# More Food, But Not Yet Enough:
# 20th Century Successes in Agriculture Growth and 21st Century Challenges

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May 2008

**Food Policy and Applied Nutrition Program**
**Discussion Paper No. 38**



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"A hungering world is facing an imminent shortage of food." (Tufty 1966)

"The threat of hunger and malnutrition is growing. Millions of the world's most vulnerable people are at risk."(United Nations Secretary-General, Ban Ki-Moon April 2008)

## Introduction

In early March 2008, global wheat prices leaped 25 percent in a single day; in the following month the price of rice rose 50 percent in just two weeks. These price 'shocks' were a wake-up call for analysts and consumers alike who had failed to appreciate the severity of growing pressures on world grain supplies. Constraints on cereal stocks, in a context of rising demand, pushed up the cereal prices, but also those of dairy products, cooking oils and pulses, with impacts felt through higher food import bills for food-deficit countries, higher prices of wheat products (bread, pasta, breakfast cereals), and higher prices of coarse grains as consumers shifted to cheaper commodities (such as maize, sorghum, and millet). FAO's *all food* price index rose on average 9 percent during 2006 (over the previous year), and increased again by more 23 percent in 2007 (FAO 2008). By December 2007, the index averaged 184--the highest recorded monthly average since established in 1990. Global wheat stocks were projected to shrink during 2008 to only 147 million tonnes, putting world wheat reserves at their lowest level since 1983, contributing to one of the lowest levels of overall grain storage since the 1970s (FAO 2008b).

The irony is that while several short-term factors contributed to the price hikes (including several years of drought in major exporting countries like Australia in 2005/06, and shifts in grain use associated with policy support for biofuel production), a key structural cause was strong and growing demand for food in developing countries that were until quite recently famine-prone. Increased demand for food in countries like India, China, Korea, Vietnam, Brazil, and Nigeria did not, in the early 2000s, reflect a failure of their own agriculture sector, but rather longer-term agricultural success. Growth in their agricultural sectors between 1970 and 2000 contributed to rapid poverty reduction, which in turn increased effective demand for food—much of which has now to be imported. Former recipients of food aid, many such countries began to export food while simultaneously being big food importers. Some, like India, China and Korea, have become food aid donors. In other words, the success of agriculture in some developing countries over the past half century is one of the factors in higher, rather than lower, food prices worldwide.

This chapter considers how it is that rapid growth in developing country food production came about in the 20th century, and what its implications are for future trends. How did rising yields in key grains lead to both high consumption domestically and higher food imports? What are the implications of such success in agricultural growth in poor countries where current and future food prices are concerned? The first section presents an overview of the issues relating to global food production and demand, trends. The second section considers the lead up to the adoption of high yielding cereal varieties in developing countries, focusing on US productivity gains in the

[1] Thanks go to Dr. Willie Lockeretz and Sen. Dr. Herman Eiselen for constructive comments on an earlier draft. All remaining errors are, of course, the author's.

first half of the 20th century. A third section elaborates on the Green (originally called the Wheat) Revolution and its gains from 1965 onwards. A fourth section considers what the successes in output did not achieve. Conclusions and remarks on future challenges are offered in the final section.

**Banishing the Specter of Famine…but not of Hunger**

Agriculture has a natural history of boom and bust. Since the domestication of plants for human consumption years of plenty have been tempered by years of scarcity, periods of productivity growth have accelerated only to be reversed. The 20th century was no exception. There were large, crippling famines in each decade of the 20th century: China around the turn of the century, Germany (1916-19), Russia (1920s), Ukraine (1930s), Bengal, China, Greece (1940s), China (1950s), Bangladesh, Biafra, Sahel (1960s and 1970s), Ethiopia and the Sahel (1980s), North Korea, Somalia, Sudan (1990s). The death toll from all of the 20th Century's famines has been estimated at more than 70 million, these people dying in the context of some 30 major multi-year events (Devereux 2001).

