Environmental Planning for Sustainable Food Supply

Robert E. Evenson

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Working Paper

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Abstract

This paper first describes two major scientific revelations affecting food supply. The first is the Green Revolution, the second, the Gene Revolution. The Green Revolution was based on "conventional" breeding techniques entailing crosses between parent cultivars with subsequent selection of progeny through several generations. The Gene Revolution, by contrast, utilizes "recombinant DNA" techniques to achieve Transgenic (genetically engineered) crop varieties.

The paper then asks whether these two scientific revolutions actively damaged the environment and if so, how? The Green Revolution was criticized first by Marxist-Leninists and then by environmental critics. The Gene Revolution is subject to more extensive criticism than the Green Revolution with many European critics recommending that developing countries consider the "precautionary principle" in regulatory policy.

The final part of the paper describes the response of USAID to the "sustainable development" movement.

About the Author

Robert E. Evenson
Professor of Economics
Yale University

Robert Evenson is a Professor of Economics at Yale University. Professor Evenson has published in three fields: agricultural productivity and growth, the economics of invention, and the economics of rural households. He has recently completed *Science for Agriculture*, Second Edition (with W. Huffman: *Science for Agriculture, Second Edition*, 2006, Iowa State University Press), and completed a study of the Green Revolution (with D. Gollin: "Assessing the Impact of the Green Revolution, 1960-2000, *Science* 300:758, 2003").

He has been an organizer of the International Consortium for Agricultural Biotechnology Resarch and has edited seven volumes of papers from the annual ICABR conferences held in Ravello, Italy.

He received both Bachelors and Masters degrees from the University of Minnesota and a PhD from the University of Chicago.

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Introduction

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Investment in the Green Revolution

Table 1 reports global expenditures for both public and private sector agricultural research in millions of 2001 U.S. dollars. We note from this table that public sector expenditures are significant for all regions. Aggregate investment in public sector agricultural research in developing countries increased more than 5 fold from 1965 to 1995.

The table also notes that private sector R&D in agriculture is high for the OECD develop countries (almost as high as public sector spending) but that for developing countries private sector R&D in 1995 was only 5.5 percent of developed country spending.

Table 2 reports public sector research "intensities" in the form of expenditures as a share of agricultural GDP and expenditures per capita. We note that developed countries have much higher expenditures as a share of agricultural GDP and very much higher expenditures per capita than do developing countries. (Data were unavailable for the Middle East-North Africa region). Developed countries had similar expenditures as a share of agricultural GDP in 1976 except for Sub-Saharan Africa where a high proportion of "expatriate" agricultural scientists led to higher expenditures as a share agricultural GDP. All regions increased spending as a share of agricultural GDP except Sub-Saharan Africa where it declined from 1985 to 1995 as expatriate scientists were replaced.

The Green Revolution

More than 40 years ago, Theodore W. Schultz wrote an influential book *Transforming Traditional Agriculture* (Yale, 1964) in which he argued that "traditional" agricultural economies were "poor but efficient" and "efficient but poor." Traditional agriculture was defined to be an agriculture where the development of improved technology in the form of improved crop varieties and improved animals was proceeding at a very slow pace. Implicit in this definition is the notion that agricultural technology has a high degree of "location specificity." Crop varieties, for example, require breeding programs in the regions served by the program.[1]

The Schultz argument implicitly suggests that agricultural extension programs cannot effectively "transform traditional agriculture," because traditional agriculture is already efficient. Note that this statement regarding efficiency holds the transaction costs associated with institutions constant. Thus, markets may be inefficient with high levels of transaction costs, but given this, farmers are efficient largely because they have had time to experiment with technological improvements under conditions of slow delivery.

We now have an opportunity to reassess the Schultz argument in the context of the Green Revolution. Agricultural extension programs might not be effective in improving the efficiency of farmers in a setting where farmers are already efficient, but agricultural extension programs could be successful in facilitating the transfer of technology produced in a foreign country to the country in question. Many countries have counted on this technology transfer function. In many Sub-Saharan African countries the number of agricultural extension personnel far exceeds the number of agricultural scientists.[2]

The Schultz position on agricultural extension and agricultural research was that the technology transfer function of agricultural extension was not realized because of the inherent "localness" of agricultural extension programs. Ultimately Schultz indicated that only a "Green Revolution" could "transform" traditional agriculture, and a Green Revolution depends primarily on competently-managed plant breeding programs in National Agricultural Research Systems (NARS) programs supported by International Agricultural Research Centers (IARCs).

