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# The Asian Green Revolution

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A total of 20 case studies are included in this project, each one based on a synthesis of the peer-reviewed literature, along with other relevant knowledge, that documents an intervention's impact on hunger and malnutrition and the pathways to food security. All these studies were in turn peer reviewed by both the Millions Fed project and IFPRI's independent Publications Review Committee.

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#### Notices

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#### **ABSTRACT**

The Green Revolution brought modern science to bear on a widening Asian food crisis in the 1960s. The speed and scale with which it solved the food problem was remarkable and unprecedented, and it contributed to a substantial reduction in poverty and the launching of broader economic growth in many Asian countries. Improved cereal varieties, fertilizers, irrigation, and modern pest control methods lay at the heart of the Green Revolution, yet it was much more than a technology fix. It also required a supporting economic and policy environment. The need for markets that could handle the surge in production and the need to educate farmers about the new technology and ensure that they had access to the inputs and receive an adequate reward to their investments, led governments across Asia to actively intervene in launching and implementing the Green Revolution. Government interventions were also important for ensuring that small farmers were included in the revolution and did not get left behind. Even with the success of the Green Revolution, there are remaining social and environmental problems that still need to be resolved and a continuing need to increase yields to meet Asia's growing food needs. There is also urgent need to bring the Green Revolution in an appropriately modified form to Sub-Saharan Africa.

Keywords: Millions Fed, Green Revolution, Agricultural Transformation, Asia

#### 1. INTRODUCTION

Driven by rapid advances in the sciences and substantial public investments and policy support for agriculture, the Green Revolution was just one aspect of a much larger transformation of global agriculture during the 20th century. The story of English wheat is typical. It took nearly 1000 years for wheat yields to increase from 0.5 to 2 tons per hectare (ha), but then wheat yields climbed to over 7 tons per ha during the 20th century. These advances were fueled by modern plant breeding, improved agronomy, and the development of inorganic fertilizers and modern pesticides. Most industrial countries had achieved sustained food surpluses by the second half of the 20th century and abolished the threat of food shortages.

These advances were much slower in reaching today's developing countries. Although the colonial powers had invested in improving the production of tropical export crops, they invested relatively little in the food production systems of their colonies. This neglect together with rapidly growing populations led to widespread hunger and malnutrition by the 1960s, especially in developing Asia, which had a growing dependence on food aid from the rich countries. Sequential droughts in India during the mid-1960s highlighted the precarious nature of the situation, and a 1967 report of the US President's Science Advisory Committee concluded that "The scale, severity and duration of the world food problem are so great that a massive, long-range innovative effort unprecedented in human history will be required to master it" (quoted in Evans 1998).

In response, the Rockefeller and Ford Foundations took the lead in establishing an international agricultural research program to help transfer and adapt scientific advances already available around the world to the conditions of the developing countries (Tribe 1994). The first investments were made in rice and wheat research, two of the most important food crops for developing countries. The breeding of improved varieties combined with the expanded use of fertilizers, other chemical inputs, and irrigation led to dramatic yield increases for these two crops in Asia and Latin America, beginning in the late 1960s. This development was coined the "Green Revolution" by USAID Administrator W. S. Gaud, hoping it would help contain the communistic "Red Revolution" that was capitalizing on poverty in developing countries at the time.

While the term "Green Revolution" originally described developments for rice and wheat, the term has since referred to the development of high yielding varieties for a number of other major food crops important to developing countries. These include sorghum, millet, maize, cassava, and beans. Moreover there is now a full-fledged system of international agricultural research centers, the Consultative Group on International Agricultural Research, that work on many aspects of developing country agriculture.

The Green Revolution was a continuing process of change rather than a single event, and even today, continuing improvements of cereal varieties and management practices help support and advance the high levels of productivity that were initially attained. Although the main thrust of the Asian Green Revolution occurred during the period 1965–1990, it had many technology and policy antecedents in the rice revolution that began in Japan in the latter part of the 19th century and spread to Taiwan and Korea during the late 1920s and 1930s (Jirström 2005). This paper focuses on the more narrowly defined Asian Green Revolution of 1965–90.

The Green Revolution spread rapidly across developing Asia and the resultant increases in food production pulled the region back from the edge of an abyss of famine and led to regional food surpluses within 25 years. It lifted many people out of poverty, made important contributions to economic growth, and saved large areas of forest, wetlands, and other fragile lands from conversion to cropping. The investments and policies that underpinned the Green Revolution were highly successful in achieving the objectives of the time, and returned a high rate of economic return. There are lingering social and environmental problems that still need to be resolved. Additionally, it will be important to: a) continue to increase the productivity of the Green Revolution areas to meet the growing demands for cereals for food, feed, and fuel; and b) spread intensive farming methods more widely, particularly to Sub-Saharan Africa

which has failed so far to adequately intensify its food production systems and as a result suffers from worsening poverty and hunger.

#### 2. INTERVENTION

The Green Revolution was driven by a technology revolution, comprising a package of modern inputs – irrigation, improved seeds, fertilizers, and pesticides – that together dramatically increased crop production. But its implementation also depended on strong public support for developing the technologies, building up the required infrastructure, ensuring that markets, finance, and input systems worked, and that ensured farmers had adequate knowledge and economic incentive to adopt the technology package. Public interventions were especially crucial for ensuring that small farmers were included, without which the Green Revolution would not have been as pro-poor as it was. Attempts have been made to separate the contributions of the different components of the Green Revolution package, but in practice it was the combined impact of interventions and their powerful interactions that made the difference.

## Irrigation

Asia had already investing heavily in irrigation prior to the Green Revolution and by 1970 around 25 percent of the agricultural land was already irrigated (Table 1). In India, there were 10.4 million hectares of canal irrigated land in 1961, and 4.6 million hectares of tank irrigated land (Evenson, Pray, and Rosegrant 1999). Significant additional investments were made across Asia during the Green Revolution era, and the irrigated area grew from 25 percent to 33 percent of the agricultural area between 1970 and 1995 (Table 1).

Table 1. Indicators of input use during the Green Revolution in Asia

	Irrigated (% of agric Area	cultural	Fertilize	ilizer (kg/ha) Annual growth rate in agricultural work force,		Annual growth rate in agricultural land area, 1967–82
	1970	1995	1970	1995	1967–82	
Bangladesh	11.6	37.6	15.7	135.5	1.07	0.05
China	37.2	37.0	43.0	346.1	1.92	0.03
India	18.4	31.8	13.7	81.9	1.59	0.19
Indonesia	15.0	15.2	9.2	84.7	1.41	0.00
Malaysia	5.9	4.5	43.6	148.6	0.57	1.03
Myanmar	8.0	15.4	2.1	16.9	1.93	-0.21
Nepal	5.9	29.8	2.7	31.6	1.82	1.56
Pakistan	67.0	79.6	14.6	116.1	2.41	0.33
Philippines	11.0	16.6	28.9	63.4	1.90	1.72
South Korea	51.5	60.8	251.7	486.7	-0.07	-0.38
Sri Lanka	24.6	29.2	55.5	106.0	1.69	-0.05
Thailand	14.2	22.7	5.9	76.5	2.17	2.52
Vietnam	16.0	29.6	50.7	214.3	1.58	0.54
TOTAL	25.2	33.2	23.9	171.1	1.76	0.28

Source: Rosegrant and Hazell (2000).

#### **Fertilizer**

Like irrigation, fertilizer use across Asia was also growing prior to the Green Revolution. In 1970, 23.9 kg of plant nutrients were applied per hectare of agricultural land and average use grew rapidly to reach 102.0 kg/ha by 1995 (Table 1).

## **Improved Seeds**

Irrigation and fertilizer helped raise cereal yields, but their full impact was only realized after the development of high-yielding varieties. Scientists sought to develop cereal varieties that were more responsive to plant nutrients, and that had shorter and stiffer straw that would not fall over under the weight of heavier heads of grains. They also wanted tropical rice varieties that could mature more quickly and grow at any time of the year, thereby permitting more crops to be grown each year on the same land. Varieties also needed to be resistant to major pests and diseases that flourish under intensive farming conditions and to retain desirable cooking and consumption traits.

