M. S. SWAMINATHAN (*)

Strategies for a New Approach to Agriculture in the Tropics (**)

The term "green revolution" was coined by Dr. William Gaud of the U.S. Agency for International Development in 1968 to draw attention to the quantum jump achieved in India and Pakistan in improving wheat yield through the use of high yielding semi-dwarf varieties of wheat developed in Mexico under the Rockefeller Foundation and Government of Mexico Wheat Improvement Program headed by Dr. N.E. Borlaug. Although the coining of this term was rather premature and led to many expectations which could not later be fulfilled, it also served an important purpose, namely, to highlight the potential for improving crop yields in the tropics and subtropics through the use of genetic strains which can respond well to water and soil fertility management.

We can now look back on the successes and failures of the last two decades and draw up a green revolution balance sheet.

Green Revolution Balance Sheet

A. Benefits

The first important benefit of the Green Revolution, particularly in rice and wheat, has been the generation of self-confidence among farmers, extension workers, scientists, and political leaders in their ability to bring about rapid improvements in food production. Since self-confidence is a basic requisite for success in any area of human endeavor, this is a great gain.

Second, the spread of new technologies in the countryside leads to a demand for inputs and infrastructure such as rural roads, power supply, marketing arrange-

(*) Foreign Fellow of the Academy; Director General, International Rice Research Institute (IRRI).

(**) Presented at the International Meeting "Towards a Second Green Revolution: from Chemical to New Biological Technologies in Agriculture in the Tropics" (Rome, 8-10 September 1986).

ments, and assured irrigation; meeting these demands requires that political priority for the farm sector gets increased.

Third, farmers and farming gained greater social prestige and recognition. Before the advent of new technologies, agriculture, particularly the cultivation of food crops, was regarded as a profession which requires only brawn and no brain. Therefore, the educated and intellectual classes did not prefer farming as a profession but sought jobs in urban areas. Similarly, agricultural colleges and universities did not attract the more bright students, who tended to prefer other fields of studies like medicine, engineering, commerce, etc. From the seventies, this position is changing in many developing countries since many young students find scientific agriculture and rural professions not only remunerative but also intellectually satisfying. The art and science of farm management are getting integrated. Farmers' associations and unions are becoming increasingly articulate and are able to get their views heard by political and administrative authorities.

Fourth, agrarian reform started attracting serious attention. New technologies made land-based occupations attractive and therefore the pressure on political leaders for equitable land rights and laws have increased.

Fifth, rural development started receiving serious attention since when agriculture moves from a subsistence level to a market-oriented one, rural comunication, rural electrification and other areas of rural infrastructure development become an economic and social necessity.

Sixth, in the countries of South and Southeast Asia, where the Green Revolution technology took place and started making an impact, production increased largely through improved productivity. In many rice growing developing countries, land and not labor is the most serious constraint. Land is also constantly required for non-agricultural uses and is hence a shrinking resource for agriculture. Therefore, the only pathway open to many developing countries for improving food production is higher productivity and cropping intensity. Before the introduction of high yield technology, production gains in many countries came largely through area expansion, which was one of the factors responsible for forest denudation. Productivity improvement in recent years has led to a considerable saving in the land required for producing food for the growing populations.

Seventh, the Malthusian prediction on famines arising from an adverse relationship between population growth and food production has so far not come true in most parts of Asia and Latin America. The Green Revolution technology thus has provided the breathing spell necessary for national policies to have an impact on adjusting population growth rates to the resource potential of each country.

Finally, an important outcome of the rate of increase in food production keeping above population growth rates has been a relative stability and even decline in the price of important food grains such as rice. This has enabled the economically handicapped sections of the population to improve their calorie

intake, thereby preventing a further growth in the number of undernourished people

B. Concerns

While the above represent some of the important benefits from the high yield technology developed and introduced jointly by international and national research systems since 1960, we cannot overlook the fact that some serious doubts and concerns have been expressed about the sustainability of this pathway of agricultural advance. The major goal of agricultural research is to work for improving the productivity, profitability, stability, and sustainability of the major farming systems of each country. Therefore, the concerns expressed since the early seventies on the sustainability of the production techniques associated with the green revolution need careful consideration. These concerns can be grouped into the following five major categories.