Figure 1 lists 87 countries classified according to aggregate Green Revolution Modern Variety (GRMV) adoption rates in 2000. The 12 countries in the first column report negligible GRMV adoption in the year 2000. All other classes are based on area weighted GRMV adoption rates for the 11 crops included in the GRMV study.[3]

Table 3 lists indicators by Green Revolution cluster. The clusters can be roughly categorized as Non-Performing (Cluster 1), Underperforming (Clusters 2, 3 and 4) and Performing (Clusters 5, 6, 7 and 8). Economic and social indicators by cluster are reported in Table 3.

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[1] This was first noted in the study of hybrid maize (corn) by Zvi Griliches (1957, 1958). Griliches noted that farmers in Alabama did not have hybrid maize varieties until 20 years after farmers in Iowa had access to hybrid maize. It was not until breeding programs were established in Alabama, selecting varieties for Alabama farm conditions that farmers in Alabama had access to hybrid maize. Farmers in West Africa did not have hybrid maize until 75 years after farmers in Iowa had hybrid maize. Farmers in Central Africa still do not have access to hybrid maize.

[2] Evenson and Kislev (1975) report relative price ratios of 20 to 1 for the cost of scientists vs. the cost of extension workers. This is partly related to the relative prices of extension personnel relative to the price of agricultural scientists.

[3] The 11 crops were rice, wheat, maize, sorghum, millets, barley, groundnuts, lentils, beans, potatoes and cassava. (Evenson and Gollin, 2003)

The economic indicators show the following:

1. Crop value (in US dollars) per hectare is very low for countries not realizing a Green Revolution and rises to high levels for countries realizing the highest levels of GRMV adoption.

2. Fertilizer application per hectare is negligible for the first four clusters and significant for the highest GRMV clusters.

3. Crop Total Factor Productivity (TFP) growth is negligible for countries not realizing a Green Revolution and highest for countries with the highest levels of GRMV adoption.[4]

4. Countries without a Green Revolution did have both agricultural scientists and extension workers. Scientists per million hectares of cropland rise with higher levels of GRMV adoption.

5. Extension workers per million hectares of cropland are roughly 20 times as great as scientists per million hectares of cropland. The number of extension workers increased in every cluster. No correlation between extension workers per million hectares of cropland and GRMV adoption exists.

6. None of the countries without a Green Revolution has industrial competitiveness. A UNIDO index of .05 or greater indicates industrial competitiveness. Only countries in the 30-40 percent GRMV clusters and above have industrial competitiveness. Improvement in industrial competitiveness is greatest for the highest GRMV clusters.[5]

The social indicators show the following:

1. Sixty-three percent of the 4.65 billion people living in developing countries are located in the ten countries in the highest Green Revolution cluster. Eighty-four percent live in performing clusters. Countries without a Green Revolution make up less than 2 percent of the population in developing countries.

2. The average population of countries in 1960 and 2000 rises as GRMV adoption levels rise. This suggests a strong bias against small countries.

3. In 1960, birth rates were similar across GRMV clusters. By 2000, birth rates had declined in all GRMV clusters, with highest declines in the highest GRMV clusters.
4. Child mortality rates in 1960 were similar in most GRMV clusters. By 2000, they had declined in all GRMV clusters with highest declines in the highest GRMV clusters. In the top two GRMV clusters, child mortality rates in 2000 were only 24 percent of their 1960 levels.

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[4] Crop TFP growth is reported in Avila and Evenson, 2007.

[5] None of the countries without a Green Revolution reported investing in R&D in 1970. The Central Africal Republic reported industrial R&D in 1990. Of the 18 countries in the 2-10% cluster, 5 reported industrial R&D in 1970, 12 reported industrial R&D in 1990.

5. Dietary Energy Sufficiency (DES) was similar for all GRMV clusters in 1960. By 2000, improvements were achieved in all clusters with highest improvements in highest GRMV clusters. DES improvement is highly correlated with child mortality reduction.

6. GDP per capita (using exchange rate conversion to dollars, Atlas Method) was lowest in countries without a Green Revolution in 1960 and did not improve in 2000. GDP per capita for the next three GRMV clusters rose from 1960 to 2000 by 56 percent. GDP per capita for the highest four GRMV clusters rose by 140 percent from 1960 to 2000.

NARS programs in specific countries bear the ultimate responsibility for failing to deliver GRMVs to their farmers. But IARC programs are not immune from criticism. There are three IARCs located in Africa – ICRAF in Kenya, ILRI in Ethiopia and Kenya, and IITA in Nigeria. ICRAF has had little impact because agroforestry generates little income for farmers. ILRI has also had little impact although it does not deal with crops. IITA has had an impact only after developing breeding programs with CIMMYT for maize and with CIAT for cassava. Similarly, ICRISAT had little impact until sorghum, millet and groundnut breeding programs were developed in Africa.