Borrowing from rice breeding work undertaken in China, Japan, and Taiwan, the fledging International Rice Research Institute (IIRI) in the Philippines developed semi-dwarf varieties that met most of these requirements and could be grown under a wide range of conditions. Similar achievements were made for wheat after Norman Borlaug (later awarded a Nobel Prize for his work) crossed Japanese semi-dwarf varieties with Mexican wheat varieties at what is now known as the International Center for Maize and Wheat Improvement (CIMMYT) in Mexico.

The adoption of high-yielding varieties occurred quickly (Table 2) and by 1980 about 40 percent of the total cereal area in Asia was planted to modern varieties (World Bank 2007). This had increased to about 80 percent of the cropped area by 2000.

Table 2. Percent of harvested area under modern varieties in Asia

	Rice	Wheat	Maize
South Asia			
1965	0.0	1.7	0.0
1970	10.2	39.6	17.1
1975	26.6	72.5	26.3
1980	36.3	78.2	34.4
1985	44.2	82.9	42.5
1990	52.6	87.3	47.1
1995	59.0	90.1	48.8
2000	71.0	94.5	53.5
East & Southeast Asia	a and the Pacific		
1965	0.3	0.0	0.0
1970	9.7	0.0	16.2
1975	27.0	14.8	39.5
1980	40.9	27.5	61.7
1985	54.1	34.3	65.9
1990	63.5	58.7	73.0
1995	71.1	78.8	83.2
2000	80.5	89.1	89.6

Source: Gollin et al. (2005)

It should be noted that the high-yielding varieties that powered the Green Revolution were not developed overnight but were the product of a long and sustained research effort. The initial varieties that were released also had to be adapted to counter evolving pest and environmental problems and better suited to local conditions and consumer needs. This required a continuing process of agricultural R&D.

## **Public Investment and Policy Support**

The Green Revolution was more than a technology fix. It also required a supporting economic and policy environment. The need to educate farmers about the new technology, rapidly expand input delivery and credit systems so they could adopt the new inputs, and increase processing, storage, trade and marketing capacities to handle the surge in production, was considered too large a challenge for the private sector on its own at the time, especially if small farmers were to participate (Johnson, Hazell, and Gulati 2003). It was also necessary to ensure that adoption of the technology package was profitable for farmers. To achieve these ends, governments across Asia actively intervened in launching and implementing the Green Revolution. Some but not all public interventions were market mediated, and all were backed by substantial public investments in agricultural development (Djurfeldt and Jirström 2005).

The levels of public investment needed to launch and sustain the Green Revolution were impressive. Asian countries not only invested heavily to launch their Green Revolution, but continued to invest in agriculture to sustain the gains that were achieved. On average, Asian countries were spending 15.4 percent of their total government spending on agriculture by 1972 and they doubled the real value of their agricultural expenditures by 1985 (Table 3). The need to sustain investment levels is especially true of agricultural R&D, since there are long lead times in developing new products and farmers continually need new crop varieties and natural resource management practices to stay ahead of evolving pest, environmental problems, and changing market demands.

Table 3. Government expenditures on agriculture in Asia, 1985 US dollars (purchasing power parity)

	1972	1975	1980	1985	1990	1972	1975	1980	1985	1990
		(n	nillion dolla	ars)		(%	total go	vernment	expenditu	ıre)
Bangladesh	2,358	528	1,187	1,749	1,269	23.2	11.0	12.3	15.7	5.4
China	11,595	17,843	24,542	21,113	28,229	8.5	12.1	12.4	8.3	8.9
India	15,491	13,680	22,877	30,549	39,109	22.1	9.7	14.6	12.6	11.5
Indonesia	1,436	3,020	5,026	4,351	6,157	7.6	9.8	9.6	6.8	7.6
Malaysia	348	458	1,264	1,581	1,830	4.0	4.2	7.2	7.9	5.7
Myanmar	272	219	655	874	296	12.5	13.3	23.6	24.5	9.3
Nepal	107	136	257	541	254	13.7	15.5	16.4	22.0	8.5
Pakistan	740	1,031	1,168	971	1,312	5.7	6.7	5.4	2.9	2.6
Philippines	416	1,145	729	604	1,409	4.5	9.0	5.3	5.7	6.0
South Korea	537	993	1,129	2,244	4,332	3.8	6.3	4.1	5.8	6.9
Sri Lanka	627	449	589	2,124	614	12.3	9.0	5.7	20.0	5.8
Thailand	902	767	1,850	3,181	3,190	7.8	5.9	8.1	11.7	10.4
Total	34,828	40,269	61,273	70,151	88,001	15.4	10.5	12.4	10.9	9.6

Source: Rosegrant and Hazell (2000)

Governments also shored up farm credit systems, subsidized key inputs—especially fertilizer, power, and water—and intervened in markets to ensure farmers received adequate prices each year to ensure the technologies were profitable. Many governments used their interventions to ensure that small farmers participated in the Green Revolution, and did not get left behind. There was substantial empirical evidence at the time showing that small farms were the more efficient producers in Asia and land reform and small farm development programs were implemented to create and support large numbers of small farms. Agricultural growth led by small farms proved not only to be more efficient but also more propoor; a win–win proposition for growth and poverty reduction. Box 1 describes the approach taken in India, which is indicative of what happened in many other Asian countries.

#### Box 1. India's Green Revolution agenda

Immediately after independence, the Government of India placed a top priority on agricultural development. Prime Minister Jawaharlal Nehru realized the importance of physical and scientific infrastructure for modern agriculture. During the First Plan (1947–1952), the government allocated about 30 percent of its budget to agriculture and irrigation, and this led to an impressive build up of rural roads, irrigation, rural power, state agricultural universities, and the national agricultural research systems. Fertilizer plants were also set up. Another important policy intervention was land reform. The land reform program began right after independence and continued into the early 1960s. It was characterized by several distinguishing features: the abolition of intermediaries such as *zamindars* and *jagirdars*, reforms to provide tenancy security, ceilings on the size of landholdings, and use of cooperatives and community development programs.

These efforts were intensified in the mid 1960's as India became more dependent on US food aid despite its own agricultural potential. Following a study made by the Ford Foundation in the early 1960's, the Indian government set up the Intensive Agricultural District Program (IADP), which invested heavily in agricultural extension and distribution of subsidized inputs. They also established the Food Corporation of India, which bought excess production at a guaranteed price in order to guarantee stability to farmers. The government also took an active role in coordinating interventions from donors and development partners, who financed agricultural extension as well as research and development. All of this came on top of India's considerable existing infrastructure, including roads and irrigation systems. In total, the Indian government coordinated interventions all along the market chain to enable the entire agricultural system to function.

As a result, most rural small farms could profitably access inputs such as scale-neutral, high-yield seeds, fertilizers, irrigation, and credit. Despite the heavy government interventions in the production, dissemination, and adoption of these inputs, the private sector was also permitted a key role. The dual presence of a private and public marketing system actually helped complement and improve the efficient distribution of inputs to farmers. The success of the Green Revolution was also catalyzed by combining subsidies to factor inputs with public investments in infrastructure (roads, power, and irrigation), as well as research and extension, followed later by marketing policy interventions that ensured that farmers had access to assured market outlets at stable prices (Johnson, Hazell, and Gulati 2003).

Early breakthroughs in productivity were concentrated in Punjab and Haryana in northwestern India, which subsequently became breadbaskets for the entire subcontinent. Impact on poverty reduction in the Punjab was significant, partly because land distribution was relatively equal and the benefits of agricultural productivity improvements reached a large proportion of the population. In neighboring states like Bihar, where the land system was more feudal, poverty reduction was more limited and growth slowed down sooner.

#### 3. THE IMPACT

Average cereal yields grew impressively in Asia; wheat yields grew by 4.1 percent per year over the period 1965–82 and rice yields by 2.5 percent per year (Table 4). Higher yields and profitability also led farmers to increase the area of rice and wheat they grew at the expense of other crops. And, with faster growing varieties and irrigation, they grew more crops on their land each year. This led to even faster growth in cereal production (Table 4). All these gains were achieved with negligible growth (0.42 percent per year) in the total area planted to cereals.

## **Impact on Food Production**

Asia-wide, total cereal production grew by 3.57 percent per year over 1967–82, with average annual growth rates of 5.43 percent, 3.25 percent, and 4.62 percent for wheat, rice and maize, respectively (Table 4).

