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**GMOs: PROSPECTS FOR INCREASED CROP
PRODUCTIVITY IN DEVELOPING COUNTRIES**

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GMOs: Prospects for Increased Crop Productivity in Developing Countries

Robert E. Evenson

Abstract

Genetically Modified Crops (GMO foods) have been widely available to farmers since 1996. The Gene Revolution, based on recombinant DNA (rDNA) genetic engineering techniques, is seen by proponents as both supplanting Green Revolution varieties, based on conventional plant breeding techniques, and potentially enabling “disadvantaged” production environments, unreached by Green Revolution varieties to achieve productivity improvements.

This paper argues that the private firms supplying GM crop products have generally had little interest in selling products in disadvantaged production environments. The paper also argues that present rDNA techniques allow only static gains from specific “trait” improvements. But these GM products can be installed on Green Revolution varieties where continued dynamic varietal improvement is possible. As a consequence, the Gene Revolution complements the Green Revolution, and because trait incorporation expands area planted to Green Revolution varieties, there is potential for productivity improvement in disadvantaged environments.

Keywords: Genetically Modified Foods, Genetic Engineering

JEL Classification: O1, O4, Q1

Some of the early claims for biotechnology methods implied that recombinant DNA (rDNA) techniques had great promise for the development of higher yielding crop varieties for production environments that were not reached by conventional breeding techniques. These are the “disadvantaged” environments that continue to be dominated by “landrace” varieties (“farmers varieties”). These claims were often put forth by private firms with little or no experience in dealing with disadvantaged environments. Disadvantaged environments in developing countries do not offer attractive investment options for commercial seed firms.

The development of “Modern Varieties” for developing country environments in the Green Revolution was not led by private firms. A recent review of Green Revolution MVs indicated that private sector firms did develop “hybrid” varieties of maize, millets, sorghum and to limited extent, rice. But they did not develop hybrid varieties until after significant improvements in “open-pollinated” varieties (OPVs) were produced by the International Agricultural Research Centers (IARCs) and National Agricultural Research Centers (NARS) programs¹. Few, if any, private sector breeding programs were developed in response to “Breeders Rights” laws. (The Intellectual Property Right (IPRs) that are likely to be chosen for the WTO-TRIPS agreement.)

Thus the private sector has had little interest in developing breeding programs in developing countries. Yet, in spite of this, GM products have been adopted on significant acreages in developing countries, and the potential for further application is great.

In this paper I address the question of the current use of rDNA products (GMOs) in developing countries and the near term prospects for further contributions.

In Part I, I outline several “mechanisms” for GMO contributions.

In Part II, I discuss the high degree of “congruence” between Green Revolution and Gene Revolution breeding strategies.

Part III summarizes contributions to date by mechanism.

Part IV discusses prospects for contributions in the near term (5 to 10 years) by mechanism.

I. Mechanisms for GMO contributions to Crop Production in Developing Countries

Figure 1 summarizes five mechanisms.

Mechanisms 1-4 are predominantly suited to “qualitative trait” GM products. Mechanism 5 addresses “quantitative trait” GM products.

1. GMOs for Rent: Developed Country Suppliers

This mechanism entails negotiations between private agro biotech suppliers of GM traits and farmers in developing countries. The supplier provides the GM product in return for a technology fee or a seed price premium. The supplier may incorporate the GM product (e.g., a Bt product) in several crop varieties (e.g., several cotton varieties). These varieties may have been developed by public NARS or IARC-NARS programs or by private seed companies. The supplier may even provide the rDNA technical services, so that little or no rDNA technical skills are actually required in the host economy.

2. GMOs for Rent: Developing Country Suppliers

This mechanism is similar to mechanism 1 except that a private firm or public NARS program in a developing country is the GM product supplier. Public NARS suppliers may choose to set different technology fees for domestic and foreign purchasers.