Why did twelve countries fail to produce a Green Revolution? A closer examination suggests three explanations. The first is the "failed state" explanation. The second is the "small state" explanation. The third is the "civil conflict" explanation. Most or all of the countries failing to deliver a Green Revolution to their farmers are effectively failed states. They cannot manage to "deliver the mail" much less produce a Green Revolution. But they are also small states with an average population of 2.5 million people in 1960 (Angola and Yemen had 5 million people in 1960). None have universities to train agricultural scientists. All have been in civil conflict for much of the past 40 years. Given low GDP per capita, limited taxing power and civil conflict, it is not surprising that they did not produce a Green Revolution.

The second GRMV cluster did have a small Green Revolution, but they too are small countries (Mozambique and Uganda being largest with populations around 7 million in 1960). Most of these countries have also been in civil conflict. Few have universities to train agricultural scientists, but they did manage a small Green Revolution.

Figure 2 depicts "real" prices for the 1960 to 2000 period (a 5-year moving average; Source: IFPRI). The prices of rice, wheat and maize in 2000 were approximately 45 percent of their 1960 level (35 percent of their 1950 level). The real prices of the world's major cereal grains have been declining by more than 1 percent per year for the past 50 years.

In the OECD developed countries, it is estimated that Total Factor Productivity rates (a measure of cost reduction) in agriculture have been roughly 1 percent per year higher than in the rest of the economy. For developing countries, crop TFP growth rates have been high except for countries in the lowest GRMV clusters. A few of the industrially competitive countries have had industrial TFP growth rates that are higher than agricultural TFP growth rates.

Why then do we have "hunger in a world awash with grain?" For this we need only look at crop value per hectare in Table 3. With low crop yields, crop value per hectare is low. The highest GRMV cluster produces more than six times as much crop value per hectare as does the lowest cluster. At 1960 prices, farmers in Sub-Saharan Africa with 1.2 hectares could earn $2 per day per capita. At 2000 prices with .8 hectares, farmers in Sub-Saharan Africa can earn only $1 per day per capita. Farmers in a number of countries have been delivered price declines without cost declines, and many have moved from mass poverty to extreme poverty.

The Gene Revolution

In 1953 Watson and Crick reported the "double helix" structure of DNA and showed that DNA conveyed inheritance from one generation to another. In 1974 Boyer and Cohen achieved the first "transformation" by inserting alien DNA from a source organism into a host organism and the field of genetic engineering was born.

The first genetically modified (GM) products (Ice Minus and the Flavor-Saver tomato) were not commercially successful. Monsanto introduced Bovine Somatotrophin Hormone (BST) in 1993 to dairy farmers. In 1995, several crop GM products were introduced to the market. One class of GM products provided herbicide tolerance enabling farmers to control weeds and practice low tillage methods with conventional herbicides (Roundup, Liberty). A second class of products conveyed insect toxicity to plants (from *Bacillus thuriengensis*).[6]

Scientific reviews for food safety show no serious food safety issues for GM crops (or foods). Environmental studies show that environmental issues can be managed using existing management technology. Thus, existing GM products convey cost reduction advantages to farmers in countries where they are approved for sale. Because farmers using GM products increase their supply, world market prices are lower. This means that farmers in countries not approving GM crops for sale suffer a double penalty. They do not realize cost reductions and they face lower prices.

The political economy of GM crops (foods) over recent years has resulted in a significant divergence between North America (the US and Canada) and the European Union (EU, before expansion). North America advises developing countries to take advantage of cost reducing opportunities. The EU countries urge developing countries to follow the "precautionary principle" in science policy.[7]

The European Union has little cost reduction potential because European countries do not produce significant quantities of cotton, soybeans, canola or rice. Thus, European Union countries have little at stake in terms of cost reduction potential. But they do have very significant influence on developing countries because they threaten to ban GM crop imports.[8]

Nonetheless several developing countries, Mexico, Argentina, Brazil, Paraguay, Bolivia, Costa Rica, China, and India have realized some cost reduction for GM crops. The potential for cost reduction in cotton producing countries in Africa is large, but only South Africa has taken

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[6] Seven multinational firms now dominate the GM product market. Three are based in the US (Monsanto, Dupont and Dow), three are based in Europe (Bayer, BASF and Syngenta), and one is based in Mexico (Savia). These seven firms now spend $3 billion per year on R&D.

[7] The precautionary principle is usually interpreted as requiring a high level of proof that food safety and environmental safety rules are being met. When applied to regulatory policies, this requirement is problematic. When applied to science, it effectively halts scientific progress.