Table 4. Annual growth rates in cereal production in Asia, 1967–82 (%)

Crop	Area	Yield	Production
Wheat	1.30	4.07	5.43
Maize	1.09	3.48	4.62
Rice	0.70	2.54	3.25
Other grains	-1.76	1.63	-0.15
All cereals	0.42	3.13	3.57

Source: Rosegrant and Hazell (2000)

The growth rates were considerably higher in the bread basket areas (for example, Punjab and Haryana in India and Central Luzon in the Philippines) where the Green Revolution was launched. Cereal production in Asia virtually doubled between 1970 and 1995, from 313 to 650 million tons per year. Although the population increased by 60 percent, the increase in food production was sufficient that instead of widespread famine, cereal, and calorie availability per person increased by nearly 30 percent, and wheat and rice became cheaper (Table 5 and ADB 2000).

Table 5. Indicators of change in Asia, 1970–1995

	India	Other S. Asia	PRC	Southeast Asia	Developing Asia
Total Population Aff	fected (millions)				
1970	554.9	156.2	834.6	204.4	1750.2
1995	929.0	293.9	1226.3	343.7	2792.9
% Change	67.4	88.2	46.9	68.2	59.6
Agricultural Populat	tion Affected (million	ns)			
1970	370.4	140.2	650.9	191.7	1353.2
1990	500.7	190.7	830.2	244.1	1765.7
% Change	35.2	36.0	27.5	27.3	30.5

Table 5. (Contined)

	India	Other S. Asia	PRC	Southeast	Developing
C1 W:-11 (//L-)				Asia	Asia
Cereal Yield (t/ha)					
1970	0.925	1.197	1.769	1.352	1.317
1995	1.743	1.846	4.007	2.237	2.627
% Change	88.4	54.2	126.5	65.6	99.5
Cereal Production (mill	ion metric tons)				
1970	92.8	25.4	161.1	33.8	313.2
1995	174.6	48.1	353.3	73.6	649.6
% Change	88.1	89.3	119.3	117.8	107.4
Per Capita Income (USS	\$/year)				
1970	241.0	187.0	91.0	351.0	177.0
1995	439.0	299.0	473.0	1027.0	512.0
% Change	82.2	60.0	419.8	192.6	189.3
Calorie Consumption (F	Kilocalories/persor	n/day)			
1970	2083	2184	2019	1945	2045
1995	2388	2274	2697	2596	2537
% Change	14.6	4.1	33.5	33.5	24.1
Poverty (millions)					
1975	472.2		568.9	108.1	1149.2
1990s	514.7		269.3	40.2	824.2
% Change	9.0		-52.7	-62.8	-28.3
Poverty (percent popula	ation)				
1975	59.1		59.5	52.9	58.7
1990s	43.1		22.2	11.5	29.9

Sources: Tables 1 and 2 in Asian Development Bank (2000); Tables V.8 and in Rosegrant and Hazell (2000), and FAOSTAT

#### **Impact on Production Fluctuations**

The high-yielding varieties were developed to give higher yields in favorable environments, such as irrigated areas with high fertilizer usage. This led to some initial concern that they would be more vulnerable to pest and weather stresses than traditional varieties, increasing the risk of major yield and food production shortfalls in unfavorable years. Early work by Mehra (1981) among others suggested that yield variability for cereals in India was increasing relative to increases in average yield (higher coefficients of variation) at the national level, raising the specter of a growing risk of national food shortages and high prices some years. Subsequent analysis showed that at the plot level, many modern varieties were no more risky than traditional varieties in terms of downside risk<sup>1</sup>, and that while some crop yields measured at regional and national levels were becoming more variable (a bigger problem for maize and other rainfed cereals than wheat or rice<sup>2</sup>), this was largely the result of more correlated or synchronized patterns of spatial yield variation across space (Hazell 1982, 1989). Several scholars suggested that these changes might be attributable to the widespread adoption of input-intensive

<sup>1</sup> See relevant case study material in Anderson and Hazell (1989).

<sup>&</sup>lt;sup>2</sup> In contrast to India, Tisdell (1988) found that relative yield and production variability of foodgrain fell at district and national levels in Bangladesh over a similar time period.

production methods that led to larger and more synchronized yield responses to changes in market signals and weather events, shorter planting periods with mechanization, and the planting of large areas to the same or genetically similar crop varieties (Hazell 1982; Ray 1983; Rao et al. 1988). Later studies showed that rice and wheat yields generally became more stable in Asia in the 1990s, but the patterns for maize and coarse grains were more mixed, especially at country and subregional levels (Sharma et al. 2006; Chand and Raju 2008; Gollin 2006; Larson et al. 2004; Deb and Bantilan 2003; Singh and Byerlee 1990).

National yield and production variability became less of a policy issue after market liberalization policies were implemented in the late 1980s and early 1990s, enabling international trade to play a bigger role in stabilizing market supplies and prices. But since large areas of major cereals are still planted to relatively few modern varieties, concern remains about the risk of possible genetic uniformity making crops vulnerable to catastrophic yield losses from changes in pests, diseases, and climate. The absence of any catastrophic crop failures despite the Green Revolution is due in large part to extensive behind-the-scenes scientific work to prevent such disasters. Crop genetic uniformity has been counteracted by spending more on conserving genetic resources and making them accessible for breeding purposes; through breeding approaches that broaden the genetic base of varieties supplied to farmers; and by changing varieties more frequently over time in order to stay ahead of evolving pests, disease, and climate risks (Smale et al. 2009). The international agricultural research system also spends significant shares of its budget on "maintenance" research in order to provide national systems with new germplasm on a timely basis in response to emerging new pest, disease, and climate risks.

## **Indirect Income and Employment Impacts**

Productivity growth in agriculture can have far reaching impacts on the productivity and growth of regional and national economies. There are several growth linkages that drive this relationship: benefits from lower food prices for workers; more abundant raw materials for agro-industry and export; release of labor and capital (in the form of rural savings and taxes) to the nonfarm sector; and increased rural demands for nonfood consumer goods and services, which in turn support growth in the service and manufacturing sectors.

The powerful economywide benefits emanating from the Green Revolution were amply demonstrated during the Green Revolution era in Asia (Mellor 1976). In India, the fact that non-agriculture's share of total national employment did not change for over a century, until the full force of the Green Revolution was underway in the 1970s, provided strong circumstantial evidence of the importance of agricultural growth as a motor for the Indian economy. This was also confirmed by Rangarajan (1982) who estimated that a 1 percentage point addition to the agricultural growth rate stimulated a 0.5 percent addition to the growth rate of industrial output, and a 0.7 percent addition to the growth rate of national income.

Regional growth linkage studies have also shown strong multiplier impacts from agricultural growth to the rural nonfarm economy (Bell, Hazell and Slade 1982; Hazell and Haggblade 1991; Hazell and Ramasamy 1991). The size of the multipliers vary depending on the method of analysis chosen, and for Asia they vary between \$0.30 to \$0.85; i.e., each dollar increase in agricultural income leads to an additional \$0.30–0.85 increase in rural nonfarm earnings (Haggblade et al. 2007). The multipliers tend to be larger in Green Revolution regions because of better infrastructure and market town development, greater use of purchased farm inputs, and higher per capita incomes and hence consumer spending power (Hazell and Haggblade 1991).

## **Impact on Poverty**

Although the primary goal of the investments underlying the Green Revolution was to increase food production, it also helped slash poverty. Reliable poverty data are not available for the early Green Revolution period, but in 1975 nearly three out of every five Asians still lived on \$1 a day. This declined to less than one in three by 1995 (Rosegrant and Hazell 2000). The absolute number of poor declined by

28 percent; from 1,150 million in 1975 to 825 million in 1995. These reductions in poverty would have been even more impressive if the total population had not grown by 60 percent over the same period. The vast majority of the poor who were lifted out of poverty were rural and obtained important shares of their livelihood from agriculture and allied activities.

Given the complex causes underlying poverty and the diversity of livelihoods found amongst poor people, the relationship between the Green Revolution and poverty alleviation is necessarily complex and this has led to a large and contentious debate in the literature. Before turning to that literature, it is useful to first consider the conceptual basis for these complexities.

There are a number of pathways through which the Green Revolution might have benefited the poor (Hazell and Haddad 2001). Within adopting regions, the Green Revolution could have helped poor farmers directly by increasing their production, providing more food and nutrients for their own consumption and increasing the surplus of products available to sell for cash income. Small farmers and landless laborers could have gained additional agricultural employment opportunities and higher wages within adopting regions.