¹ The study also showed that Green Revolution’s MVs were not produced by developed country programs or by NGOs. (See Evenson and Gollin 2003)

3. GMOs for Rent: International Agency Support

For this mechanism, an International Donor Agency negotiates with a GM product supplier to provide specific GM products to farmers in specific countries. The International Donor Agency makes payments to the GM product supplier. Farmers may then utilize the GM product without paying a technology fee.

4. GM Product Germplasm Conversion

Most GM products being marketed today can be converted to germplasm in the form of “breeding lines”. Once the initial “transgenic” incorporation of DNA into a breeding line is made, the GM product is expressed in the variety and in most cases will be expressed in progeny varieties where the transgenic line is utilized as a parent in a conventional cross. This effectively converts the GM product into a form where “conventional” breeding methods can be utilized to replicate the GM product. This germplasm conversion could be utilized by IARC programs in much the same way that wide crossing methods were used to incorporate “wild” (i.e. uncultivated) species” DNA into breeding lines.²

5. Quantitative Enhancement: Genomics, Proteonomics Research

This mechanism entails “quantitative” trait breeding. Some prospects for quantitative trait locus (QTL) breeding have been developed to date, but the science of genomics and proteonomics studies is still in its infancy. But there are prospects for important gains in achieving gains in photosynthetic efficiency in plants. This research is very demanding of skills and creativity.

² A good example is the XA21 gene for bacterial leaf blight resistance in rice. This gene was first “backcrossed” into breeding lines in the early 1970s. Today it can be incorporated into breeding lines using rDNA techniques.

It should be noted that at present, GM products are basically “qualitative trait” products. And qualitative trait products endow plants with specific cost advantages that vary from environment to environment, but are “static” in nature. That is the cost advantage gains are of a “one-time” nature. They do not grow over time. It is possible to “stack” more than one GM product in a crop variety, but stacking does not produce cumulative gains.

It is sometimes said that the Gene revolution will replace the Green Revolution. But this will not happen until and unless mechanism 5 enables breeders to produce “dynamic” gains in generations of varieties. Until such time the Gene Revolution GM products can only complement conventional Green Revolution breeding (see below for a discussion of MV3 Green Revolution varieties). This complementarity takes the form of installing “static” GM products on the dynamic MV3 generations of varieties produced by conventional Green Revolution methods.

II. Gene-Green Revolution Congruity

Figure 2 depicts three Green Revolution stages and two pre-conditions.

The initiating stage of the Green Revolution is characterized as the MV1 stage. This entails the development of a high yielding “plant type” for an Agro-Ecological Zone (AEZ). This high yielding material raises the yield potential significantly for the AEZ. MV1 rice and wheat varieties utilized semi-dwarf genetic resources to produce a plant design with stronger stalks, and leaf placement better suited to sunlight harvesting and shortened maturity periods (growing seasons). These varieties were designed for higher levels of fertilizer application. This made economic sense as the cost of production for nitrogen fertilizer was lowered by production improvements. (In fact, the real price of urea fertilizer has been declining for the past 50 years.)

The achievement of the MV1 stage depends on pre-conditions and on the AEZ diversity under which the crop is produced. In the case of wheat, the breeding program dedicated to MV1 production was initiated 20 years before the establishment of CIMMYT, the International Center for Wheat and Maize improvement. Norman Borlaug began the quest for wheat MV1s in 1943 in the Rockefeller Program in Mexico. In addition, most wheat varieties in the developed world had been improved beyond the landrace (farmer selected) stage in NARS breeding programs prior to the introduction of MV1 wheat varieties in 1964. Because of the low degree of AEZ diversity for wheat production, MV1 wheat varieties were delivered to most countries in 1964 and 1965.

For rice MV1 varieties, the delivery of MV1 varieties was quite different, partly because pre-conditions varied and partly because AEZ diversity is much higher for rice production than for wheat production. Actually, rice MV1 development programs also preceded the establishment of the International Rice Research Institute (IRRI) in 1959. The FAO sponsored an Indica-Japonica crossing program in the 1950s in India. In addition, the “Ponlai” varieties developed in Taiwan represented a transfer of high-yielding Japonica traits to low yielding Indica varieties. The semi-dwarf plant type with a shorter growing season was also the prototype for MV1s in Asia. Most Asian and Latin American rices had earlier been improved beyond landraces. But the bulk of African rice production was still suited to landrace varieties. And many of these landraces were farmer selections of *Oryza glaberrima*, the second cultivated species.