[8] Actually most of the countries in Sub-Saharan Africa export little or nothing to the European Union.

advantage of this potential. None of the countries not realizing a Green Revolution has realized a Gene Revolution.[9]

Table 4 reports potential cost reduction gains from adopting Genetically Modified crops and the gains realized as of 2004. As noted earlier European countries produce little cotton, canola, soybeans or rice. Even with 80 percent adoption of transgenic crops, European countries have little to gain from adopting transgenic crops. But several countries in Sub-Saharan Africa (Mali, Benin, Burkina Faso and Zimbabwe) have considerable potential (mostly because they produce cotton) gains, but have not realized these gains because they do not have adequate food safety and environmental safety regulations in place.

Returns to Research

Two sets of returns to agricultural research investments have been reported. The first is reported in Evenson (2001) in Volume 1A of the Handbook of Agricultural Economics. The methods for estimating returns to research range from project evaluation methods for cases where technology adoption rates are available to statistical methods utilizing research stock variables with time and spatial weights. Table 5 summarizes studies of returns to research as measured by Internal Rates of Return (IRRs).[10]

Pre-Invention Science IRRs are for basic research investments. Private Sector R&D programs do not reflect returns to R&D in the private companies but measure returns that spill-in to the agricultural sector.

Table 6 reports IRRs and B/C ratios for IARCs and NARS programs for the Green Revolution. They are based on GRMV adoption rates. The low rates for Sub-Saharan Africa reflect the fact that many Sub-Saharan NARS have been spending significant funds for many years, often with few benefits.

Evidence on Environmental Effects

The Green Revolution

Early critics of the Green Revolution criticized the Green Revolution from a Marxist-Leninist perspective. They made the following arguments.

Marx and Lenin did not appreciate the distinctions between mechanical and biological (Green Revolution) technology because little biological technology was being realized when they were publishing. Biological technology is highly management intensive and is actually well suited to small farms. Many early critics have also failed to appreciate this distinction. Critics have also failed to appreciate the fact that population pressure from population growth has effects on pre-capitalist institutions that are to some degree independent of biological technology effects. Ruttan (2004) notes that the original critics argued that:

[9] It is unlikely that unimproved crop varieties benefit from genetic modifications.
[10] Internal rates of return are the rates for which the present value of benefits equals the present value of costs.

a) New technology is monopolized by large farmers and landlords.
b) Financial constraints prevent small farms from purchasing fertilizer and chemicals.
c) Large farms use profits to enlarge their holdings.
d) Large farms realize scale economies and purchase machinery to reduce labor costs.

To address these concerns, we can ask the following questions?

1. Was farm size or tenancy a serious constraint to GRMV adoption?
2. Did farm size change with the adoption of GRMVs?
3. Did the adoption of GRMVs promote mechanization?
4. Did the adoption of GRMVs reduce labor employment and wage?

Ruttan provides evidence on each question. He notes first that farm size differs by country. Most Asian farms are small. African farms are larger and Latin American farms are much larger than Asian farms. But farms of all sizes adopted GRMVs. In some cases large farms adopted slightly earlier. Adoption was largely guided by whether the GRMVs were suited to the location.

On the second question, farm size in Asia and Africa actually declined over recent decades. In Latin America, farm sizes increased in some countries (Brazil and Argentina). But farm size is driven by population growth and by the wage/machine price ratio. Mechanization of farm operations is driven mainly by the wage/machine price ratio. Mechanization does increase farm size, particularly in high income countries (Huffman and Evenson 2006).

Did the adoption of GRMVs promote mechanization? There is a little evidence that it did. Many farms in Asia adopted GRMVs and are not mechanized. As countries like India begin to generate non-farm employment opportunities and wages begin to rise, they are mechanizing rapidly. But mechanization is the consequence of a rising wage/machine price ratio. Did the adoption of GRMVs promote a reduction in employment and wages? In India, the regions adopting GRMVs first experienced an increase in wages. Ultimately wages rise as economies generate non-farm jobs and this is now occurring in India.

The reader will note that the criticism noted above has an "old-fashioned" Marxist flavor. Most of these criticisms have been made by sociologists and anthropologists. Most economists, particularly empirical economists working in Asia and Africa reach different conclusions.

The criticism that GRMVs have been "fertilizer-using" is accepted as valid. It is also accepted as rational. The price of nitrogen fertilizer has declined in real terms since the Haber process was introduced for the production of ammonia. Before 1965, traditional crop varieties were not fertilizer-using. But every developed country had actually taken advantage of low cost nitrogen fertilizer by then. This was achieved through breeding. Developing countries were following the lead of developed countries in this regard.

The criticism that GRMVs were linked to more insecticide use is also accepted as valid for the first generation GRMVs. Again, this was a matter of developing countries following the path of developed countries.

The argument that GRMVs were herbicide-using does not hold up well. All farmers know that if you don't control weeds, you are not a competent farmer. In Asia, most weed control is done by hand weeding. Many African countries have poor levels of weed control, but do not use herbicides. Only in some Latin American countries are herbicides used. For the most part, the developing countries have not followed the lead of the developed countries in this case.