The Green Revolution could also have benefited the poor in less direct ways. Growth in adopting regions could have created employment opportunities for migrant workers from other less dynamic regions. It could also have stimulated growth in the rural and urban nonfarm economy with benefits for a wide range of rural and urban poor people. Greater food production could also have led to lower food prices for all types of poor people. It might also have improved poor peoples' access to foods that are high in nutrients and crucial to their well-being—particularly poor women.

But the Green Revolution could also have worked against the poor. Although its technology was in principle scale-neutral it may nevertheless have favored large farms because of their better access to irrigation water, fertilizers, seeds, and credit. The accompanying use of machines and herbicides might have displaced labor, leading to lower wage earnings for agricultural workers. By favoring some regions or farmers over others, the Green Revolution might have harmed non-adopting farmers by lowering their product prices even though only the adopting farmers benefited from cost-reducing technologies.

Given that many of the rural poor are simultaneously farmers, paid agricultural workers, net buyers of food, and earn nonfarm sources of income, the net impact of the Green Revolution on their poverty status can be complex, with households experiencing gains in some dimensions and losses in others. For example, the same household might have gained from reduced food prices and from higher nonfarm wage earnings, but lost from lower farm gate prices and agricultural wages. Measuring the net benefits to the poor requires a full household income analysis of direct and indirect impacts, as well as consideration of the impacts on poor households that are not engaged in agriculture and/or who live outside adopting regions. Much of the controversy that exists in the literature about how the Green Revolution impacted on the poor has arisen because too many studies have only taken a partial view of the problem.

Much of the available literature on the Green Revolution's impact focuses on the direct poverty impacts within adopting regions, while a smaller body of literature assesses the broader and indirect poverty impact arising through food price changes and intersectoral linkages.

## Impacts within Adopting Regions

A number of village and household studies conducted soon after the release of Green Revolution technologies raised concern that large farms were the main beneficiaries of the technology and poor farmers were either unaffected or made worse off. Later evidence showed mixed outcomes. Small farmers did lag behind large farmers in adopting Green Revolution technologies, but many of them eventually did adopt them (Pinstrup-Andersen and Hazell 1987). Many of these adopters of small farms benefited from increased production, greater employment opportunities, and higher wages in the agricultural and nonfarm sectors (Lipton with Longhurst 1989). In some cases, small farmers and landless laborers actually ended up gaining proportionally more income than larger farmers, resulting in a

net improvement in the distribution of village income (Hazell and Ramasamy 1991; Maheshwari 1998; Thapa et al. 1992).

Freebairn (1995) performed a meta-analysis of 307 published studies on the Green Revolution. The primary concern of nearly all the studies that he reviewed was on changes in inequality and income distribution rather than absolute poverty, the latter emerging as a more important issue in the 1990s. He found that 40 percent of the studies reviewed reported income became more concentrated within adopting regions, 12 percent reported that it remained unchanged or improved, and 48 percent offered no conclusion. Freebairn found more favorable outcomes of the revolution in the literature on Asia than elsewhere, and found that within the Asian literature, Asian authors gave more favorable conclusions than non-Asian authors. Freebairn also found that later studies reported similar equity outcomes to those reported in earlier studies, thereby casting some doubt on the proposition that because small farmers adopted later than large farmers, equity improved over time. However, it should be noted that his analysis did not include repeat studies undertaken at the same sites over longer period of time, such as Hazell and Ramasamy (1991), Hayami and Kikuchi (2000), and Jewitt and Baker (2007), all of whom found favorable longer term impacts on inequality. Freebairn also found that microbased case studies reported the most favorable outcomes, while macrobased essays reported the worst outcomes.

Walker (2000) argues that reducing inequality is not the same thing as reducing poverty and may be much more difficult to achieve through technologically driven agricultural growth. More recent studies focusing directly on poverty confirm that improved technologies do impact favorably on many small farmers, but the gains for the smallest farms and landless agricultural workers can be too small to raise them above poverty thresholds (Hossain et al. 2007; Mendola 2007). However, the poor can benefit in other ways too. Hossain et al. (2007) find that in Bangladesh, the spread of high-yielding variety rice helped reduce the vulnerability of the poor by stabilizing employment earnings, reducing food prices and their seasonal fluctuations, and enhancing their ability to cope with natural disasters. Use of participatory research methods in the selection of improved rice varieties in Uttar Pradesh, India has been shown to empower women as decision makers in their farming and family roles as well as leading to greater adoption of improved varieties (Paris et al.2008).

## Indirect Impacts on Poverty

A number of econometric studies have used cross-country and/or time-series data to estimate the relationship between agricultural productivity growth and poverty and they cover the Green Revolution era. These studies generally find agricultural productivity growth has high poverty reduction elasticities. Thirtle, Lin, and Piesse (2003) estimate that each 1 percent increase in crop productivity reduces the number of poor people by 0.48 percent in Asia. For India, Ravallion and Datt (1996) estimate that a 1 percent increase in agricultural value added per hectare leads to a 0.4 percent reduction in poverty in the short run and 1.9 percent in the long run, the latter arising through the indirect effects of lower food prices and higher wages. Fan, Hazell and Thorat (1999) estimate that each 1 percent increase in agricultural production in India reduces the number of rural poor by 0.24 percent. For Asia, these poverty elasticities are still higher for agriculture than for other sectors of the economy (World Bank 2007; Hasan and Quibria 2004).

There is some evidence that the poverty elasticity of agricultural growth may be diminishing because the rural poor are becoming less dependent on agriculture. In Pakistan, for example, agricultural growth was associated with rapid reductions in rural poverty in the 1970s and 1980s, but the incidence of rural poverty hardly changed in the 1990s despite continuing agricultural growth (Dorosh et al. 2003). This is partly because a growing share of the rural poor households (46 percent by 2002) had become disengaged from agriculture; even small farm households and landless agricultural worker households received about half their income from nonfarm sources (Dorosh, et al. 2003).

Lower food prices and growth linkages to the nonfarm economy play an important role in most of the results cited above, and these benefit the urban as well as the rural poor. These indirect impacts have sometimes proved more powerful and positive than the direct impacts of R&D on the poor within

adopting regions (Hazell and Haddad 2001). A question arises as to whether the power of these indirect benefits has diminished over time with market liberalization and greater diversification of Asian economies.

#### Interregional Disparities

The Green Revolution began in regions with assured irrigation and although it subsequently spread to areas that depended more on rainfed crops, it did not benefit many of the poorest regions (Prahladachar 1983). The widening regional income gaps that resulted have been buffered to some extent by interregional migration. In India, the Green Revolution led to the seasonal migration of over 1 million agricultural workers each year from the eastern states to Punjab and Haryana (Oberai and Singh 1980; Westley 1986). These numbers were tempered in later years as the Green Revolution technology eventually spilt over into eastern India in conjunction with the spread of tube wells. In a study of the impact of the Green Revolution in a sample of Asian villages, David and Otsuka (1994) asked whether regional labor markets were able to spread the benefits between adopting and non-adopting villages and found that seasonal migration did go some way to fulfilling that role. But while migration can buffer widening income differentials between regions, it is rarely sufficient to avoid them. In India, for example, regional inequalities widened during the Green Revolution era (Galwani et al.2007), and the incidence of poverty remains high in many less-favored areas (Fan and Hazell 2000).

## **Impact on Nutrition**

The Green Revolution was very successful in increasing the per capita supply of food and reducing prices of food staples in Asia. Making food staples more available and less costly has proved an important way through which poor people benefited (Rosegrant and Hazell 2000; Fan, Hazell and Thorat 1999; Fan 2007). Several microlevel studies from the Green Revolution era in Asia found that higher yields typically led to greater calorie and protein intake amongst rural households within adopting regions. For example, Pinstrup-Andersen and Jaramillo (1986) found that the spread of high-yielding variety rice in North Arcot district, South India, led to substantial increases over a ten-year period in the energy and protein consumption for farmers and landless workers. Their analysis showed that, after controlling for changes in nonfarm sources of income and food prices, about one-third of the calorie increase could be attributed to increased rice production. Ryan and Asokan (1977) also found complementary net increases in protein and calorie availability as a result of Green Revolution wheat in the six major producing states of India, despite some reduction in the area of pulses grown.