IRRI did deliver MV1s suited to the irrigated rice areas in most Asian countries in 1964 and 1965 although there was some variation in dates of delivery. And IRRI also delivered MV1s for “favorable” rain fed AEZs. But IRRI never did deliver MV1s for deep water AEZs or for upland AEZs. Furthermore, IRRI MV1s were not delivered to Latin America. The CIAT program in Columbia modified IRRI materials and MV1s were delivered to Latin America

farmers 10 years after they were delivered to Asian farmers. And, for practical purposes IRRI also failed to deliver MV1s to Sub-Saharan Africa.³ It was not until the West Africa Rice Development Association (WARDA) introduced a breeding program in the 1980s that Sub-Saharan Africa farmers had any MVI rice varieties.⁴

Thus, the delivery of MV1 varieties to producers varied by crop and region. Much of this variation was dictated by pre-conditions. These are described in figure 3 where the extent of pre-Green Revolution plant breeding developments beyond landraces is described for crops and regions. In many cases, where landrace agriculture has predominated, even today, MV1 varieties have not been produced. Figure 4 describes the extent of MV1 varietal achievement. MV1 achievement was based on “quantitative” trait breeding. New higher yielding plant types were required.⁵

MV2 breeding, the “second generation” of the Green Revolution, was based on “qualitative trait” breeding. MV1 varieties were in almost all cases susceptible to plant diseases and to insect pests (and in some cases the insects served as the vector for the diseases). Furthermore, the susceptibility to specific diseases and insect pests was not easily predictable. Thus, the achievement of the MV2 stage where “host plant resistance” to diseases and insect pests was developed, required evaluation of genetic resources for resistance traits. In the case of rice varieties, IR-8, the first MV1 variety was susceptible to the Tungro disease and to several insect pests. The Genetic Evaluation Unit (GEU) program at IRRI, where host plant resistance

³ A number of IRRI varieties were released in West Africa, but were not adopted by farmers.

⁴ WARDA was originally designed as a “screening” program. It failed to identify useful MVs. It was not until WARDA relocated to Boake, Ivory Coast, that it began to develop MVs for Africa. The NERICA varieties developed at WARDA now have considerable promise. Sadly, WARDA has been disrupted again in the past 2 years.

⁵ These MV1 achievements were of major importance and attest to the contributions of IARC programs.

for several diseases and insect pests was achieved, produced the MV2 varieties IR-26 and IR-36.⁶

The “congruity” of rDNA techniques and MV2 conventional breeding techniques is obvious. Both techniques required genetic resource evaluation and host plant trait breeding. In conventional breeding this entails “backcrossing” techniques. For rDNA breeding direct transgenic techniques are used.

MV3 breeding, the third stage in the Green revolution, is a stage of dynamic generational breeding. It is led by NARS programs (and in some cases by private sector firms engaged in hybrid breeding) with germplasm support by IARC programs. Many of the successful NARS-bred MVs utilize an IARC parent (or other ancestor). Agronomic quality traits and abiotic stress traits are breeding objectives. And these require “local” breeding objectives.

The achievement of MV3 status—the dynamic engagement of NARS breeding programs is far from complete. Figure 5 provides estimates. These indicate that Sub-Saharan Africa has achieved relatively little MV3 capacity.

In general, breeders do not consider developing hybrid varieties until the MV2 stage. It is also unlikely that it pays to incorporate GM traits into MV1, early MVs or landrace varieties.

