MEETING WORLD FOOD NEEDS: LESSONS OF THE GREEN REVOLUTION

D. R. MacKenzie

ABSTRACT

The GREEN REVOLUTION has been offered as an example of both what to do and what not to do as international agriculture development. An appraisal is made of the benefits and consequences of the GREEN REVOLUTION for both wheat and rice. The history of the GREEN REVOLUTION is traced to its origins in pre-war Japan for both its concept and as the source of genetic material. The successful "production technology" approach of the wheat research program in Mexico is compared to the "appropriate technology" of the less successful maize research program. Lessons are drawn from the experience of the GREEN REVOLUTION that may prove helpful when planning or evaluating international agricultural development projects.

INTRODUCTION

An executive for a large United States computer company stationed in Mexico once wired corporate headquarters bragging that he was donating computer time to help in the GREEN REVOLUTION. Corporate headquarters cabled back their concern for Latin American politics--"was Mexico having a revolution too?"

Some have said that the phrase GREEN REVOLUTION is unfortunate because it portrays poorly the efforts and accomplishments of some very dedicated scientists. Others have argued that the catchy term GREEN REVOLUTION, coined for newspapers, helped capture the imagination of the general public and thereby raised a lot of money for agricultural research.

The GREEN REVOLUTION did demonstrate the potential for vastly increasing yields of wheat and rice under some conditions. When cultural conditions are ideal (e.g., good soil fertility, satisfactory soil moisture, good climate, etc.) wheat and rice yields can sometimes be four times above those of traditional cropping practices.

The success of the GREEN REVOLUTION in the late 60's and early 70's spawned a network of International Centers that continues to look for other ways to increase yields of other crops dramatically. That network receives in excess of $80,000,000 annually to support its efforts.

The optimism created by the GREEN REVOLUTION and, in particular, the awarding of the 1970 Nobel Peace Prize to Dr. Norman E. Borlaug encouraged agricultural research efforts that might not have otherwise been tried.

Critics of the GREEN REVOLUTION have pointed out that the high technology of the GREEN REVOLUTION played into the hands of the more wealthy farmers. The need for large amounts of fertilizer, well controlled irrigation, and other factors to obtain the higher yields, demands capital or credit that is all too often unavailable to the poorest of the poor farmers.

The author is Professor of Plant Pathology, The Pennsylvania State University.

Other critics point to the energy crisis and the effect this had on deploying the GREEN REVOLUTION technology. Cheap nitrogen fertilizer was one of the major components of the GREEN REVOLUTION technology. Cheap nitrogen fertilizer became scarce with O.P.E.C.'s energy pricing starting in the early 1970's.

The so-called magic of the GREEN REVOLUTION is quite simple. In soils depleted of their fertility and where management practices may allow weeds and other pest problems, the traditional varieties are typically tall (they must be tall to compete with the weeds) and are not necessarily high-yielding. It has long been known that correcting infertile soils with fertilizer often causes traditional varieties of wheat, rice, and other small grain crops to grow much taller and, under the burden of their grain, to fall over or, in technical jargon, to lodge.

The solution to this lodging problem came to be known as the GREEN REVOLUTION. The magic was to shorten the plants genetically so that they could respond to better soil fertility without falling over. What is more interesting, but not generally known, is the history of how this specific technology was developed.

HISTORY OF THE GREEN REVOLUTION

During World War I, Japan, dependent on outside sources of grain to supplement insufficient domestic production, was cut off from the world grain markets. Japan's population suffered.

In the early 1920's the Japanese Imperial Government restructured its agricultural research to address the need for greater self-sufficiency in grain production. That newly-formed organization became known as "Norin" which is from the first syllables of the Japanese title for the Ministry of Agriculture and Forestry. Norin organized and coordinated agricultural research in Japan beginning in the mid-1920's. Of the many research objectives undertaken by Norin scientists, increased yields of the major crops was primary. (Increasing production through new land was not an option on the population dense islands of Japan.)

The history of small grain variety improvement in Japan from 1925 to 1945 is interesting. Major W. H. Leonard (1947, 1948) of the U.S. Army documented the situation in Japan shortly after the conclusion of World War II. Small grain yields in Japan had increased significantly as a result of short statured varieties that were responsive to nitrogen fertilizer. Average rice yields in Japan in 1936-40 were 50% greater than in the United States. Moreover, wheat and barley yields in Japan were double those of the United States.