i) *Economics*

The first among them is *economic factors*. The cost, risk, and return structure of agriculture influences greatly land and water use planning, varietal choice, and input application levels for small farmers. In most developing countries, effective crop insurance schemes do not exist. If crops are damaged by natural calamities like typhoons, cyclones, floods, and drought or by pest epidemics, financial institutions and governments may agree to the rescheduling of debts and waiving of interest. They are not in a position to write off the debt. Therefore in disaster-and-risk prone areas, farmers will choose not to apply purchased inputs as far as possible. Following the escalation in the cost of fossil fuels in the early 70s, inputs like fertilizers and pesticides having petroleum products as feed stocks became more expensive. While the input prices went up, the output prices did not register a commensurate rise. The terms of trade became adverse in many countries with farmers paying more for the goods they buy and getting less for the products they sell. Therefore, the ratio between input and output prices became a major determinant in the level of nutrient supply to crops and consequently of yield.

Though it is true that high yielding varieties of rice and wheat can express their full yield potential only under conditions of adequate nutrient supply and soil and plant health care, the view that they can perform better than the earlier tall varieties only if they are given large qualities of fertilizer is not correct. In fact, the new high yielding strains give more yield than the earlier tall varieties of rice at all levels of nutrient supply (Fig. 1). The reason for this is their ability to partition more of the dry matter for grain and less for straw and other parts of the plant. In other words, if a tall variety and a semidwarf variety both make 10 tons of dry matter under similar soil fertility conditions, the tall strain may give 2 to 3 tons of grains and 7-8 tons of the remaining plant parts. On the other hand, semidwarf high yielding varieties may give 4-5 tons of grain and 5-6 tons

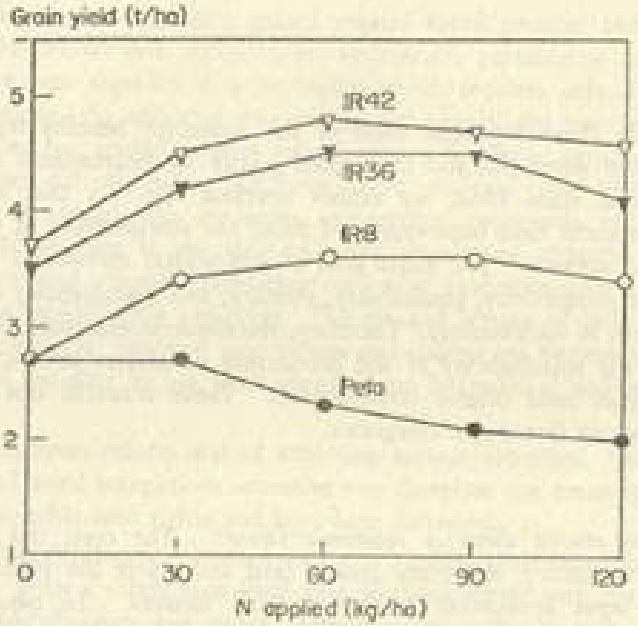

Fig. 1 - Grain yield response of 4 rices to different levels of nitrogen. Data are average for IRRI and three experiment stations of the Bureau of Plant Industry (Maligaya, Bicol and Visayas) 1976-1984 wet seasons.
Data source: IRRI, Agronomy Department.

of other plant parts. The other reason why carefully tested and selected high yielding varieties perform better than traditional varieties under many situations is the broad spectrum of resistance to pests and diseases and soil stresses possessed by the new strains (Table 1). Therefore, under resource-scarce conditions, what is important is the identification and popularization of varieties which can give maximum yields with the available resources. Before the advent of high yielding varieties, land and water use patterns were largely based on the needs of both the farmer's family and the immediate neighborhood. However, when production and productivity increased, farmers had surplus produce for the market. Under such conditions, farmers' decisions on investment in inputs are influenced by the market environment. Government policies in input and output pricing then become crucial to sustaining the interest of farmers in improved technologies. Farmers' decisions on technology choice and adoption will always be based on the net return per hectare as well as security of that return and not by gross yield per hectare.

TABLE 1 - Elite breeding lines with superior grain quality and multiple disease and insect resistance.