III. GMO Coverage to 2002

Data from the International Service for the Acquisition of Agro-biotech Applications (ISAAA) indicate that for the year 2002, the global area planted to GM crops is 58.7 million hectares grown by between 5.5 million and 6 million farmers in 16 countries. This represents a 12 percent increase over the previous year. Twenty seven percent of this area (16.0 million

⁶ These MV2 varieties were developed very quickly at IRRI. IR-36 became one of the most widely-planted MVs ever developed as a result.

hectares) was grown in developing countries. This was a 19 percent increase over the previous year.

The leading developing countries in GM acreage were:

Argentina with 13.5 millions hectares (corn, soybeans)

China with 2.1 millions hectares (cotton)

South Africa with .3 million hectares (cotton)

India, Uruguay, Mexico, Indonesia, Columbia and Honduras with less than one million hectares each (corn, cotton, soybeans).

However, Brazil has recently announced that it will not penalize growers for using “illegal” Glysohate tolerant soybean seed.⁷

As of 2002, 51 percent of the world’s soybean acreage, 20 percent of the world’s cotton acreage, 12 percent of the world’s canola acreage and 9 percent of the world’s maize acreage was planted to GM crops.

India, the world’s largest cotton producer, approved Bt cotton in 2002, joining Indonesia, South Africa and Mexico in approving Bt cotton production.

The leading GM products in 2002 were: herbicide tolerance (75%), insect resistance (Bt) (17%), stacked herbicide tolerance, insect resistance (8%) and virus resistance/other (1%).

Studies of cost advantages clearly show large advantages for Bt cotton in virtually all countries. It appears that B_t cotton conveys at least a 10 percent cost advantage to farmers.⁸ As a rough estimate, GM cost advantages lowered production costs in developing countries by 300 to 500 million dollars in 2002.

⁷ Brazilian soybeans production has experienced rapid growth, particularly in the Cerrado region. It is predicted that Brazilian soybean production may exceed U.S. production in 2004.

⁸ See Pray, Zilberman and other studies.

Virtually all of the GM acreage in developing countries utilized mechanism 1, GMOs for Rent: Developed Country Suppliers. Sales of GM products were entirely from private sector firms in developed countries.

IV. Prospects by Mechanism

In view of the fact that virtually all GM product use has occurred through mechanism 1, it will be useful to assess prospects for future use of mechanism 1 and other mechanisms.

A. Future Prospects: Mechanism 1: GMOs for Rent: Developed Country Suppliers

There is little doubt that mechanism 1 will dominate GM product sales for some time to come. The expanding markets for GM soybeans and GM cotton are likely to be served by developed country suppliers for the next decade and so. More countries are likely to approve GM marketing as they develop regulatory protocols. Cotton producers, in particular, will apply political pressure for Bt cotton production approval in view of the significant cost advantages. But we will see expanded markets for other GM products as well. This mechanism “works” because it is not location specific for GM products.

B. Prospects: Mechanism 2: GMOs for Rent: Developing Country Suppliers

A recent study by ISNAR (Cohen) indicates that several countries are developing the capacity to be GM suppliers. This capacity is primarily in public sector NARS programs. China, Brazil and India are rapidly developing NARS capacity. Argentina, Thailand, the Philippines, Indonesia, Mexico, Costa Rica, South Africa and Kenya have more rudimentary capacity but are making progress.

Brazil, India and Argentina have possibilities for private firm development.

Little of the public or private firm capacity for GM product development was stimulated by IARC programs.

China with some 6500 plant genetic engineers, is well along in its GM capacity development and may well be offering GM products through mechanism 4 in China and mechanism 2 to other countries within the next 5 years. Scientists in China are working on several Bt products.⁹

India represents a case of “conflicting politics”. Most farm political sentiment and most general political sentiment in India is hostile to GMOs and hostile to Multinational Corporations (MNCs). But India, has considerable prospects for GM product development. India has exploited its capacity to produce software and has benefited greatly from this capacity. The reforms of the early 1990s are now producing unprecedented growth in India. It is quite likely that India will recognize that it has agro-biotech potential, just as it has software development potential.¹⁰

Brazil and Argentina are more hospitable to private firms than India and they could achieve GM product capacity quite quickly.