More aggregate analysis of the impacts of rising incomes on diets and nutrient intake has proved more complex, particularly as concern has shifted from calorie and protein deficiencies to micro nutrients and broader nutritional well being. Food price declines are, in general, good for households that purchase more food than they sell, as this amounts to an increase in their real income. Real income increases can be used to increase consumption of important staples and to purchase more diverse and nutritionally rich diets. However, a study of Bangladesh showed that a downward trend in the price of rice from 1973–1975 to 1994–1996 was accompanied by upward trends in the real prices of others foods that are richer in micronutrients, making these less accessible to the poor (Bouis 2000). Similar patterns were observed in India during the 1970s and 1980s when farmers diverted land away from pulses to wheat and rice, leading to sharp increases in the price of pulses and a drop in their per capita consumption (Kennedy and Bouis 1993; Kataki 2002).

Since then there have been substantial changes in food intake patterns in rural Asia. In India, for example, the share of cereals in total food expenditure has declined while that of milk, meat, vegetables, and fruits has increased. Per capita consumption of cereals has also fallen in absolute terms (Nasurudeen et al.2006) and this is true for all income groups. However, since deficiencies in iron and the B vitamins are common amongst the poor the increases in micronutrient-rich foods must not always have been high enough to offset the decline from cereals. Other micronutrient deficiencies exist (for example, vitamin C and D) but these are not related to reductions in cereal consumption.

As the Green Revolution unfolded, strategies were implemented to enhance the nutritional quality of the diets of the poor. These included:

- a) improvements in the productivity of fruits, vegetables, livestock and fish, both in home gardens and ponds for on-farm consumption and more generally to increase the marketed supplies of these nutrient rich foods;
- b) promotion of food-crop biodiversity, especially traditional crops and cultivars that are rich in nutrients; and
- c) biofortification of major food staples.

While improved technologies have helped enhance the nutritional value of diets, studies show that the most effective results are obtained when technology interventions are complemented by investments in nutrition education and health services and targeted in ways that empower women with additional spending power (Ali and Hau 2001; Berti et al.2004).

#### **Returns to Public Investments**

Given the key role that the public sector played in launching and sustaining the Green Revolution, it is important to ask if the returns to its investments were justified.

Fan, Gulati and Thorat (2008) have estimated the returns to different types of public investments in agriculture in India over a four-decade period, beginning in the 1960s (Table 6). The marginal returns to these investments in terms of growth and poverty alleviation were very favorable in the early stages of the Green Revolution, and many, especially additional investments in rural roads and agricultural R&D, continued to give high returns through the 1990s. Although the returns to most input subsidies were initially high and have declined sharply over time, suggesting the need for an exit strategy, this does not negate the important role they played in the early years of the Green Revolution in helping to promote small farm led growth.

Table 1. Returns to agricultural growth and poverty reduction from investments in public goods and subsidies in different phases of the India's Green Revolution

	1960s	1970s	1980s	1990s
Returns in Agric GDP (Rupo	ees per Rupees spe	ent)		
Road investment	8.79	3.8	3.03	3.17
Educational investment	5.97	7.8	3.88	1.53
Irrigation investment	2.65	2.1	3.61	1.41
Irrigation subsidies	2.24	1.22	2.38	NS
Fertilizer subsidies	2.41	3.03	0.88	0.53
Power subsidies	1.18	0.95	1.66	0.58
Credit subsidies	3.86	1.68	5.2	0.89
Agricultural R&D	3.12	5.9	6.95	6.93
Decrease in the number of p	oor people per mil	lion Rupees spent		
Road investment	1272	1346	295	335
Educational investment	411	469	447	109
Irrigation investment	182	125	197	67
Irrigation subsidies	149	68	113	ns
Fertilizer subsidies	166	181	48	24
Power subsidies	79	52	83	27
Credit subsidies	257	93	259	42
Agricultural R&D	207	326	345	323

Source: (Fan, Gulati, and Thorat2008)

Other studies provide more focused analysis of the returns to public investments in agricultural research during the Green Revolution era. Evenson, Pray, and Rosegrant (1999) reviewed several impact studies from South Asia and found the returns to national agricultural R&D investments exceeded 60 percent in all cases. At commodity levels, Alston et al. (2000) reviewed 222 impact studies from Asia and found a median rate of return of 50 percent, higher than in other developing country regions (Table 7).

Table 2. Rates of return to agricultural research

Region	Number of estimates	Median rate of return
Africa	188	34
Asia	222	50
Latin America	262	43
Middle East/ North Africa	36	11
All developing countries	683	43
All developed countries	990	46

Source: Alston et al. (2000)

#### 4. SUSTAINABILITY

## **Declining Growth in Yields and Total Factor Productivity**

The Green Revolution was built upon rapid growth in cereal yields and an associated increase in total factor productivity (TFP) that enabled food prices to decline. A weak form of sustainability requires that these higher levels be sustained into the future. But given growing populations and demands for cereals for food and feed, a stronger form of sustainability is those yields and TFP need to continue to grow.

In reality, cereal yields have continued to rise on average across Asia since the Green Revolution era, but annual growth rates are slowing (Rosegrant and Hazell 2000; Hazell 2008). This is confirmed by more careful, microbased studies of wheat and rice yields in the Indo-Gangetic Plain (Murgai et al.2001; Ladha et al. 2003; Cassman and Pingali 1993; Bhandari et al. 2003), in India's major irrigated rice growing states (Janaiah et al.2005), and in East Asia's rice bowls (Pingali et al.1997).

There are several possible reasons for this slow down: displacement of cereals on better lands by more profitable crops like groundnuts (Maheshwari 1998); diminishing returns to modern varieties when irrigation and fertilizer use are already at high levels; and the fact that cereal prices have until recently been low relative to input costs making additional intensification less profitable. But there are concerns that the slow down also reflects a deteriorating crop-growing environment in intensive monocrop systems. Ali and Byerlee (2002) and Murgai, Ali, and Byerlee (2001), for example, report deteriorating soil and water quality in the rice—wheat system of the Indo-Gangetic Plain, and Pingali et al. (1997) report degradation of soils and build up of toxins in intensive paddy systems in a number of Asian countries.

These problems are reflected in growing evidence on stagnating or even declining levels of total factor productivity in some of these farming systems (Janaiah et al.2005). Ali and Byerlee (2002) have shown that degradation of soil and water are directly implicated in the slowing of TFP growth in the wheat—rice system of the Pakistan Punjab. Ladha et al. (2003) examined long-term yield trials data at multiple sites across South Asia and found stagnating or declining yield trends when input use is held constant. One consequence has been that farmers have had to use increasing amounts of fertilizers to maintain the same yields over time (Pingali et al. 1997). There is also concern that pest and disease resistance to modern pesticides now slows yield growth, and that breeders have largely exploited the yield potentials of major Green Revolution crops — though sizeable gaps still remain between experiment-plot and average farmer yields.

#### **Environmental Problems**

The concerns about the environmental stresses that may underlie the decline in growth rates of yields and total factor productivity also link to broader worries about the environmental sustainability of the green revolution. These wider issues include: excessive and inappropriate use of fertilizers and pesticides that pollute waterways and kill beneficial insects and other wildlife; irrigation practices that lead to salt build up and eventual abandonment of some of the best farming lands; increasing water scarcities in major river basins; and retreating groundwater levels in areas where more water is being pumped for irrigation than can be replenished (Hazell and Wood 2008). Some of these outcomes were inevitable as millions of largely illiterate farmers began to use modern inputs for the first time, but the problem was exacerbated by inadequate extension and training, an absence of effective regulation of water use and quality, and by input pricing and subsidy policies that made modern inputs too cheap and encouraged excessive use.

Just how serious are the environmental problems associated with the Green Revolution and are they likely to undermine future food production and Asia's ability to feed itself? Measuring environmental impacts is difficult and as a result good empirical evidence is fragmentary, often subjective and sometimes in direct contradiction with the overall trends in agricultural productivity. The best evidence relates to the degradation of irrigated land, increasing water scarcities, and the consequences of poor pest management practices.