Breeding line	Growth duration (days)	Amylose content (%)	Reaction to							
			BL	BB	RTV	GSV	GLH	BPH biotypes		
								1	2	3
IR21820-154-3-2-2	130	23	MS	R	R	R	R	R	R	S
IR31802-48-2-2-2	107	22	MR	R	R	R	R	R	R	R
IR31831-63-1-2-3-2	108	22	R	R	R	R	R	R	R	R
IR31868-64-2-3-3-3	110	22	R	R	R	R	R	R	R	S
IR32429-47-3-2-2	103	23	R	R	R	R	R	R	R	R
IR28228-12-3-1-1-2	135	24	MR	R	R	R	R	R	R	R
IR28130-84-3-3-2	135	23	MS	R	R	R	R	R	R	R

BL = blast; BB = bacterial blight; RTV = tungro virus; GSV = grassy stunt virus; GLH = green leafhopper; BPH = brown planthopper.

ii) *Equity*

The second group of concerns relates to *equity issues*. Some of the issues involved are the relative benefits derived by small and large farmers, the fate of landless labor, and the impact of new technologies on the income and well-being of women. It is now widely recognized that new technologies by themselves tend to be scale neutral, i.e., all farmers irrespective of the size of their holding can derive economic benefit from them provided they have access to the needed inputs. However, high yield technologies are not resource neutral. In other words, more inputs are required for higher output. A certain degree of resource neutrality can be introduced by substituting non-monetary inputs for purchased inputs. There is however a limit to which such a substitution is possible particularly when a vertical growth in productivity is the only available method for increasing production. Therefore, government policies rather than scientific work will have to provide the tools for enabling all farmers irrespective of the size of their holding, input purchasing and risk-taking capacity, and social status to derive economic benefit from new technologies. Similarly, the adverse impact of modern technology on rural women can be avoided through a careful study of the potential consequences of new technologies for women and men before they are widely popularized.

iii) *Employment*

The third group of concerns relates to the impact of new technology on *employment*. Developing countries with large rural populations have already serious problems of unemployment and underemployment. This is reflected in

the unplanned migration of rural poor to towns and cities seeking opportunities to earn their daily bread. Therefore, technologies which reduce labor use will have to be concurrently accompanied by the creation of alternative avenues of employment. Unless job destruction and job creation are concurrent events, considerable human hardship can be the outcome from the adoption of technologies which substitute capital and machines for human labor. In several countries of Asia, undernutrition, or calorie inadequacy is the major nutritional problem. This in turn tends to be related more to inadequate purchasing power than to the lack of an adequate supply of food in the market. Hence, an employment revolution is important for families without assets in the form of either land or livestock to derive economic and nutritional benefit from the green revolution. New technologies should hence be subjected to an employment impact analysis before they are recommended for large scale adoption.

iv) *Energy*

The fourth group of issues relates to the *energy requirements* of the green revolution technology. If the pathway of productivity advance chosen requires increasing consumption of non-renewable forms of energy, the technology will become self-defeating in the long run since a finite source of energy cannot be exploited in an exponential manner. The question hence arises as to how far renewable sources of energy can provide substitutes for fossil fuel-based energy.

v) *Ecology*

The final group of factors which are causing concern relates to the *ecological impact* of new technology. These cover areas like the erosion and loss of plant genetic resources, vulnerability to pests and disease epidemics arising from genetic homogeneity, destruction of soil fertility and soil erosion, and pollution caused by the use of toxic chemicals and high doses of fertilizers. It is possible today to integrate considerations of ecology, economics, employment generation, energy conservation, and social equity in technology development and transfer. This will however call for a systems approach in the organization of research and extension programmes.

Second Green Revolution

A Second Green Revolution therefore will have to be based on maximizing the benefits of the first phase and minimizing or eliminating the drawbacks. For this purpose, we need to intensify research in 3 major directions:

i) Achieving a continuous improvement in productivity of crops, animals, and fishes at as low a cost as possible. This will call for the substitution of market purchased chemical inputs with farm grown biological inputs as well as the maximum use of non-monetary knowledge-intensive techniques;

ii) Optimizing income and employment from the available land, water, labor, and credit resources through multiple cropping, intercropping, and mixed farming involving crop-livestock and crop-aquaculture integrated production systems; and

iii) Preparation of value-added products from every part of the plant and agricultural biomass.

I would like to briefly discuss the scientific challenges ahead if we are to convert the second phase of the Green Revolution into a blessing. These are in the areas of *conservation, commerce,* and *consumption.* Increasingly the basic agricultural assets of land, water, flora, fauna, and the atmosphere are being threatened with different forms of damage. Both domestic and international trade are being affected by low prices for output and high prices for inputs. The main characteristics of international markets for most agricultural commodities during 1985 were ample supplies, weak demand, and declining prices. Inadequate purchasing power is leading to millions of people going to bed hungry. A global foodgrain reserve of more than 300 million tons and more than 500 million hungry people co-exist today.