Does this produce chemical residue problems in GRMVs? Yes! Are they manageable? Yes, they are at least as manageable as they are in developed countries where fertilizer use and chemical use is much higher than in developing countries.

The critiques regarding mechanization have some validity in Latin America, but little in Asian agriculture. Many countries are being rapidly mechanized today but mechanization appears not to be having the farm size effects observed in North America and Europe. Harvesting equipment is also being adopted, but at a slower rate. We do not see the same harvesting equipment in Asia that we see in the U.S. We do see some of this equipment, however, in Latin America. Africa, particularly Sub-Saharan Africa, has relatively low levels of mechanization. Many countries have not fully adopted animal power. The poorest farmers in Africa utilize simple planting technology (dibble stick) and achieve very low yields.

The Green Revolution and the Environment

Curiously, the Green Revolution was not criticized for its uneven delivery but for an increase in resource intensity. Most, but not all, crops subject to the Green Revolution experienced an increase in fertilizer use. In Table 3 it was noted that many countries have very low rates of fertilizer use per hectare. All countries with major Green Revolutions have increased fertilizer use. Indeed, prior to the Green Revolution (i.e., in 1960), fertilizer use rates were low because both wheat and rice "lodged (i.e., fell over) when high rates of fertilizer were applied. By judiciously using "semi-dwarfing" genes in breeding programs, the lodging problem was overcome.

The increased use of fertilizer was thus consistent with breeding obectives of the Green Revolution and consistent with the "induced innovation" model of productivity change. This model indicates that when the price of an input (urea) is falling over time, this signals inventors that they should exploit this advantage.

Has increased fertilizer use had environmental effects? It is, of course, possible that "runoff" problems might exist, but it should be noted that even the maximum rates of fertilizer use in developing countries are well below the OECD levels of fertilizer use (the Netherlands applies roughly 700 kg of fertilizer per hectare), and OECD countries manage to control runoff problems effectively.

Two other concerns to the environment are the broad scale use of insecticides and of herbicides (see below for comment on Gene Revolution impacts). There is little question that insecticide use increased during the Green Revolution. Many farmers increased the "spraying" of insecticides to very high levels in the Green Revolution. This was in part a response to lower cost insecticides. As Integrated Pest Management (IPM) techniques were developed and as breeding objectives were further developed, insecticide use was reduced[11]. It is not always appreciated that Green Revolution plant breeders found that the first generation of Green Revolution Modern

[11] Some of the "gains" from IPM programs are overstated because a major objective of second generation GRMV is insect resistance.

Varieties (GRMVs) were susceptible to insect pest damage. As breeders responded to this susceptibility they developed varieties with "insect resistance" and this helped reduce insecticide use.

Until the Gene Revolution, most developing countries used relatively little herbicides.

The Gene Revolution and the Environment

The first crop GM products introduced in 1995 included herbicide tolerant products and insect toxicity products.

Approximately 60 percent or more of the soybeans and canola produced in the world are now herbicide tolerant. The most widely used herbicide in the world is "Roundup," produced by Monsanto, and most of the world's soybeans are now "Roundup-Ready." As a result, most soybeans are now produced under "minimum tillage" conditions. A single spraying with Roundup is sufficient to control weeds. Herbicide use has probably declined as a result of this trait.

The insect toxicity (*Bacillus thuriengiensis*) products have dramatically reduced insecticide use. These products are now available for cotton, rice, maize, sorghum and millets. The yields of cotton, in particular, are higher because of these products.

The net effect of these Gene Revolution products is certainly to reduce insecticide use and to have minimal effects on herbicide use.

USAID's Response to Sustainable Development and the General Decline in Aid Effectiveness

In 1985 USAID provided roughly $2.5 billion in aid to farmers. Virtually all of this aid was provided to small family farms. Some of this aid was for research and extension programs, and some was for agricultural credit programs. In 2005 USAID was providing only $400 million in aid to farmers. The USAID response to sustainable development was to eliminate aid to farmers. In addition, support for Ph.D. training was effectively eliminated by USAID.

The Millennium Challenge Account (MCA) policy strategy of the U.S. State Department argues that aid is ineffective in countries below a certain institutional/ governance threshold. The first MCA grant went to Madagascar (see Figure 1). Most countries with lower levels of institutional development than Madagascar are ineligible for MCA grants.

Table 3 shows that there is a sectoral sequence to development. In the 1960s only 25 or so of the developing countries in Figure 1 could be considered to be industrialized. Since 1960, virtually all countries in Figure 1 realized productivity gains in the agricultural sector before they realized productivity gains in the industrial sector. The abandonment of the agricultural sector by USAID and, to a lesser extent by the World Bank, is thus a serious matter.