The short statured small grains were typically 50-85 cm in height and were cultivated almost entirely on highly fertile soils in the warmer regions of middle and southern Japan. Good barley farmers were said to use 80 to 100 kg/ha of nitrogen "but the best farmers apply even greater amounts of fertilizers" (Leonard, 1947). Rice farmers were said to use 65 to 150 kg/ha of nitrogen (Leonard, 1948). The intensity of production was even more remarkable as two crops of rice were grown in Southern Japan. In Southwestern Japan double cropping rice with barley was common (Leonard, 1947).

The principal rice varieties grown in Japan during this period were a series of numbered Norin varieties which totalled 3.5 million hectares (Leonard, 1948).

The Rice Green Revolution: The island of Taiwan was a protectorate of Japan from 1894-1945 and the history of rice breeding of that island tells another interesting story. Japanese breeders developed what were called the ponlai rice varieties for cropping in Taiwan. Ponlai in Chinese means "heavenly," a joking reference to the Japanese "gift" of these japonica-like sticky rices. Ponlai rices are characterized by being short in stature, with dark green, narrow, erect leaves. They are day-length insensitive and do not grow back after harvest (non-ratooning).

The special characteristics of ponlai rices permitted spring and fall planting without regard to the length of day. When day-length sensitive types are planted out of season, flowering is triggered at inopportune times resulting in yield losses. Day-length insensitive cultivars are, therefore, ideal for regional and even global deployment. Ponlai rices can still be found in areas of Japanese occupation during World War II such as Malaysia (Chew and Sivanaser).

In 1973 and 1974 I was stationed in Taiwan at the Asian Vegetable Research Development Center as a plant breeder. My previous assignments --the wheat project at the International Maize and Wheat Improvement Center (CIMMYT) in Mexico and the rice project at the International Rice Research Institute (IRRI) in the Philippines--no doubt contributed to my more than usual curiosity. What I discovered was far beyond the generally accepted history of the Green Revolution.

I visited farmers in Southern Taiwan with several research assistants to get answers to questions on rice production. The language difficulty caused by the several Chinese dialects on Taiwan was quickly solved when my assistants discovered that Japanese could serve as a common language of communication with the farmers. The cropping system used by the Southern Taiwanese farmers was a three-crop system evolved to a level of technology that I had not seen before. A spring crop of rice was followed by a fall crop, followed by a third crop of either soybeans or adzuki beans. The soybean cultivar is an extremely early, relatively day-length insensitive cultivar of unknown origin.

The bean crops are grown at very high plant densities in a no-till system. Four bean seeds are placed at the base of the rice stubble, giving plant densities of 400,000 plants/hectare. The more questions we asked, the more we recognized how intricate the system was. Quite often the farmer's answers to our highly technical questions would be, "we don't know--we were just told to do it that way by the Japanese."

For instance, we were told that the rice straw that had been removed from the fall harvest should be stacked and saved. Immediately following the planting of the beans, the straw should be distributed over the seed bed and, if the soil was wet, burned. If the soil was dry it should not be burned. When asked why, the farmer responded "we don't know, the Japanese just told us to do it that way." (It may be part of a pest management tactic and deserves research attention.)

I was so impressed with this technology that I recommended a small trial in the Bangkok basin in South Central Thailand. The experiment was a dismal failure for one reason--the rice types grown in Thailand ratooned or resprouted following harvest. When moisture was sufficient for the soybeans to grow, the rice ratoon crop choked off the soybeans, giving miserable bean yields.

The adzuki beans, a product of pre-1945 Japanese plant breeding efforts, are grown in Southern Taiwan exclusively for export to Japan. Yields of adzuki beans and soybeans exceed 2 metric tons/hectare or more than twice that of mung bean (used to make the famous Chinese bean sprouts). Mung beans, when subjected to such intense plant density, dropped their flowers and gave poor yields (MacKenzie, et al.). Apparently the soybean and adzuki bean cultivars had been bred for tolerance to high plant density.