## Degradation of Irrigated Land

There is growing evidence that poor irrigation practices have led to significant waterlogging and salinization of irrigated land. The Comprehensive Assessment of Water Management in Agriculture (2007) estimates that nearly 40 percent of irrigated land in dry areas of Asia is thought to be affected by salinization. For Pakistan, Ghassemi et al. (1995) estimate that 4.2 million hectares of irrigated lands (26 percent total) are affected by salinization, while Chakravorty (1998) claims one-third of the irrigated area is subject to waterlogging, and 14 percent is saline. For India, Dogra (1986) estimates that nearly 4.5 million hectares of irrigated land are affected by salinization and a further 6 million hectares by waterlogging, while Umali (1993) claims that 7 million hectares of arable land has been abandoned because of excessive salts.

## Water Scarcity

Even more worrying for irrigated agriculture is the threat from the growing scarcity of fresh water in much of Asia. Many countries are approaching the point where they can no longer afford to allocate two-thirds or more of their fresh water supplies to agriculture (Comprehensive Assessment of Water Management in Agriculture 2007). Most of the major river systems in Asia are already fully exploited at least part of the year, and the massive expansion of tubewell irrigation in South Asia has led to serious overdrawing of groundwater and falling water tables. In the Indian subcontinent, groundwater withdrawals have surged from less than 20 cubic kilometers to more than 250 cubic kilometers per year since the 1950s (Shah et al. 2003). More than a fifth of groundwater aquifers are overexploited in Punjab, Haryana, Rajasthan, and Tamil Nadu, and groundwater levels are falling (World Bank 2007; Postel 1993). Even as current water supplies are stretched, the demands for industry, urban household use, and environmental purposes are growing (Comprehensive Assessment of Water Management in Agriculture 2007; Rosegrant and Hazell 2000). It would seem that either many Asian farmers must learn to use irrigation water more sparingly and more sustainably or the irrigated area will have to contract.

## Pest Management

Pest problems emerged as an important problem during the early Green Revolution era because many of the first high-yielding varieties released had poor resistance to some important pests. The problem was compounded by a shift to higher cropping intensities, monocropping, high fertilizer use (which creates dense, lush canopies in which pests can thrive), and the planting of large adjacent areas to similar varieties with a common susceptibility. Control was initially based on prophylactic chemical applications, driven by the calendar rather than incidence of pest attack. This approach disrupted the natural pest–predator balance, and led to a resurgence of pest populations that required even more pesticide applications to control. Problems were compounded by the buildup of pest resistance to the commonly used pesticides. As pesticide use increased so did environmental and health problems. Rola and Pingali (1993) found that the health costs of pesticide use in rice reached the point where they more than offset the economic benefits from pest control.

#### **Efforts to Achieve Environmental Sustainability**

A growing awareness of these environmental problems has led a few Green Revolution critics to argue for a drastic reversal to the traditional technologies that dominated Asia before the Green Revolution (Shiva 1991; Nellithanam et al.1998). Such authors claim that yield growth rates were already high before the Green Revolution, but ignore the fact that this was largely the result of the spread of irrigation and fertilizers prior to the introduction of high-yielding varieties (Evenson et al. 1999).

More generally, environmental concerns have led to a significant research response and a wider array of more sustainable technologies and farming practices. Some of these have been spearheaded by environmentally oriented NGOs who have contested the Green Revolution approach and undertaken research and extension activities of their own. Others have been developed by the national and

international R&D systems for improving water, pest, and soil fertility management within intensive Green Revolution systems.

One of the outcomes of greater NGO involvement has been a lively debate about competing farming paradigms, and 'alternative' farming<sup>3</sup> has been offered as a more sustainable and environmentally friendly alternative to the modern input-based approach associated with the Green Revolution. The alternative farming approach includes extremes that eschew use of any modern inputs as a matter of principle (for example, organic farming), but also includes more eclectic whole-farming systems approaches such as low external input farming (Tripp 2006) and eco-agriculture (McNeely and Scherr 2003). Pretty (2008) provides a useful review of these approaches.

#### Alternative Farming

While the alternative farming literature provides many successful examples of agricultural intensification, most of these have arisen in rainfed farming systems that largely missed out on the Green Revolution. But by 'sleight of aggregation,' proponents of alternative agriculture frequently mix these kinds of successes with much more modest results obtained in Green Revolution areas, giving the impression that productivity levels can be increased significantly across the board by switching to alternative farming approaches. In fact, most alternative farming approaches cannot match the high productivity levels achieved by modern farming methods in Green Revolution areas. Pretty et al. (2007) in a revisit of Pretty et al. (2003) examined yield claims for 286 sustainable agriculture projects disaggregated into eight farming systems categories developed by Dixon et al. (2001) and showed that the more sizeable gains nearly all arose within rainfed farming systems. Moreover, the gains reported for rice and wheat yields, the main Green Revolution crops, were modest, sometimes even negative.

Badgley et al. (2007) also reviewed a large number of published studies comparing organic and conventional crops. Although they claim organically grown grains in developing countries have an average yield advantage of 57 percent, the more detailed results in their Table A1 tell a more nuanced story. Organically grown rice and wheat under irrigated conditions in Asian countries showed little if any yield gain, including when grown using the much publicized System of Rice Intensification (SRI)<sup>4</sup>. The best organic farming yield gains for Asia were obtained on upland rice and for maize, sorghum, and millets grown under rainfed conditions. These are areas where the conventionally grown crops usually receive limited nutrient inputs of any kind and hence have low yields.

## Improved Soil Nutrient Management

More eclectic approaches to making intensive Green Revolution farming sustainable seek to increase the efficiency of fertilizer use rather than displace it, thereby reducing production costs and environmental problems. Fertilizer efficiency can be improved through more precise matching of nutrients with plant needs during the growing season, and by switching to improved fertilizers such as controlled release fertilizers and deep placement technologies.

Site-specific nutrient management (SSNM) was developed by the International Rice Research Institute and its partners as a way of reducing fertilizer use, raising yields, and avoiding nitrate runoff and green house gas emissions (especially nitrous oxide) from intensive rice paddies (Pampolina et al.2007). Developed in the mid-1990s, SSNM is a form of precision farming that aims to apply nutrients at optimal rates and times—taking account of other sources of nutrients in the field and the stage of plant growth—to achieve high rice yields and high efficiency of nutrient use by the crop. Farmers apply N several times over the growing period and use leaf color charts to determine how much N to apply at different stages. SSNM has been tested through on-farm trials in several Asian countries and the institute has developed practical manuals and a web site (www.irri.org/irrc/ssnm) to guide application.

<sup>&</sup>lt;sup>3</sup> Sometimes also called "sustainable" or "ecological" farming.

<sup>&</sup>lt;sup>4</sup> For details, see, the web site (http://ciifad.cornell.edu/sri) run by the International Institute for Food, Agriculture and Development (IIFAD) at Cornell University. McDonald et al. (2006) provides a recent review of the evidence on the impact of system of rice intensification.

The International Fertilizer Development Center has pioneered a urea deep placement (UDP) technology in rice. This involves the deep placement of urea in the form of super granules or small briquettes into puddled soil shortly after transplanting the rice (Bowen et al.2005). The method improves nitrogen use-efficiency by keeping most of the urea N in the soil close to the plant roots and out of the floodwater where it is susceptible to loss. On-farm trials in Bangladesh that compared UDP with standard urea broadcasting practices showed 50 to 60 percent savings in urea use and yield increases of about 1 ton per ha (Bowen et al.2005). The briquettes are also simple to make with small pressing machines, and can create additional local employment.

#### Low or Zero Tillage

In response to the declining growth in productivity of the rice—wheat farming system in the Indo-Gangetic Plain, zero tillage has been adapted and introduced by the Rice—Wheat Consortium, a partnership of CGIAR centers and the National Agricultural Research System from Bangladesh, India, Nepal, and Pakistan. The technology involves the direct planting of wheat after rice without any land preparation. Rice crop residues from the previous season are left on the ground as mulch. The wheat seed is typically inserted together with small amounts of fertilizer into slits made with a special tractor-drawn seed drill. The technology has many claimed advantages over conventional tillage in the rice—wheat system: it saves labor, fertilizer and energy, minimizes planting delays between crops, conserves soil, reduces irrigation water needs, increases tolerance to drought, and reduces greenhouse gas emissions (Erenstein et al. 2007; World Bank 2007). But it often requires some use of herbicides for general weed control. A key ingredient for its success has been the development of an appropriate seed drill for local conditions in the Indo-Gangetic Plain.