The decline in aid effectiveness and in aid support is related to the end of the Cold War. Prior to the early 1990s, both the West and the East (the Soviet Union) vied for influence in developing countries. Many developing countries initiated Marxist-style revolutions only to find that the economic model underlying these revolutions, the Centrally Planned Economy, collapsed in both the Soviet Union and China.

A Summary

Jones (2002) summarizes the literature on economic growth. He points out that the "steady state" equilibrium in early models without invention or innovation show that product per worker is constant without invention and innovation. He also reports a Malthusian extension of growth models showing that the rate of population growth does slow growth in product per worker, but that this can be easily affected by growth in technology. Many developing countries experienced a tripling of population from 1950 to 2000.

The more recent "endogenous" growth models treat R&D as a variable endogenously determined by incentive structures, particularly regarding intellectual property rights. Endogenous growth models treat population growth as a positive inducement to invention and innovation. The reasoning is that invention and innovation is proportional to population size and that invention and innovation produce externalities that benefit all members of the population. Data on patents granted certainly do not bear this out. The number of patents granted to inventors in Sub-Saharan Africa and even in South Asia is negligible. Inventions are not proportional to population.

Because of the Green Revolution, Dietary Energy Sufficiency (reported by FAO, a measure of calories consumed per capita) increased in virtually all developing countries.

This paper also deals with the Gene Revolution (i.e., the recombinant DNA revolution), and the Gene Revolution has also had a major impact on crop cultivation.

Have these revolutions damaged the environment? This is in part affected by one's perception. Countries in the European Union (before expansion) advise developing countries to follow the "precautionary principle" in regulatory policy (and indirectly in science policy). This advice can be defended for regulatory policy, but not for science policy. There simply is no possible rationale for allowing the precautionary principle to dominate science policy.

Does the production of "transgenic" crop varieties harm the environment? The development of herbicide tolerant soybean, canola and maize varieties may possibly have increased herbicide use, but the herbicides in question are quite benign.

There is little question regarding the insect toxicity (B_t) products for cotton, rice and wheat. They reduce insecticide use and associated insecticide spill-overs.

Table 1: Global Expenditures on Agricultural Research in 1995 (millions 2001 US Dollars)

	1965	1976	1985	1995
Public Sector Agricultural Research				
Developed Countries	**6532**	**8270**	**10192**	**11900**
Developing Countries				
China	**377**	**709**	**1396**	**2036**
Other Asia	**441**	**1321**	**2453**	**4619**
Middle East-North Africa	**360**	**582**	**981**	**1521**
Latin America & Caribbean	**562**	**1087**	**1583**	**1947**
Sub-Saharan Africa	**472**	**993**	**1181**	**1270**
International Agricultural Research Centers	**12**	**163**	**315**	**400**
Private Sector R&D in Agriculture				
Developed Countries				10829
Developing Countries				672

Source: Pardey and Beintema (2001) and Boyce and Evenson (1975)

Table 2: Public Agricultural Research Intensities

	Expenditures as a Share of Agricultural GDP			**Expenditures Per Capita**		
	1976	**1985**	**1995**	**1976**	**1985**	**1995**
Developed Countries	**1.53**	**2.13**	**2.64**	**9.6**	**11.0**	**12.0**
Developing Countries	**0.44**	**0.53**	**0.62**	**1.5**	**2.0**	**2.5**
China	0.41	0.42	0.43	0.7	1.3	1.7
Other Asia	0.31	0.44	0.63	1.1	1.7	2.6
Latin America and Caribbean	0.55	0.72	0.98	3.4	4.0	4.6
Sub-Saharan Africa	0.91	0.95	0.85	3.5	3.0	2.0

Source: Pardey and Beintema (2001), Evenson Estimates for Sub-Saharan Africa

Table 3: Green Revolution Cluster Indicators

Economic Indicators

Clusters By GRMV Adoption	Crop Value per Ha (dollars)	Fertilizer per Hectare (kg/ha)	Crop TFP Growth (1961-2000)	Scientists per Million Ha Cropland		Extension Work per Million Ha		Industrial Competitiveness (UNIDO)	
				1960	2000	1960	2000	1985	1998
LT 2%	78	2	.09	.019	.030	.230	.461	.002	.002
2-10%	128	22	.72	.018	.093	.392	.402	.020	.028
10-20%	94	6	1.07	.013	.033	.149	.220	.028	.029
20-30%	112	12	.87	.033	.076	.245	.416	.037	.051
30-40%	180	40	1.30	.033	.179	.070	.371	.050	.076
40-50%	227	52	.96	.023	.063	.287	,827	.038	.072
50-60%	300	68	1.36	.050	.063	.070	.140	.060	.080
GT 65%	488	166	1.56	.079	.120	.150	.442	.047	.111