Some of those famines were linked to natural disasters and other environmental hazards, including drought across the entire African Sahel in the early 1970s. In most cases, however, failures of policy and governance (including armed conflicts), and social and economic stagnation carry most of the blame (Webb 2005). For example, while floods triggered what became the 20th century's last 'great' famine in North Korea (1993-1999), it was a lack of governance (distorted market policies, restrictions on private activity and movement, political repression), linked with a lack of investment in farm productivity over the long term, that underpinned a humanitarian catastrophe that was hidden from the world until it was too late to save an estimated 3 million people from death (Webb and Thorne-Lyman 2007).

Since the mid-1990s, a sea-change has occurred in the way that national governments and the international community deal with political, economic or conflict-based disasters. Ethnic-based genocide has not yet disappeared (as in Rwanda, Bosnia or Darfur), clan-based atrocities continue (as in Somalia and East Timor), military and/or militia clashes over contested resources persist (as in Burundi, West Bank/Gaza and Haiti)—yet, deaths in the context of humanitarian upheaval have been falling (Salama et. al. 2004), and the number of emergencies that can be labeled as outright 'famine' has dwindled. Improvements can be attributed to improvements in early warning systems, growing effectiveness of humanitarian response, professionalization of relief organizations, enhanced coordination across multiple actors in emergency response, and global recognition of the moral imperative to act in times of crisis to save lives—such as Resolution 1674, adopted by the Security Council in April 2006, which endorses the principle of a "responsibility to protect"--a formulation of the right of humanitarian intervention developed by a U.N. commission (ICISS 2001) and proposed to the General Assembly by Kofi Annan, then Secretary-General, as a central platform of his UN reform package.

However, there is no equivalent requirement for action against a chronic lack of food consumption (commonly called 'hunger'). While a 'right' to be free of hunger has been on the global statute books since 1966 (in the context of the International Covenant on Economic, Social and Cultural Rights), that has not been matched by defined responsibilities to act. The 2008 call by the World Bank's chief for "a New Deal for global food policy" reflects, at least in part, the absence of global statues and duty-bearers in this particular domain (Zoellick 2008). This is critical because, on the one hand, chronic undernutrition remains not only a major problem worldwide, but a serious constraint to socioeconomic development. As the Hunger Task Force of the Millennium Project put it, “those suffering from…acute hunger represent only a small part—roughly 10 percent—of the world’s hunger. Most of the hunger, approximately 90 percent, are chronically undernourished.“ (HTF 2005) On the other hand, it is crucial to resolve the chronic problem of hunger, not only the acute conditions reflected in famines. Nobel prize-winner Robert Fogel demonstrated that while preventing mortality in the context of famines has been important to enhancing life expectancy in countries with low energy consumption levels, a far greater contribution to reduced mortality levels over time has come from tackling chronic dietary deficiencies (Fogel 1994; see also Post 1974).

Tables 1 and 2 together highlight three critically important facts. The first is that the share of undernourished people in the world has fallen significantly—the success story of global agriculture that we shall deal with in more depth in the following sections. There is no question that more cereals were produced annually in the last quarter of the 20th century than in any other period in human history. As a result, the proportion of chronically undernourished people [a country-specific measure of food sufficiency based on commodity balance sheets, population needs, and distributional parameters relating to food access] was reduced by half since 1969-1971, the earliest period for which reliable estimates are available (FAO 2007).

The second is that progress has been uneven. The greatest gains were recorded in east Asia (including China), South Asia (which started from very high levels of undernutrition in both relative and absolute terms) and Latin America and the Caribbean. By contrast, the north Africa/near east (sometimes called West Asia) region remained largely unchanged, and sub-Saharan Africa trailed far behind. While Table 1 shows an estimate for 2015 of only 15 percent undernourished in Africa this appears to be wildly optimistic given that the numbers have been rising. Africa is the only continent in the world that has seen child malnutrition rise in the past decade, and it is rising in every sub-region of the continent (World Bank 2006).

The third (related) point is that past gains remain fragile. On one side, there is the stubbornly high level (even increase) in the number of undernourished, which relates in part to population growth staying ahead of poverty reduction, and in part to reduced mortality which (ironically) leaves more people alive but still food insecure. Low productivity agriculture in Africa, poor market integration in many other parts of the developing world, and eroding purchasing power for net food-importing countries across north Africa and west Asia suggest that the numbers will not fall in the near future. Indeed, projections to 2030 suggest that around half a billion people will still be undernourished, with the social and economic consequences that this would entail.