The Green Revolution of rice came from Taiwan as the semi-dwarfed rice variety Dee-geo-woo-gen (DGWG) which donated the single recessive gene now used throughout the world (Hargrove, et al.). DGWG was crossed with the tropical rice cultivar Peta to give the Green Revolution variety known as IR8.

I once asked the plant breeder who bred IR8, Dr. Peter Jennings, how he hit upon the idea of IR8. He told me that when he first joined the International Rice Research Institute in 1961 he had several brain-storming sessions with the Institute's plant physiologist, Dr. Akira Tanaka from Japan. Dr. Tanaka sketched on paper for him the ideal rice plant-type. That ideal rice plant was then described in the first Annual Report of IRRI:

> "It would seem that the following plant type might be useful in the near future throughout much of the tropics--a combination of short, stiff culms bearing erect, moderately sized, dark green leaves; responsiveness in yield to fertilizer; mid-season maturity and, in most cases, photoperiod insensitivity to permit double cropping practices. These objectives are being pursued in the initial stages of the plant breeding program with both indica by indica and indica by japonica hybridization" (International Rice Research Institute).

It now seems more than serendipity that the eighth cross made by the rice institue resulted in the spectacular rice Green Revolution. It is particularly significant when one considers that since the development of IR8 and the Green Revolution, the International Rice Research Institute has made over 35,000 additional crosses.

Tsailai (= native = indica) rices are generally tall, leafy, susceptible to lodging and low in yield potential. They cook to a dry rice rather than the sticky japonica or ponlai rices. One exception is DGWG which is short statured, dry cooking tsailai said to have been introduced to Taiwan from China. It is not known when DGWG was introduced to Taiwan or by whom.

Huang, et al. says of occupied Taiwan, "The lack of hybridization work to further improve the tsailai varieties during Japanese occupation could be traced to the colonial government's support for ponlai rice production. A substantial amount of the ponlai rice was exported to Japan, especially during World War II."

The first fertilizer responsive tsailai rice is said to be Taichung Native 1 (Dalrymple). DGWG was crossed with Tsai-yuan-chung, a tall drought-resistant native type, to give Taichung Native 1. It was named in 1956. Questions remain as to who first conceived the idea of semi-dwarfed tsailai/native/indica rice. My best guess is that Chinese scientists in post-World War II Taiwan borrowed heavily from their Japanese predecessors. This, of course, requires an objective evaluation of events during and following colonial occupation (not easy). It also requires an honest evaluation of how much original research could have been done in post-war Taiwan given the turmoil caused by China's War of Liberation and the re-settlement of the Nationalists Chinese on Taiwan during the late 1940's. In any event, Taiwan became the source of ideas and germplasm for the rice Green Revolution.

The Wheat Green Revolution: Much more of the information and germplasm of the Japanese agricultural research effort prior to and during World War II might have been lost were it not for the foresight of the occupation forces of the United States. A collection of Japanese wheat germplasm was sent to Dr. O. A. Vogel, USDA scientist at Washington State University for his evaluation. Of those samples, Vogel crossed the semi-dwarf wheat Norin 10 with the locally adapted variety Brevor. Material from that cross was then made available to other plant breeders.

A Mid-west plant breeder once told me that he had received a sample of Norin 10 x Brevor from Vogel in 1954 for evaluation. He recounted how he discarded it asking himself the question "who would ever want short wheat?"

In that same year, a sample of Norin 10 x Brevor was sent to Mexico and was evaluated by Dr. Norman E. Borlaug. Borlaug had been working for the 10 previous years for the Rockefeller Foundation with the assignment to increase wheat production in Mexico. Borlaug recognized the value of the short statured wheat. But, unfortunately, its susceptibility to rust disease was so severe that no seed was produced that year. Borlaug requested more seed from Vogel and in the following year, by using a fungicide, he was able to nurse the material along far enough to make crosses to other wheats with resistance to rust. From those crosses came the first of a series of semi-dwarf varieties, making up the wheat Green Revolution.

My fascination with the history of the Green Revolution comes from two interests. First, few individuals understand the complicated chain of events leading to the final developments of what we call the Green Revolution. I tell the story not to detract from significance of the contributions of individuals like Norman Borlaug or Peter Jennings, but to stress that there was a lot of hard work and only a little magic.

