saharan Africa and South Asia where the per capita consumption is expected to increase, and population will grow faster. In the next 25 years the food requirement is projected to double in sub-Saharan Africa, and grow by 50 to 75 percent in other regions of the developing world. Only in East Asia, is the growth in demand for cereals expected to slacken.

The increase in cereal production to meet the massive increase in food grain requirements in the developing world will not be an easy task without continuing efforts towards crop improvement particularly for rice (South and Southeast Asia), maize (Sub-Saharan Africa, and Southeast Asia) and root crops (Africa). In Asia, the land frontier has long been exhausted, and the increase in cropped area in the past has come from more intensive utilization of land for raising two to three crops per year which has put pressure on sustaining the natural resource base. With growing urbanization and industrialization, some of the fertile agricultural land has gradually been diverted to meet the demand for housing, factories, and roads. The perception of abundance of water, another key natural resource, has been changing even for the humid tropics and subtropics, with competing demand arising from the growth of population, urbanization, and industrialization. In Africa, the abundant land resources cannot be brought under high-productive agriculture because of the scarcity of water resources and the high-cost of water resource development projects. Environmental concerns regarding the adverse effects of irrigation and flood control projects on water logging, build-up of soil salinity, fish production and the quality of ground water has been growing. Land covered by crops year round with increasing intensity of cropping, provides excellent habitat for pests. With the movement from a low-intensity, low-yield production system to a high-intensity, high-yield system, pest pressure has been growing, and along with the increased use of agrochemicals produces harmful effects on human health and the environment. Even labor is getting scarce, and the wage rate is rising faster than food grain prices with opportunities for more remunerative employment created in the fast-growing non-farm sectors of the economy. The challenge to the developing countries therefore is how to produce more foodgrains from less land, with less water, less labor and less harmful agrochemicals.

The international trade of cereals—the movement of surplus grains from developed to developing countries through the market mechanism—may be only a part of the solution of the mismatch of the demand-supply balances between the developed and the developing regions of the world. The developed country farmers may expect an expansion of markets for wheat and corn as livestock feed but mainly in the middle-income countries of the developing world who can afford to pay for such transactions. A large part of the future demand for human food will originate from South-Asia and sub-Saharan Africa who would not have adequate foreign exchange earnings to pay for commercial transactions for staple food. Also at low-levels of income, the production of staple food is the major source of employment and incomes for the people. The growth in productivity and production of staple food within the country is considered by policy-makers a high priority strategy considering the socio-political compulsion of generating employment and income for the poor farm producers and consumers. So, meeting the demand-supply gap through further improvements in crop productivity within the national borders, rather than through trade may be considered an appropriate strategy for addressing the problem of food insecurity and poverty in the developing world. Technological progress is thus still of paramount importance in our struggle for feeding the world.

Various strategies for increasing crop productivity can be grouped into three categories.

- genetic improvement of crop cultivars;
- improved management of crop, pests, water, nutrients, and soil resources;
- farmer-friendly public policies.

2. Genetic Improvement Strategies

Genetic improvement strategies aim at developing crop cultivars with higher yield potential, higher yield stability, and greater production efficiency.

2.1 Increasing Yield Potential

Crop cultivars with higher yield potential are the key to increased productivity. World food crops have been improved progressively since their domestication starting about ten thousand years ago. Progress was especially rapid after the rediscovery of Mendel's laws of inheritance when scientific principles could be applied to crop improvement. Further improvements will continue to be emphasized. The following breeding approaches are useful for raising the yield potential.

2.1.1 Conventional Hybridization and Selection Procedures

This is the time-tested strategy for selecting crop cultivars with higher yield potential. It has two phases. The first involves creation of variability and in the second phase desirable individuals are selected. Selection criteria generally involve growth duration, lodging resistance, disease and insect resistance, quality considerations and adaptation to a specific environment. Selected genotypes are evaluated for yield, and superior ones are released as varieties. It has been estimated that on average about one percent increase has occurred per year in the yield potential of major crops. For example the yield potential of wheat developed at the International Center for Wheat and Maize Improvement (CIMMYT) increased by 0.83% per year over the last 30 years. The yield of cotton lint in the US increased from about 600 kg/ha in 1950 to about 900 kg in 1980 or an increase of 50% over a 30 year period. The yields of most crops where there is enough investment in research have been continuously improved and there is no reason why further increases cannot be attained.