## Improved Water Management

Improved water management in Asian agriculture is essential for redressing growing water scarcities, improving water quality, and halting the degradation of additional irrigated land. This will require significant and complementary changes in policies, institutions, and water management technologies.

Technical research has shown the potential to increase yields in irrigated farming with substantial savings in water use (Mondal et al. 1993; Guerra et al. 1998). Realizing these gains is easiest when farmers have direct control over their water supplies, as with tubewell irrigation or small-scale farmer managed irrigation schemes. For larger schemes the best hope lies in the devolution of water management to local water user groups or associations.

## Integrated Pest Management

As problems with the use of pesticides began to emerge, researchers gave greater attention to the development of crop varieties that have good resistance to important pests and biological and ecological pest control methods. This led to the development of integrated pest management (IPM), an approach that integrates pest-resistant varieties, natural control mechanisms, and the judicious use of some pesticides (Waibel 1999).

Bangladesh has been in the forefront of IPM since 1981, and the government, with assistance from the Food and Agriculture Organization has aggressively promoted the approach through farmers' training schools. Sabur and Molla (2001) undertook a farm survey in 1997–1998 and found that IPM farmers used less than half the amount of pesticides on rice as non-IPM farmers and had significantly higher gross income per hectare. Similar results were obtained by Susmita et al. (2007) and by Rasul and Thapa (2003). Both studies found that IPM farmers saved significantly on costs (labor and pesticides). None of the studies report any significant productivity impact from use or IPM, so the main economic benefits arise from lower costs. Farmers perceived fewer health problems with IPM in all three studies, though neither Susmita et al. (2007) or Rasul and Thapa (2003) could find statistical differences between

the perceptions of adopting and non-adopting farmers. None of the studies provides any data on environmental impacts.

Despite the development of more sustainable technologies and farming practices for Asia's Green Revolution areas, their uptake and spread remains inadequate. There are several possible reasons for this, including high levels of knowledge required for their practice, perverse incentives caused by input subsidies, labor constraints, and insecure property rights, difficulties of organizing collective action, and externality problems. These constraints require more calibrated policy responses, and developing these remains a major challenge for the future management of the Green Revolution areas.

#### 5. LESSONS

Several general lessons can be drawn from this study of the Asian Green Revolution. First, technological barriers to expanded food production among small and large farmers in developing countries can be alleviated and at a cost that is far less than the resulting gains in growth and poverty reduction. Second, Green Revolutions do not just happen, but require considerable and sustained nurturing by the state. Third, Green Revolutions are not necessarily pro-poor or environmentally benign, and achieving favorable outcomes requires appropriate and supporting government policies. We discuss each in turn and then consider the implications for realizing a comparable Green Revolution in Africa.

## **Technological Barriers to Food Production Can Be Overcome**

Asia was able to break out of its food production constraint by bringing the force of the 20<sup>th</sup> century scientific revolution in agriculture to its farmers. Governments and their international partners invested heavily in agricultural R&D, extension, irrigation, and fertilizer supplies and farmers made major changes to their traditional and well honed farming systems. The switch from low-input, low-output farming to high-input, high-output farming was not without its problems, but it sufficed to provide the needed productivity breakthroughs that had otherwise failed to materialize.

The initial Green Revolution technology package worked best for wheat and rice in the best irrigated areas, but within 10 to 15 years the technologies had evolved to accommodate the challenges of many poorer regions growing a wider range of food crops under rainfed or less assured irrigation conditions. Continuing advances in the agricultural sciences have increased the range of areas that can benefit from Green Revolution technologies, and often the major bottleneck to their uptake lies with public policies and investments rather than lack of suitable technologies.

## **Making Green Revolutions Happen**

Market forces alone are insufficient for launching green revolutions in poor developing countries where market chains for food staples are typically characterized by numerous failures and coordination problems (Dorward, Kidd and Poulton 1998). More than a single technology fix, a set of policy initiatives and preconditions came together in Asia to create an enabling and sustained economic environment that ensured all sized farms could participate in a fully functional market chain for food staples. These included access to a game changing technology package; threshold levels of infrastructure and market and institutional development; and an enabling policy environment.

#### The Pre-Conditions Needed for a Green Revolution

If farmers are to adopt Green Revolution technologies, they need access to a package of affordable inputs (fertilizer, improved seed, pesticides and irrigation water), seasonal credit to buy them each season, extension to provide the knowledge to use them, and assured access to markets at profitable and stable prices. A Green Revolution only takes off if all these things come together in an integrated way and under conditions that enable significant productivity gains. Achieving these pre-conditions requires critical accumulated levels of investment in agricultural R&D, extension, roads, irrigation, power and other infrastructure, as well as effective public and private institutions that serve agriculture. In Asia, these things were built up over several decades in an integrated way—guided by national agricultural development plans—and were already advanced prior to the Green Revolution.

#### An Enabling Economic Environment

Although many Asian countries initially discriminated against agriculture in their macro, taxation, and industrial sector policies (Krueger, Schiff and Valdés 1991)<sup>5</sup>, they offset many of these biases with subsidies on key inputs like fertilizers, water, and power, by shoring up farm credit systems, and intervening in markets to ensure farmers received fair and stable prices. The net result was to ensure the Green Revolution technologies were profitable for farmers. Moreover, although the Asian Green Revolution was initiated and led by governments, the private sector was given an important mediating role and this helped reduce marketing inefficiencies and corruption.

#### Sustained Investment and Support

Asian countries not only invested heavily to launch the Green Revolution, but continued to invest in agriculture to sustain the gains that were achieved. On average, Asian countries were spending over 15 percent of their total government spending on agriculture by 1972 and they doubled the real value of their agricultural expenditure by 1985 (Table 3). The need to sustain investment levels is especially true of agricultural R&D, since there are long lead times in developing new products and farmers continually need new crop varieties and natural resource management practices to stay ahead of evolving pest and environmental problems.

The investments made by Asian governments were driven by concerns about food insecurity and poverty, and they made impressive contributions towards overcoming those problems. But they also paid off handsomely in terms of their economic rates of return. Even input subsidies generated favorable benefit—cost ratios in the early years as they helped kick start fledgling markets. A key lesson is that a wide range of investments are needed to launch a Green Revolution, but that the mix of expenditures needs to be adjusted as a Green Revolution matures. For input subsidies, this means having an adequate exit strategy from an early stage.

## **Making Green Revolutions Pro Poor**

Green Revolutions need to be small farm led to be pro-poor, but this does not automatically happen without supportive government policies. In Asia, the conditions under which the Green Revolution proved pro-poor included: a) a scale-neutral technology package that could be profitably adopted on farms of all sizes; b) an equitable distribution of land with secure ownership or tenancy rights; c) modern input and credit systems that served small farms at prices they could afford; d) public extension systems that prioritized small farms, and e) product markets and price support policies that ensured small farms received stable and profitable prices. Meeting these requirements typically required proactive efforts by governments in the form of land reforms, small farm development programs, and input and credit subsidies. Not all Asian countries were successful in meeting these conditions, particularly those that began with inequitable land distributions.

## Making Green Revolutions Environmentally Sustainable

The Green Revolution made important environmental contributions by saving large areas of forest and woodland areas from conversion to agriculture. But it also generated some environmental problems of its own, imposing high off-site externality costs on populations at large and undermining the long term sustainability of some intensive farming systems. Inappropriate management of modern inputs by farmers was the primary cause, and the problem was exacerbated by inadequate extension and training, ineffective regulation of water quality, and input pricing and subsidy policies that made modern inputs too cheap and encouraged excessive use.

<sup>&</sup>lt;sup>5</sup> The worst of these biases were removed in the late 1980s and early 1990s as part of structural adjustment programs, but they prevailed during the early GR era.

Policy and institutional reforms that correct inappropriate incentives can make an important difference. Improved technologies, such as precision farming, integrated pest management, and improved water management practices can even increase yields while reducing chemical use, implying that intensification does not have to be inconsistent with good management of the environment. Farmers have been slow to switch to these kinds of improved practices. There are several possible reasons for this, including high levels of knowledge required for their practice, perverse incentives caused by input subsidies, labor constraints, insecure property rights, difficulties of organizing collective action, and externality problems. These constraints require more calibrated policy responses, and developing these remains a major challenge for the future management of the Green Revolution areas.