C. Prospects: Mechanism 3: GMOs for Rent: International Agency Support

Will International Agencies step forward to purchase GM rights for farmers in poor countries? This clearly would have benefits for cotton farmers in Africa. But in today’s political climate it appears unlikely that this will happen. The political “hysteria” in “Old Europe” is probably, itself sufficient to discourage any efforts in this direction. This state of affairs is likely to last at least a decade.

UN agencies are particularly unlikely to move in this direction, given their European members.

The Rockefeller Foundation has been the most steadfast supporter of developing research capacity in developing country NARS over the past two decades. The Rice Biotechnology

⁹ China is very likely to introduce new Bt products in the next year or so.

program has produced agro-biotech capacity in many countries and in terms of capacity building has been very important. The Rockefeller Foundation is now supporting programs to facilitate issues associated with Intellectual Property rights and the continued exchange of genetic resources. But it is a substantial step to negotiate for GM rights for the poorest farmers in Africa in view of European hostility to GMOs.

D. Prospects: Mechanism 4: Germplasm Conversion

The discussion of Green-Gene Congruity (Part II) shows that IARC programs were successful in producing MV1 varieties, albeit at different rates in different countries because of pre-conditions. rDNA techniques at present are not suited to MV1 production. But they are suited to MV2 production. Furthermore, they are ideally suited to germplasm conversion where GM transgenic products can be incorporated into breeding lines that can then enter conventional breeding programs.

IARC programs were successful in using conventional breeding techniques (including wide-crossing) to produce the Host Plant Resistance traits in MV2 varieties. MV2 varieties in turn, made NARS programs more productive.¹¹ And, on balance, IARC MV2 programs led to increased NARS investments in plant breeding (although not for small countries with low population densities).¹²

Why then, are IARC programs not providing the same kind of leadership in the development of rDNA techniques, given the high degree of congruity with conventional breeding techniques? Even the most generous estimates of rDNA and genetic resource

¹⁰ India has considerable agro-biotech capacity, both in private firms and in the public NARS program. The reforms in the early 1990s position India for science-led growth.

¹¹ See Evenson and Kislev (2003) for an analysis of MV2 germplasm impacts on NARS breeding program.

¹² Evenson and Kislev (2003)

evaluations techniques indicate that less than 10 percent of IARC scientists are using rDNA techniques.

There are two classes of explanations for the “failure” of IARC programs to provide leadership in the Gene Revolution comparable to the leadership that they provided in the Green Revolution.

The first class includes “political” explanations. The leading contender in this class is simply that the CGIAR support system for IARC programs is dependent on consensus building for all potential donors. The European political hostility to GMOs is sufficient to cause IARC programs to “go slow” and be cautious in implementing rDNA techniques. The concern is that IARC programs pushing GM products will lose support. Given the current state of political support for the CGIAR, where funding in real terms has been declining for the past two decades. The prospect for further erosion of support is real.

The second class of explanations is “systemic”. Figure 6 (from Huffman and Evenson, 1993) depicts the organization of agricultural science programs in U.S. land grant University programs in the early 1990s. A distinction is made between the “basic” sciences (I) and the pre-invention sciences (II). U.S. agricultural research programs in the 1980s had developed structured pre-invention sciences in response to “demands from below” i.e. demands from plant breeders and genetic inventors (level III). University administrators had convinced state legislators of the value of these applied science programs.

The IARC system did not actually develop a fully comparable organization. It did support plant physiologists, pathologists, entomologists as part of Crop Genetic Improvement (CGI) programs. But the IARCs did not support pre-invention research programs *per se*.

Both the U.S. land grant programs and the IARC programs were caught “asleep at the switch” by the development of rDNA techniques. These came by and large from the basic (level I) sciences, not from the pre-invention sciences. They were also fueled by the Bayh-Dole Act that made Universities more aware of patent licensing revenues.¹³

This has been a source of frustration and embarrassment to the U.S. land grants and to the IARCs as well. They have been “scrambling” to restore their intellectual standing in rDNA techniques since 1980.