While the poor are suffering from undernutrition and malnutrition, the dietary habits of the rich reveal rapid changes. The well-to-do of both developed and developing countries are reducing their consumption of basic staples and shifting to what I term *health foods of the future.* These include salad vegetables, fruits, fibrous material, and processed foods.

How are we going to help the small farmers in developing countries meet the triple challenges of conservation, commerce, and consumption? How can we assist national research systems to help their countries promote sustainable livelihood security in rice farming areas? *The only way we can achieve our aim is through an intensification of our work in the development and spread of knowledge-intensive production systems.* The economist, Dr. Theodore W. Schultz, has frequently emphasized the potential of agricultural research to substitute for land and capital.

The triple goals of a knowledge-intensive production system are:

— Promote the use of farm-grown inputs and reduce the dependence on inputs based on fossil fuel feedstocks.

— Maximize the returns from the available labor, land, water, and financial resources.

— Pay concurrent attention to achieving a continuous improvement in the productivity, profitability, stability, and sustainability of rice production systems.

Some areas of research relevant to the development of knowledge-intensive production systems are the following:

— Transdisciplinary research, e.g., integrated pest management, integrated nutrient supply, scientific water use, biotechnology.

— Blending traditional and frontier technologies, e.g., agricultural refineries designed to produce value-added products from agricultural biomass.

— Farming systems research — technological and socio-economic aspects.

— Linkages with international data banks through advanced computer and telecommunication systems for up-to-date data on trends in weather, yield, prices, trade, and research.

Conservation

The following statement by B.F. Skinner should be kept in view by all scientists engaged in developing new production techniques:

> "Every new source from which man has increased his power on earth has been used to diminish the prospects of his successors. All his progress is being made at the expense of damage to the environment which he cannot repair and cannot foresee."

Globally, developing countries in particular face serious problems of denudation of forests, loss of genetic resources, loss of crop land, soil erosion, and desertification. The key environmental pollution problems include CO_2 concentration, ozone depletion, trace gases, air pollution, acid rain, water pollution, and hazardous wastes.

An underlying cause for many of these problems is the rapid growth in population since World War II. In October 1985, thirty-five heads of states of both developing and developed countries gave a memorandum to the Secretary General of the United Nations. I wish to quote a few sentences from this document:

> Mankind has many challenges: to obtain a lasting peace between nations; to preserve the quality of the environment; to conserve natural resources at a sustainable level; to advance the economic and social progress of the less developed nations; and to stabilize population growth.
>
> At present there are 76 million more births than deaths on our planet each year. If present rates continue, by the year 2000 there will be 100 million more births than deaths. A billion people have been added in the last 13 years and the next billion will be added in 12 years.

Ecological journals continually publish alarming reports on the consequences of the environmental damage now taking place on an unprecedented scale particularly in developing countries. The African food crisis is in part a result of such damage.

What are the research programs in the conservation field that need further strengthening? Some of the important ones are:

— germplasm collection and conservation with priority going to wild species and strains,

— genetic evaluation and utilization, with greater use of a global grid of hot spot screening sites,

— integrated pest management,

— integrated nutrient supply,

— scientific water management,

— soil health care on a systems basis,

— farming systems research based on integrated principles of ecology and economics, and

— energy efficient farm machinery and equipment.

A. *Integrated Nutrient Supply* (INS)

Research in this field should have the goal of developing a sustainable blend of the following sources of nutrients for irrigated and rain-fed rice farming systems:

— *in situ* conservation of biomass in rice fields and control of grazing with the help of botanical pesticides such as neem cake,

— Azolla application,

— straw incorporation,

— cultivation and incorporation of green manures, and

— application of mineral fertilizers coupled with floodwater management.

B. *Integrated Pest Management* (IPM)

There is need for greater interaction among scientists working on the following components of IPM strategy:

— genetic,

— biological,

— cultural,

— chemical,

— botanical pesticides,

— socio-economic.

Varietal development and recommendations should be for a cropping system and not just for one crop. The varieties recommended should be tailored to the pest problems of each growing season.

Basic studies such as the ecology of weeds and weed problems related to moisture availability, as well as more detailed work on disease epidemiology, need to be intensified.

Concepts like insect thresholds need very careful field application or there could be problems of vector-borne diseases.

Above all, the social engineering aspects of transferring IPM and INS procedures to the field need greater attention.