## Implications for Achieving an African Green Revolution Today

The Green Revolution was not confined to Asia and successfully spread to large parts of Latin America, the Middle East, and North Africa. But despite several attempts to bring the Green Revolution to Africa, it has not yet happened at the scale that is needed. Moreover, many promising starts failed to sustain over time. The experience with hybrid maize in Eastern and Southern Africa is salutary. Initial success was based on the Asian model with improved varieties that originated from regional plant breeding efforts, subsidized inputs, and grain marketing boards that bought up maize at guaranteed minimum prices. But inefficient and corrupt marketing boards, escalating fiscal costs that could not be sustained, and soil degradation due to specialized maize cultivation on fragile lands led to eventual collapse of the system (Smale and Jayne 2003).

By missing out on the Green Revolution, average cereal yields in Africa have changed little since 1960 while those in Asia and other developing regions have nearly tripled (Figure 1). This has been a major factor underlying the trend decline in per capita food availability in Africa, and for worsening poverty and malnutrition (World Bank 2007).

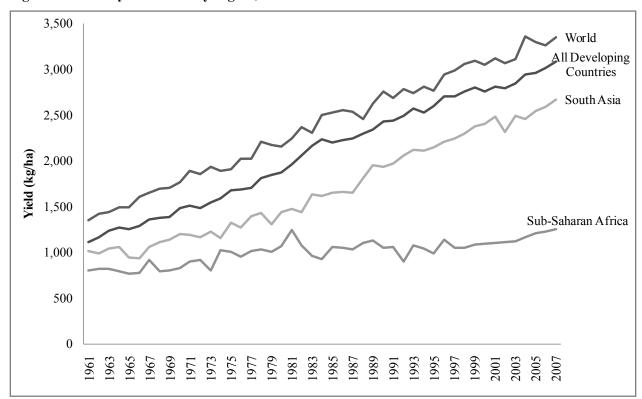


Figure 1. Cereal yield trends by region, 1961–2007

Source: FAOSTAT 2009 (data goes from 1961 to 2007 for all regions included)

Why has the Green Revolution failed in Africa? An important reason is the nature of Africa's farming systems. Irrigation and rice and wheat play much smaller roles in Africa than Asia, hence Africa simply could not benefit much from the first round of Green Revolution technologies and had to wait for improvements in crops like maize, sorghum, millets, and cassava grown under rainfed conditions. But even then, the scale of success with second -round technologies has been disappointing.

A more fundamental problem is that Africa has invested relatively little in developing its rural infrastructure, leading to unusually high transport and marketing costs for African farmers<sup>6</sup>. Import prices for fertilizer are also high because many African countries are landlocked and buy insufficiently large amounts of fertilizer to secure good price discounts (Morris et al.2007). The net result is that it is simply not profitable for most African farmers to shift to high-input, high-output farming systems. Many African governments initially attempted to offset these high costs with hefty input subsidies, but given the severe nature of the underlying structural problems, the fiscal burden proved too great to sustain and the subsidies had to be withdrawn as part of the Structural Adjustment Programs orchestrated by International Monetary Fund and World Bank in the 1990s.

A related problem has been the lack of government and donor commitment to agricultural development in Africa. Whereas Asian governments took the lead in driving their national green revolutions and implemented supporting policies and investments with widespread donor support, African governments have lagged far behind. On average, public spending on agriculture as a share of total government spending has been consistently low at 5 to 6 percent in Africa for over 40 years, whereas Asian countries spent 15 percent or more of their total budget on agriculture during the Green Revolution era (Fan and Rao 2003). Donor support for African agriculture also fell sharply after the 1980s. Low and declining investment in African agriculture has weakened already low levels of rural infrastructure, stifled agricultural research and the generation of new technologies for African farmers, and reduced public services in rural areas to the point where there has been widespread migration to low-paying jobs in the cities. Low investment has also eroded civil service salaries and anemic recurrent budgets have immobilized extension and research staff, diminished staff incentives, and fueled an exodus of senior scientists from public research institutions (Pardey, Rosebom and Beintma1995; InterAcademy Council 2004).

African governments have also been far less effective in creating a supportive policy environment for their farmers. Prior to the Structural Adjustment Programs and agricultural market liberalization programs of the 1990s, macro, trade, and taxation policies worked heavily against the agricultural sector (Krueger, Schiff and Valdés 1991). Marketing parastatals that were often corrupt and inefficient also controlled farmers' access to modern inputs and markets. The worst of these biases were removed as part of the Structural Adjustment Programs, but the private sector has yet to play an adequate role in Africa's market chains for food staples. Moreover, African farmers must compete with low-cost food imports from countries whose farmers do not share these disadvantages, and whose exports are often subsidized. In this policy environment, it is hardly surprising that Africa's farmers have not taken up Green Revolution technologies.

Yet, Africa badly needs a Green Revolution, as amply demonstrated by the food shortages brought about by the recent world food crisis. Many experts agree that Africa has the biophysical potential to dramatically increase cereal production. Moreover, as small farms dominate the continent, the promise remains for a Green Revolution led by small farms that could prove a win—win proposition for growth and poverty alleviation, much as occurred in Asia during the Green Revolution. Africa is also less likely to be exposed to the same kind of environmental problems that arose in the Asian Green Revolution because of the inherent diversity of its farming systems, limited large scale irrigation potential, and the relatively high cost of modern inputs. There is also great scope for Africa to learn from

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<sup>&</sup>lt;sup>6</sup> Africa still has less infrastructure today than Asia had at the beginning of its Green Revolution. The road density in mainland Africa from 2000to 2005 ranged from 3–4km/1000 square km in Ethiopia and Mali to 50–70km/1000 square km in Namibia and Botswana (World Bank 2008). In contrast, India's average road density at the start of the Green Revolution was 388km/1000 square km (Spencer 1994).

Asia and leapfrog directly to policies, technologies, and management practices that are more environmentally benign. The question remains: How can Africa realize its Green Revolution potential?

As Africa's past experience demonstrates, simply copying the Asian Green Revolution model is not enough. While a successful Green Revolution must be built around rapid increases in the use of improved seeds, fertilizer, and water, Africa's relatively low irrigation potential, diverse rainfed farming systems, and degraded soils mean that these must be developed and promoted in flexible ways that enable farmers to combine and adapt them to local conditions (InterAcademy Council 2004). They must also be supplied in cost effective ways that are socially profitable and do not bankrupt the state through massive input subsidies or unrealistic price supports. Farmers also need access to assured market outlets at competitive prices and reasonable assurance of stable (at least on the down side) prices.

As in Asia, the state will need to play a leading role, developing and coordinating national Green Revolution strategies that ensure farmers have affordable and sustained access to critical packages of key inputs, credit, and marketing services and not just access to some components some of the time (Dorward et al.2004). But this state role will have to be managed within a very different institutional landscape than existed in early Green Revolution Asia. At local levels, communities and extended family networks still play important roles in Africa, controlling access and rights to land and water and providing indigenous safety nets that are important for risk management and the poor. At meso and macro levels, the public institutions that serve African agriculture are much weaker and more disempowered than their Asian Green Revolution predecessors. On the other hand, NGOs, community-based organizations, and some types of private firms have grown to play important roles, larger than was the case in Asia at a comparable stage of development. In this context, rather than following the kind of top down role that worked in Green Revolution Asia, African countries will need to take a more flexible and opportunistic approach that builds strategic partnerships between key actors at local, meso, and macro levels.

All the above will need to be launched with existing low levels of rural infrastructure, market access, and public expenditure that cannot be changed quickly. This will require that the Green Revolution initially be launched in priority "bread basket" areas with good existing infrastructure and market access. Moreover, unlike pre-Green Revolution Asia, the policy support for a small-farm led Green Revolution in Africa remains uncertain. Although national policy makers and donors have made several recent declarations to the contrary (for example, by African Heads of State at Maputo 2003 and G8 Heads of State at Glen Eagles 2006 and at L'Aquila 2009), levels of public and donor spending on agriculture remain too low and there is widespread belief in some quarters about the superiority of large-scale farming. There is still a dearth of national or regional champions for a Green Revolution led by small farms in Africa. Two promising Africa-led initiatives that may yet catalyze the development of the continent's Green Revolution potential are the Alliance for a Green Revolution in Africa and the Comprehensive African Agricultural Development Program of the New Economic Partnership for Africa. But if they are to succeed in mobilizing significant political support and funding for a Green Revolution they will need to demonstrate early and significant successes.

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