Leading agro-biotech firms were much quicker to recognize the potential in rDNA technology. They moved quickly with large investments to produce the GM products that we see on the market today. In many ways, with the expansion of IPR coverage for rDNA products, we may be seeing the loss of comparative advantage in Crop Genetic Improvement (CGI) programs of public sector NARS to the private sector in developed countries. Just as public sector NARS in the OECD countries have dominated chemical, mechanical and electrical inventions for agriculture; they are now poised to dominate genetic invention as well.

But private agro-biotech firms are not going to be active in many developing countries; certainly not in the poorest countries. These GM markets are not promising. In practical terms, the poorest countries may be as dependent on the IARCs for Gene Revolution products as they were for Green Revolution products. The IARCs are the de-facto “gate-keepers” for access to this technology.

E. Prospects: Mechanism 5: Quantitative Trait Improvement

¹³ The Bayh-Dole Act of 1980 ended the requirement that Federally Funded research in Universities share patent rights with the federal government. It also ended the prohibitions at exclusive licensing. Today, many Universities have significant patent licensing resources and they provide strong incentives to research fourthly to obtain patentable inventions.

With the publication of genome maps (human, aridopsis, rice and others), the field of genomics and proteonomics research have now been initiated. In these research programs, systematic studies of genome functions are being pursued. Many agricultural research programs in developed countries, as well as some IARC research either have now enter this field of research. It is too early to predict the prospects for improved quantitative trait performance in plants (and animals).

This statement is based on two fields of experience. The first is the experience to date with quantitative trait locus (QTL) markers. The second is the conventional breeding progress achieved by shorter growing season selection.

QTL breeding strategies are now well developed and show promise for increasing crop yields.

Conventional breeding with selection for shorter growing season traits in rice have been successful in raising crop yields per day of growing season.

There is some evidence to suggest that conventionally bred varieties exhibit “synergy” in traits i.e. the sum of host plant resistance (hpr) (Gollin and Evenson) traits may be greater than the sum of individual parts (many rice varieties have multiple hpr traits – the rDNA counterpart is stacked hpr traits).

V. Synthesis

The following statements follow from the analysis of mechanisms and congruence:

- a) Current GM products probably add little or no value to landrace varieties. They probably add little value to pre-Green Revolution MVs as well.
- b) Current GM technologies are not suited to producing MV1 varieties.

- c) Current GM products are suited to MV2 varieties. A recent study of HYV adoption in India reports estimates of hpr trait incorporation on the area planted to high yielding varieties (HYVs). (Evenson and McKinsey, 2003) The estimates show that trait incorporation does drive HYV adoption. This is the mechanism by which Green Revolution area can be expanded. MV2 and MV3 incorporation of traits can bring MV1 technology to more areas. GM products can be used in this context.
- d) Current GM products can be inserted into MV3 crop varieties. MV3 varietal development is based on conventional Green Revolution techniques. GM products convey static one-time cost advantages. By inserting GM products into dynamic generations of MV3 varieties, GM products complement Green Revolution breeding.
- e) It will be a number of years before GM techniques will allow quantitative traits. Even then Gene Revolution techniques will continue to complement Green Revolution techniques.

The following statements follow from the analysis of institutions and investments:

- a) Mechanism 1: Genes for Rent, Developed Country Suppliers, is responsible for all current GM product use in developing countries. Few improved second generation GM products have been introduced to the market. The use of this mechanism attests to the potential contributions that GM products can make in developing countries.
- b) Mechanism 2: Genes for Rent, Developing Country Suppliers has some promise for delivering GM products within 5 years. These are likely to be public NARS products.
- c) IARC programs have failed to provide leadership in delivering GM products to poor farmers. Ironically, these same programs did provide leadership in the Green Revolution by producing MV1 and MV2 varieties. IARC programs are not producing GM products that can be converted to ordinary Green Revolution type

breeding lines.