But it cannot even be assumed that the number will be that *low*. There has been success in poverty reduction across the developing world, and this has translated into growth in effective demand (higher purchasing power) among increasingly urban, increasingly selective consumers from China and India to Brazil and South Africa. Higher income brings with it changes in dietary patterns combined with higher demand for food products. The result in recent years has been higher food prices which in turn push more poor people into the category of consumers unable to meet daily food needs—hence more undernourished people.

**Table 1: Share of global population chronically undernourished**[2]

| | 1969-71 | 1979-81 | 1990-92 | 1997-99 | 2001-03 | 2015[3] (Est.) |
|---|---|---|---|---|---|---|
| | | | (Percentage) | | | |
| Developing World | 37 | 29 | 20 | 18 | 17 | 11 |
| East Asia | 43 | 28 | 16 | 11 | 12 | 6 |
| S Asia | 37 | 37 | 26 | 23 | 22 | 12 |
| LatAm | 20 | 13 | 13 | 11 | 10 | 8 |
| N Africa/Near East | 23 | 9 | 8 | 4 | 9 | 7 |
| SSAfrica | 36 | 37 | 36 | 34 | 33 | 15 |

Source: FAOSTAT data; FAO 2005;

**Table 2: Numbers of people chronically undernourished**

| | 1969-71 | 1979-81 | 1990-92 | 1997-99 | 2001-03 | 2015[4] (Est.) |
|---|---|---|---|---|---|---|
| | | | (millions) | | | |
| Developing World | 961 | 925 | 823 | 791 | 820 | 610 |
| East Asia | 504 | 401 | 199 | 193 | 160 | 135 |
| S Asia | 265 | 329 | 291 | 303 | 299 | 203 |
| LatAm | 55 | 46 | 59 | 54 | 52 | 41 |
| N Africa/Near East | 42 | 20 | 25 | 32 | 39 | 36 |
| SSAfrica | 93 | 128 | 169 | 186 | 203 | 205 |

Source: FAOSTAT data; FAO 2007; FAO 2005; MoEJ 1994.

[2] It should be understood that trends in undernutrition are difficult to standardize due to shifting methodologies over time, changes in the way that regional composites are defined, and on-going backward corrections of data. In other words, FAO's own data and estimations are always subject to update.
[3] Projections from FAO 2006 and 2005.
[4] Projections from FAO 2006 and 2005.

At the same time, there are concerns that the future demand for food will be increasingly hard to meet on the supply side. An additional billion tonnes of cereals will be needed to meet projected demand by 2030 (FAO 2002). Developing country production is not expected to keep pace with growth in demand, such that by 2030 they could be producing only 86 percent of their own cereal consumption, with net imports rising from 103 million tonnes in 2000 to some 265 million tonnes by 2030. But to keep imports to manageable levels (especially given the damage done by global price shocks), developing countries will still have to invest much more in their own agriculture. Indeed, almost 70 percent of the increase in crop production in developing countries will need to come from higher yields (FAO 2002).

Thus, the story of agriculture since the middle of the 20th century has two sub-plots: on the one hand, it is a story of success. No less than a revolution in agronomic technology and practices that allowed the world to reduce hunger by half over a period of 4 decades. On the other hand, it is a story of insufficiency. Too many people continue to live with hunger at the start of the 21st century--an unalloyed human tragedy—and it is unclear if the world has made the appropriate investments to meet the continued challenge of further demand growth in the coming 4 decades. The following sections explore these two subplots in more detail.

**The Seeds of Revolution: 1900-1960**

References to the 'Green Revolution' typically focus on the period around 1965 when dramatic shifts occurred in the yield potential of seeds adapted to tropical climates and in their uptake in countries like India, the Philippines, and Mexico. But, the story has its origins before that period. There were two main periods of 20th century productivity growth that laid the foundations for the Green Revolution, the late 1920s/30s and the mid 1940s/early 50s.