Social Indicators

Clusters By GRMV Adoption	Countries in Class	Population in 2000 (Millions)	Population (Millions)		Birth Rates (Millions)		Child Mortality Rates (Millions)		Dietary Energy Sufficiency		GDP Per Capita	
			1960	2000	1960	2000	1960	2000	1960	2000	1960	2000
LT 2%	12	75	2.2	6.1	47	41	293	160	2029	2192	361	388
2-10%	18	153	3.1	8.5	45	36	236	118	2074	2387	815	1291
10-20%	18	385	7.0	21.4	44	36	214	134	1983	2282	866	1295
20-30%	8	115	9.0	14.3	46	32	238	124	2070	2384	695	1156
30-40%	9	337	14.3	37.4	42	26	156	27	2050	2574	1169	3514
40-50%	2	284	15.5	40.3	46	26	221	61	2084	2506	805	1660
50-60%	5	385	34.9	76.7	46	23	240	50	2038	2391	1096	2153
GT 65%	10	2886	135.1	288.6	39	22	165	43	2100	2719	1049	2305

Table 4: Potential and Realized (as of 2004) Cost Reduction Gains, Selected Countries.

	Potential Cost Reduction (%)	Realized Cost Reduction, 2004 (%)
Developed Countries		
Canada	5	2
USA	9	6
Japan	1.5	0
European Union - Northern	0.6	0
European Union - Southern	1.5	0.1
Eastern Europe	3	0.1
Former Soviet Union	4	0
Developed Countries		
Latin America:		
Mexico	3	0.5
Argentina	9	8
Brazil	7	2
Paraguay	9	2
Bolivia	7	1
Costa Rica	10	2
Other Latin American Countries	4	0
Asia:		
China	4	1
Southeast Asia	4	0
Bangladesh	5	1
India	3	1
Pakistan	5	0
Africa:		
Egypt	3	0
Kenya	3	0
Central Africa	3	0
Mali	12	0
Benin	11	0
Burkina Faso	11	0
Malawi	4	0
South Africa	5	1
Zimbabwe	11	0

Table 5. Returns to Agricultural Research

	Number Of IRRs Reported	Percent Distribution						Approximate Median IRR
		0-20	21-40	41-60	61-80	81-100	100+	
Applied Research								
Project Evaluation	121	.25	.31	.14	.18	.06	.07	39
Statistical	254	.14	.20	.23	.12	.10	.20	45
Aggregate Programs	126	.16	.27	.29	.10	.09	.09	40
Commodity Programs								
Wheat	30	.30	.13	.17	.10	.13	.17	50
Rice	48	.08	.23	.19	.27	.08	.14	58
Maize	25	.12	.28	.12	.16	.08	.24	55
Other Cereals	27	.26	.15	.30	.11	.07	.11	45
Fruits and Vegetables	34	.18	.18	.09	.15	.09	.32	60
All Crops	207	.19	.19	.14	.16	.10	.21	52
Forest Products	13	.23	.31	.68	.16	0	.23	35
Livestock	32	.21	.31	.25	.09	.03	.09	30
By Region								
OECD	146	.15	.35	.21	.10	.07	.11	35
Asia	120	.08	.18	.21	.15	.11	.26	60
Latin America	80	.15	.29	.29	.15	.07	.06	45
Africa	44	.27	.27	.18	.11	.11	.05	35
All Applied Research	375	.18	.23	.20	.14	.08	.16	45
Pre-Technology Science	12	0	.17	.33	.17	.17	.17	50
Private Sector R&D	11	.18	.09	.45	.09	.18	0	45
Ex Ante Research	83	.11	.36	.16	.07	.01	.05	40