- d) IARC failures are partly related to political hysteria in “Old Europe”. But it is more likely that this failure is systemic and related to the failure of the traditional pre-invention agricultural sciences to produce rDNA technology.
- e) Quantitative trait rDNA techniques have promise. As they are developed the prices of agricultural products will decline from their already low levels. These developments may exacerbate the problems for the poorest countries even further. Unless the poorest farmers in the world are delivered cost reductions to at least match real world market price reductions, they will continue to be trapped in mass poverty.

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Figure 1: Mechanisms: GM Technology Developing Countries

1. GMOs for Rent: Developed Country Suppliers Private? Public?
2. GMOs for Rent: Developing Country Suppliers Private? Public?
3. GMOs for Rent: International Agency Funded
4. GM Conversion to Conventional Breeding Lines IARCs – Green Revolution
5. Quantitative GMs: Genomics, Proteonomics

Figure 2 : Green Revolution Stages

<p style="text-align: center;">➤ Pre-Conditions:</p> <p>-- Landraces (Farmer Selected Varieties)</p> <p>-- Early Modern Varieties - NARS-Bred</p> <p style="text-align: center;">➤ MVs:</p> <p>-- MV1 (First Generation) IARC-Bred High-Yielding Plant Type</p> <p>-- MV2 (Second Generation) IARC-Bred - NARS Combinations Host Plant Resistance: Diseases – Pests</p> <p>-- MV3 Third Generation) NARS-Bred, IARC Parents Host Plant Tolerance: Abiotic Stresses Agronomic Qualities</p>

Figure 3: Initial Conditions: Pre-Green Revolution MVs (Percent)

	Asia	Latin America	Middle East - North Africa	Sub-Saharan Africa
Wheat	80-90	70-80	50-60	50-60
Rice	70-80	70-80	10-20	5-10
Maize	30-40	60-70	10-20	10-20
Other cereals	50-60	50-60	10-20	5-10
Protein Crops	30-40	40-50	10-20	5-10
Root crops	20-30	30-40	5-10	5-10

Figure 4: MV1 Coverage

	Asia	Latin America	Middle East – North Africa	Sub-Saharan Africa
Wheat	90-95	90-95	90-95	85-90
Rice	75-80	80-85	40-50	25-30
Maize	50-60	65-75	40-50	25-30
Other cereals	40-50	50-60	40-50	30-40
Protein Crops	50-60	50-60	40-50	20-30
Root crops	50-60	70-80	40-50	30-40

Figure 5: MV3 Coverage

	Asia	Latin America	Middle East- North Africa	Sub-Saharan Africa
Wheat	80-85	85-90	40-50	20-30
Rice	65-70	75-80	30-40	5-10
Maize	40-50	50-60	30-40	5-10
Other cereals	30-40	40-50	20-30	5-10
Protein Crops	30-40	40-50	15-20	5-10
Root Crops	30-40	40-50	10-20	5-10

Figure 6: The Structure of Applied Sciences

	Biological Sciences		Chemical Sciences		Engineering Sciences
	<i>Agricultural</i>	<i>Medical</i>			
I. Basic Sciences	Molecular Biology Biology Genetics	Evolutionary Biology Physiology	Inorganic Chemistry	Organic Chemistry	Physics Mathematics
II. Pre-Invention Applied Sciences	Pathology Applied Genetics (Ecology?)	Oncology etc	Chemical Engineering	Animal Nutrition	Mechanical Engineering Applied Physics
III. Invention Applied Sciences	Plant Breeding Conventional Breeding rDNA Breeding	Surgery rDNA drugs	Fertilizer Herbicides Insecticides Fungicides	Food Additives	Tractors Harvesters Planters etc GIS System
IV. Innovation	Seed Replication	Hospital Tests	Plant Design	Plant Design	Plant Design
V. Diffusion	Private Sales and Extension Public Extension	Private Sales and Extension	Private Sales and Extension	Private Sales and Extension	Private Sales and Extension