2.1.2 Ideotype Concept for Increasing Yield Potential

Another approach for increasing yield potential is the modification of plant types for increasing yield potential. Thus, selection for short statured cereals such as wheat, rice and sorghum has resulted in the doubling of yield potential. Yield is a function of total dry matter or biomass and the harvest index (the grain-to-straw ratio). Tall and traditional rices had a harvest index of around 0.3 and total biomass of about 12 tons/ha. Thus, maximum yield was about 4 tons/ha. This biomass could not be increased by application of nitrogenous fertilizers as the plants grew excessively tall, lodged badly and the yield decreased instead of increasing. To increase yield potential of tropical rice, it was necessary to improve the harvest index and increase nitrogen responsiveness by increasing lodging resistance. This was accomplished by reducing the plant height through incorporation of a recessive gene for short stature from a Chinese variety.

The first short statured variety, IR8, developed at the International Rice Research Institute (IRRI), also had a combination of other desirable traits such as profuse tillering, dark green and erect leaves for good canopy architecture and sturdy stems. It responded to nitrogenous fertilizer much better and had higher biomass production (about 18 tons) and improved the harvest index to 0.45. Its yield potential was 8–9 tons per ha.

Similar modifications were made to raise the yield potential of wheats in Mexico by Nobel Laureate Norman E. Borlaug. Further increases in the yield potential of semi-dwarf wheats and rice have been made primarily through selection for yield *per se*.

In 1968 an Australian wheat breeder (C. N. M. Donald) proposed the ideotype approach to plant breeding which is theoretically efficient based on the knowledge of physiology and morphology as defined first. Breeders then select directly for the ideotype rather than select only for yield. The ideotype concept, initially emphasized morphological traits that are desirable for light interception and assimilate partitioning, was extended to include biochemical traits. It is hoped that during the next decades, using the physiological attributes as selection criteria, genetic improvement of yield potential would be accelerated.

To increase the yield potential of semi-dwarf rice further, a new plant type was conceptualized in 1988 at IRRI. Modern semi-dwarf rices produce a large number of unproductive tillers and excessive leaf area which cause mutual shading and reduce canopy photosynthesis and sink size, especially when they are grown under direct-seeded conditions. To increase the yield potential of these semi-dwarf rices, IRRI scientists proposed further modifications of plant architecture which included essentially the following: 1) low tillering capacity (3–4 tillers when direct seeded, 8-10 when transplanted); 2) no unproductive tillers; 3) 200–250 grains per panicle; 4) very sturdy stems; 5) dark green thick and erect leaves; 6) vigorous and deeper root systems; 7) increased harvest index (see Figure. 1).