Commerce

In the past, land use decisions were taken by farming families largely on the basis of the home needs of the family and of the immediate neighborhood. With modernization of agriculture, farmers produce food grains and other commodities not only for themselves but, more important, for the market. When this transition takes place, opportunities for producer-oriented and remunerative marketing become essential for sustaining and stimulating farmers' interest in modern technology.

In domestic trade, both cost and quality influence consumer demand. In international trade, in addition to competitive cost and desirable quality, stability of supply becomes extremely important. If appropriate technologies and remunerative marketing opportunities co-exist, a very rapid growth is observed in production gains. For example, the Punjab State of India produced 300,000 tons of rice in 1965-66. During 1984-85, the State harvested more than 5 million tons of rice, achieving an annual growth rate of 16% from 1965-66 to 1984-85. This was due to the availability of high yielding varieties coupled with the necessary support services and, above all, assured and remunerative marketing opportunities. Under commercial agriculture, the old distinction between *food and cash crops* vanishes and all crops become *cash crops*. This is where government policies in infrastructure development for improved post-harvest technology, marketing, and transport as well as steps for ensuring fair returns to producers and reasonable prices to consumers become very important. Most developing nations have to simultaneously increase production by small farmers and consumption by the rural and urban poor. Hence attention to policy formulation becomes crucial to success.

The international trade environment is unfortunately very depressive for farmers. World prices have been moving downward across practically the entire range of agricultural commodities. The prospect of a general improvement in the situation does not seem bright. It is to sort out such international trade issues that the GATT Committee on Trade and Agriculture has been going into the problems of multilateral trade. Although this work was started more than 3 years ago, concrete conclusions are yet to emerge. Meanwhile, for many tropical products such as coffee, cocoa, and tea, the market is projected to expand by little more than 1% per annum up to 1990.

Research areas which need attention in order to enhance the economic sustainability of high yield technologies are:

— Reduction of production cost without yield reduction.

— Tailoring grain quality to match differential trade needs.

— Promoting stability through:

a. minimizing risks through pest epidemics,

b. risk distribution agronomy to suit different weather probabilities based on computer simulation models, and

c. promotion of sound public policies.

CONSUMPTION

In this field again we face two contrasting challenges. On the one hand, the rural and urban poor suffer from undernutrition and malnutrition due to inadequate purchasing power. On the other hand, the food habits of the more affluent sector of the population are fast changing.

As I mentioned earlier, more than 300 million tons of grain reserves and more than 500 million hungry people co-exist on our planet. If a famine of food was the major obsession in the immediate past, a famine of jobs will be the central preoccupation of the immediate future. Fortunately, a drop in the consumer price of rice helps poor families. There is evidence to suggest such benefits to poor families during the last 10 years as a result of higher rice production and productivity.

How can we help in adding a dimension of employment and income generation to productivity increases in major farming systems? The following areas of research are relevant in this context:

— Income and nutrition orientation to farming and cropping systems research.

— Grain drying and storage, food processing, and marketing.

— Whole plant utilization.

— Management aspects of decentralized production supported by key centralized services.

It is obvious that the farm sector alone cannot absorb all the surplus landless labor in the rural areas. We have to give a new orientation to the concept of land reform and widen this concept to include all forms of asset reform. For example, one of the greatest assets in rural areas could be the intelligent and effective use of emerging technologies such as biotechnology and microelectronics. Unless steps are taken immediately to train rural women and men, particularly those belonging to landless labor families, in new technologies, the poor will again be bypassed by the new technological opportunities. In fact, rural development should be defined as the conversion of all unskilled persons into skilled ones. It is only in this way that productivity can be increased and the quality of life improved.

Regarding the foods of the future, which will be increasingly the foods of

choice among the rich, it is important to develop techniques and varieties suitable for use in various processed forms. For example, the following are some of the opportunities available in the case of rice:

— Precooked and quick cooking rice, including infant foods.

— Convenience rice foods such as canned rice and ready-to-eat baby foods.

— Rice products such as puffed and popped rice, dry breakfast cereals and snack foods, and extrusion-cooked products.

— Rice dishes, puddings, breads, cakes, and crackers.

— Rice flour and starch.

— Rice noodles (extruded round and sheeted flat).

— Fermented rice foods including *idli* and *dosai* prepared in India.

— Rice wines and beer adjunct.

Conclusion

From the foregoing, it will be clear that what we need is integrated approaches both in agricultural research and development which pay concurrent attention to all links in the production-consumption chain. If we can achieve this, we will have laid the foundation for ecologically and economically sustainable agricultural progress.