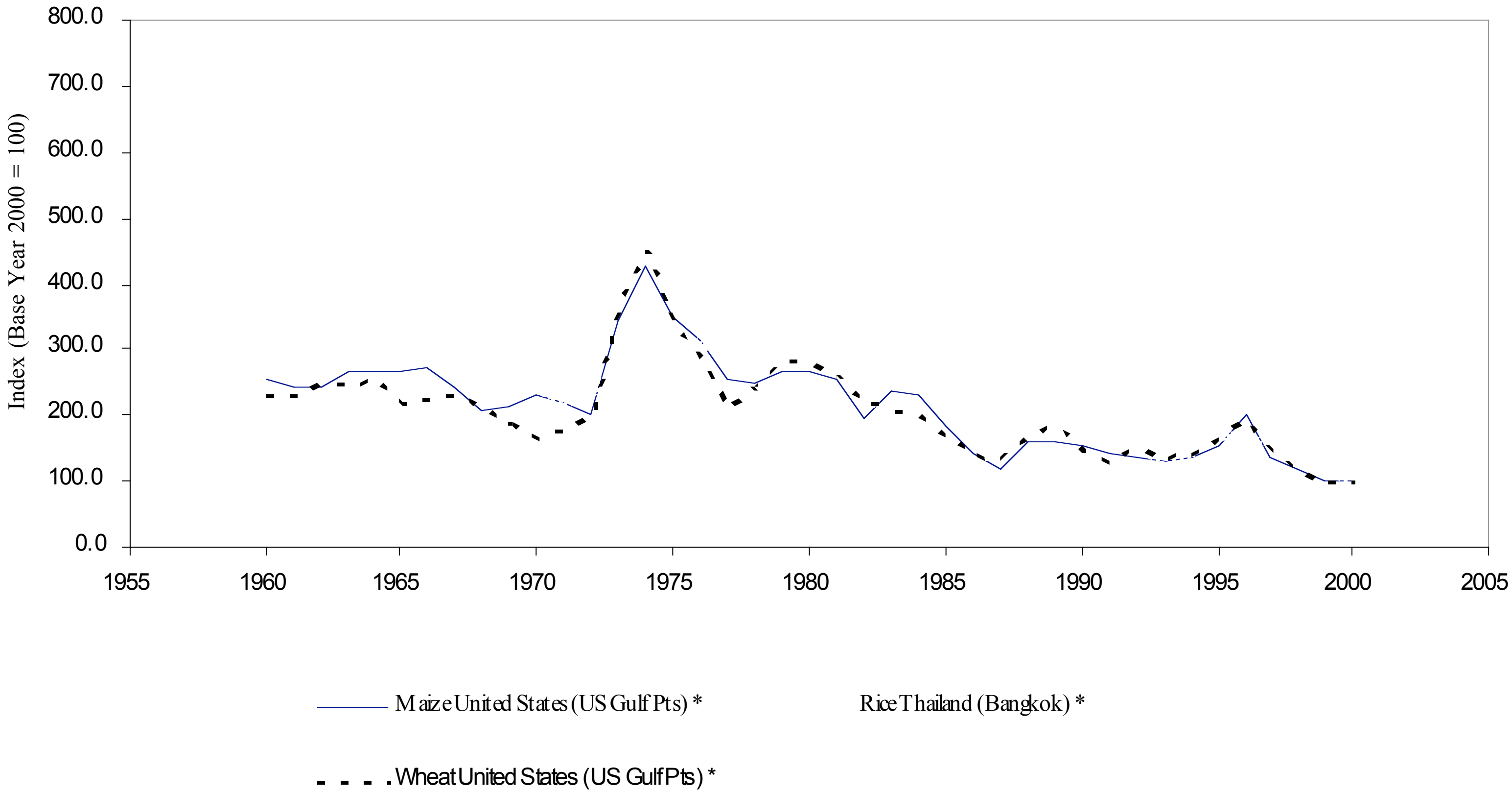
Table 6: Estimated B/C Ratios and Internal Rates of Return from Green Revolution Contributions

Region	NARS B/C	NARS IRRs	IARC B/C	IARC IRRs
Latin America	56	31	34	39
Asia	115	33	104	115
West Asia-North Africa	54	22	147	165
Sub-Saharan Africa	4	9	57	68
Source: Evenson calculations.				

Figure 1: Green Revolution Clusters by GRMV Adoption Level in 2000

LT 2%	2-10%	10-20%	20-30%	30-40%	40-50%	50-65%	GT 65%
Afghanistan	Burkina Faso	Bolivia	Colombia	Cuba	Dominican Republic	Algeria	Argentina
Angola	Cambodia	Benin	Costa Rica	Egypt	Iran	Bangladesh	Chile
Burundi	Chad	Botswana	Ecuador	Mexico	Kenya	Brazil	China
Central African Republic	El Salvador	Cameroon	Ghana	Namibia	Morocco	Myanmar	India
Congo (B)	Gabon	Congo (Z)	Laos	Paraguay	Nepal	Tunisia	Indonesia
Gambia	Guatemala	Côte d'Ivoire	Madagascar	Peru	Thailand		Malaysia
Guinea Bissau	Guinea	Ethiopia	Mali	Saudi Arabia	Turkey		Pakistan
Mauritania	Haiti	Liberia	Sierra Leone	South Africa			Philippines
Mongolia	Jamaica	Honduras		Syria			Sri Lanka
Niger	Libya	Mauritius					Vietnam
Somalia	Malawi	Nicaragua					
Yemen	Mozambique	Nigeria					
	Panama	Rwanda					
	Senegal	Sudan					
	Swaziland	Tanzania					
	Togo	Uruguay					
	Uganda	Venezuela					
	Zambia	Zimbabwe					

Figure 2 World Grain Prices, 1960-2000



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