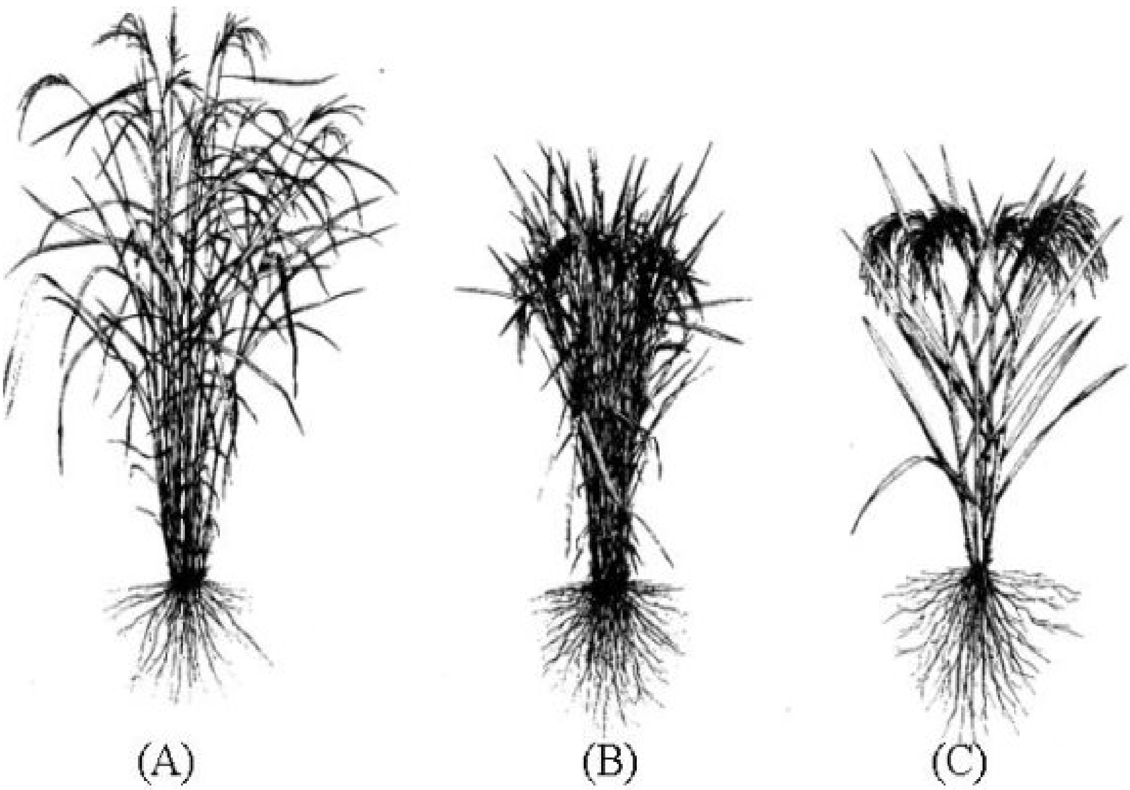

Figure 1: Sketches of different plant types of rice. Left; tall conventional plant type. Center; improved high yielding high tillering plant type; Right; proposed low tillering ideotype

This ideotype became the "New Plant Type" highlighted in the IRRI's strategic plan and the breeding effort to develop this germplasm became a major core research project of IRRI's work plan. The goal is to increase the yield potential of modern semi-dwarf rice varieties by 20%. Donors for developing the new plant type were identified and breeding work was initiated in 1989.

Numerous breeding lines with the desired characteristics have been developed and are being evaluated in replicated yield trials. In initial trials many breeding lines have outyielded the best checks by 15–20 per cent. Genes for disease and insect resistance are now being incorporated in the new plant type lines. New plant type lines with 20% higher yield potential should become available for large scale evaluation in 3–4 years.

Future research should focus on modifying plant architecture and designing new ideotypes in cereals, pulses and oil seed crops which could utilize solar energy, nutrients and water more efficiently.

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Biographical Sketches

Dr. Gurdev S. Khush is one of the world's premier rice breeders and has led the rice breeding program of the International Rice Research Institute, Manila, Philippines, for the last 34 years. More than 300 breeding lines of rice developed under his leadership have been released as varieties in different rice growing countries of the world. Many others have been used as parents in the national rice breeding programs. It is estimated that IRRI-bred varieties or their progenies are now grown on 60% of the world's rice land. Increased rice production resulting from adoption of these materials feeds 1 billion rice consumers annually. Dr Khush is a world-renowned cytogeneticist and author of a widely-used text on cytogenetics. He has authored two other books, edited 5 books, and published 70 book chapters and 130 research papers in refereed journals. For his contributions to world food security, Dr Khush has been honored with prestigious international awards such as the Japan Prize, the World Food Prize, the Rank Prize, and the Wolf Prize. For his scientific contributions, Dr Khush has been elected to the world's most prestigious academies such as the Indian National Science Academy, The Third World Academy of Sciences, Foreign Associate US National Academy of Sciences, and The Royal Society (London). He has received Honorary Doctorate degrees from seven universities including the University of Cambridge.

Mahabub Hossain has been Head of the Social Sciences Division of the International Rice Research Institute, Manila, Philippines, since 1992. He began his career as a Staff Economist in the Bangladesh Institute of Development Studies in 1970 and rose through the ranks to serve as the Director General of this development policy research institute during 1989–1992. He also served the International Food Policy Research Institute, Washington, D.C., as a visiting scientist during 1985–1987, when he published the highly acclaimed IFPRI Research Reports on the Grameen Bank Credit Program, and the Development Impact of Rural Infrastructures. At IRRI, he has led the project on "'socioeconomic study, technology impact and policy analysis," and providing support to management in planning and prioritization of rice research issues. Dr Hossain earned his Ph.D. in economics in 1977 from the University of Cambridge, England. He is a fellow of the Economic Development Institute of the World Bank. He was awarded the first gold medal by the Bangladesh Association of Agricultural Economists for his outstanding contribution to the understanding of the rural economy of Bangladesh.