The second level of my interest in this history of the Green Revolution is from the conclusions that can be drawn about agricultural technology and agricultural development. Those are the lessons of the Green Revolution.

THE LESSONS OF THE GREEN REVOLUTION

The Green Revolution is not now, nor was it ever, American technology transplanted to Third World situations. The Green Revolution grew from a need to produce more food when land resources were constrained. In Japan during the 1930's and early 1940's nitrogen fertilizer rates exceeded by far those in the United States where little or no fertilizer was applied to the wheat crop.

Agricultural scientists who have received their education and training in North America rarely face the constraints of truly limited agricultural land. The difficulties of Japan in the 1920's and 1930's, caused by population pressure and demand for food, are similar to the present realities of many Third World countries. This, for me, explains why the effort of the Japanese scientists 50 years ago so nicely fit as contemporary solutions to Third World food production problems.

The Japanese Green Revolution is still not fully exploited. Barley germplasm described by Major Leonard (1947) has still not found its way into international breeding programs. The soybean varieties of Southern Taiwan have been pretty much neglected. The intense plant density common for soybean production in Southern Taiwan is just now becoming of interest in the United States. Within the last two years Eli Lilly Corporation has announced the development of a new, narrow-row soybean planter for the United States. Traditionally American soybean rows have been planted on 36 inch rows, greatly restricting yield potential. The new planters permit planting soybeans at narrow row spacing, giving plant densities comparable to the soybean production system long used in Taiwan.

Other attributes of the Taiwan multiple cropping systems that have languished since World War II are the use of no-till practices (now catching on in the United States), rotating crops with a legume for nitrogen fixation, and a growing interest in non-ratooning rice for multiple cropping systems. Much more needs to be learned about the characteristics of the Taiwanese cropping systems. Several farming activities suggest pest management techniques that are not yet understood (biological control?).

A critical difference between the Japanese Green Revolution and the International Green Revolution was the type of nitrogen fertilizer used. Sources of nitrogen for the Japanese Green Revolution were predominantly or exclusively organic. The International Green Revolution was pretty much or exclusively dependent on synthetic nitrogen fertilizer—with significant economic and ecological consequences. The Energy Crisis dealt a sharp blow to world food production for those crops that were dependent on high levels of synthetic nitrogen fertilizer. Ecologically, it is now understood that even moderate amounts of synthetic nitrogen fertilizer cause the Rhizobium nitrogen fixation system of legume plants to cease functioning. Hence, crop rotation schemes should seek to employ leguminous crops in rotation and avoid, when possible, large amounts of synthetic nitrogen fertilizer.

Criticisms of the Green Revolution: In the 1950's it was a generally held belief that the solution to the Third World's problems could come through its industrialization. After much effort (and little success) the world's "thinkers" looked for an alternative. During the 1960's agricultural development was held up as the next solution to Third World difficulties. I can vividly remember economic planners explaining to me that through the Green Revolution wealth would accumulate creating a base for industrialization. Profit-making farmers would have cash to buy transistor radios and bicycles—or so the argument continued. As progress was attained, economic, social, and cultural problems would dissipate and the world would become a better place—or so it was reasoned.

In the 1970's frustration grew from the lack of progress in solving socio-economic and cultural problems in many of the countries that were then experiencing the most success with the Green Revolution. A new "battle charge" was ordered up by the World Bank. The new task was to develop "bootstraps" agricultural technology for the poorest of the poor farmers. An interesting comparison is available to show the frustrations and futility of agricultural development through "appropriate technology."

Wheat Versus Maize Research in Mexico: The primary objective of the wheat program in Mexico, first with the Rockefeller Foundation and then as it evolved with CIMMYT, was to increase wheat production for the country of Mexico. The technology of the Green Revolution focused on the sparsely inhabited desert coastal plains of Sonora. Large irrigation projects were funded by the Mexican government to help the agricultural development projects. At first small farmers obtained big yields and big profits. Those small farmers became large farmers as their expertise and success accumulated. Some joked that the only concern that the Mexican Ministry of Agriculture had for wheat was the potential for overproduction.

Critics of this system point to the few who got rich and the virtual uselessness of the technology for the poorest of the poor.

At precisely the same moment in time and with near equal funding the maize program of the Rockefeller Foundation (later to evolve into CIMMYT) started with an objective totally different from the wheat project. Maize, which continues to be a very important staple crop in Mexico, has been grown by the poorest of the poor since pre-Columbian times. The maize program set out to help the poorest of the poor with improved technology.

The maize program in Mexico has been in operation for more than 35 years. It must then be a humbling experience for the staff scientists to gaze out their office window and see farmers still using the red-leafed, "rat-tailed" tassel, open pollinated maize variety described by Cortez when he conquered Mexico. Efforts to replace the old Aztec corn have been fruitless and undoubtedly a source of frustration for the many who have worked on the project.

The explanation of this failure traces to their original objective--to help the poorest of the poor farmers. This target caused the program to reject out-of-hand certain technologies that might have worked. A good example is hybrid maize. In the United States hybrid maize is the commonly cited example of how agricultural research can really pay off. Hybrid maize was not pursued in Mexico out of fear of creating a few rich seed companies. In contrast, several Texas seed companies moved hybrid sorghum into Mexican markets with spectacular results.

Other potential improvements in maize production technology were also ruled out. Innovative tools, fertilizers, pesticides, etc., were declared to be inappropriate for the poorest of the poor. These were self-imposed constraints intended to yield "appropriate technology" for maize. But it was fear of the absence of capital or credit. Without capital or credit what could be done? Not much!

There is a lesson to be learned by comparing the CIMMYT wheat and maize research programs. Stated simply, the use of agricultural technology as a quick-fix for socio-economic problems does not work. If the problems of an area or a nation are related to the inequitable distribution of wealth or land, the introduction of new agricultural technology cannot solve those problems. In fact, the injection of agricultural technology in some cases may only aggravate the situation. Attempts to substitute agricultural technology for needed socio-economic reforms are destined to fail no matter how frustrating this fact may seem to our global planners.

Other lessons to be Learned From the Green Revolution: Conceiving, developing and deploying agricultural technology is a long-term investment. In the United States, given good opportunities for research and communication, new knowledge takes 5 to 20 years to reach most farmers. If in developing economies, when communication with production farmers is quite often poor, more time may be required. Consider the duration of the Green Revolution's development. From its inception in post World War I in Japan (ca. 1924) to its recognition in 1970, it was 46 years in the making.

The International Centers network has made significant strides in the development of new varieties of crops as well as production technology. Too much of that know-how still sits on the shelf for lack of methods to communicate with national programs. More importantly, how will they ever communicate with farmers? The millions of dollars that are spent annually in the United States for the Cooperative Extension Service seems an extravagance for "developing economy" nations. How can we, then, share new research information, particularly with the poorest of the poor farmers? I do not have an answer.

Social, economic, and political problems need attention in many areas of the world. The "sudden" problems now raging in Central America were seen for years...and ignored. The true frustrations of agricultural development come from the inability (and the undesirability) of us, the foreigners, forcing or even suggesting socio-economic or political changes in another country. The standard U. S. gifts of A.I.D. (mostly arms) and food (a disincentive to local agriculture) do little to solve real problems. New methods are needed. New commitments must be made. And the old trick of "tossing a few scraps" of agricultural technology must be abandoned unless the commitment is to be substantial and continuing.

Agricultural technology is not a vehicle for venting population pressures except for the short term. At the height of the euphoria for the Green Revolution it was claimed that the research had bought 30 years of time. That estimate was soon discounted and in 1970 the Green Revolution was said to have bought only 10 years. Those years are now spent and little has been done to relieve the pressures of world population growth. Unfortunately, far too many individuals believe that the population problem was solved by the Green Revolution. Nothing could be further from the truth!

The final lesson to be learned from the Green Revolution is that there is no one solution to the world's food CRISES. The world's population continues to increase. Chronic malnutrition persists. The prospect of famines continues to be a clear and present danger. All of these complex problems need attention. I have no doubt that they will require complex solutions. Agricultural technology can be a part of that final solution but we must be realistic as to the contributions agricultural technology can make. There is no magic bullet.

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