Crop yields worldwide had stagnated around the turn of the 20th century. In the United States, wheat yields were only 1.7 percent higher in 1909 than they had been a decade earlier (NYT 1914), and prices were rising globally as demand increased, leading the New York Times to remark that "food costs are increasing and subsistence pressure is ever becoming greater." (NYT 1915) There were many contributors to this early 'food crisis', including crop failures, growing effective demand, commodity speculation, inflation, trade constraints in the form of steep tariffs, and other market constraints (NYT 1910).[5] However, an important constraint on the input side was the shortage of nitrogen for fertilizers. Wheat yields in the US had fluctuated between 1,000 and 1,700 lbs/ac since the late 1800s (Smith 1995), while in Great Britain they were no higher in 1930 than they had been in 1850 (Buringh 1985). The same was true for maize, in that the average US maize yield in 1935 was no higher than it had been in 1866.[6]

Two things were already understood at the time: first, that supply gains would have to be built on productivity enhancement. As Emerick (1900) argued, increasing cereal consumption "will have to be met by enlarging the yield per acre, rather than by an extension of… growing areas." Second, yield increase would need to be made through breakthroughs in agricultural technology and techniques. New forms of fertilizer, new seeds, and new forms of credit would all play a role in increasing US farm productivity and output in the 1930s.

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[5] All of these same factors also played a role in the 2008 food price escalation.

[6] The average yield of maize in both 1866 and 1935 was 24 bushels per acre (for maize 1bu/ac equals 62.7 kg/ha). But by 1990 this had climbed to 118 bu/ac (Smith 1995).

Through the first two decades of the 1900s farmers in the US and Europe suffered a lack of access to nitrates. Land reserves in Europe and the US were depleted and all attention was focused on large saltpeter deposits in Chile. In 1914, nitrates represented by far the largest volume of commodities shipped through the Panama canal in either direction, and nitrates were still among the top three commodities shipped in the mid-1920s (Mason and Rowlands 1938).[7] There were also credit constraints for farmers wanting to purchase improved inputs, to the extent that in 1919, the War Department of the US worked with the Agriculture Department to distribute 150,000 tons of nitrates from stocks that had been held for the production of high explosive shells (NYT 1919).

However, moves were afoot to synthesize nitrates in the laboratory. A widely-held view, stated by Darlington (1917), was that the world needed to make itself "independent of Chile for its nitrates—this is one of the things the great war has taught us. We must prepare for a large scale production of artificial nitrogen compounds, while will be used mainly for fertilizer in times of peace, and for explosives in times of war". Optimism ran high, such that one analyst, Sir William Crookes (1917), argued that "before we are in the grip of actual dearth, the chemist will step in and postpone the day of famine [by] the fixation of atmospheric nitrogen [in the soil]."

The 'chemists' who did step in were those who put the research of Nobel Prize-winning scientists into practice through what became known as the Haber–Bosch process—the industrial-scale interaction of nitrogen and hydrogen, passed over an iron catalyst, to produce ammonia. In 1927 this led to the production of *Nitrophoska*--a breakthrough composite fertilizer.[8] The concentration of nutrients was several times higher than in earlier multi-component fertilizers, and each grain of fertilizer had a homogeneous composition, unlike earlier composites which had problems when synthetic components from differing sources were mixed. (BASF 2008) The result was rapid uptake, causing global fertilizer consumption to triple from 1910 to 1938 (MoEJ 1994).

The rapid global increase in fertilizer consumption was driven by US and European farmers who benefitted, on the one hand, from various initiatives to improve agricultural extension and credit systems during the 1920 and 1930s, and by the availability of new seeds, on the other. Key advances in seed quality were made by L.T. Waldron in North Dakota in the 1920, where his CERES HRS wheat variety expanded rapidly, such that 5 million acres of this hybrid were planted by 1933.[9] As a result, in the inter-war period the US was already obtaining wheat yields that were significantly higher than in other grain exporting countries.[10]

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[7] Of course, since nitrates are a key ingredient of military munitions, as well as fertilizer, the advent of the first World War played a big role in increased demand.

[8] Its name included the most important plant nutrients: nitrogen, phosphate and potassium (*kalium* in German).

[9] Waldron was not the first researcher to make breakthroughs of course. He built on the work of A. E. Blount who worked in Colorado on wheat hybrids in the 1890s that were evaluated in Australia before being re-implanted in the US. Also important in releasing in new wheat cultivars was W. J. Spillman and E. F. Gaines working in Washington State at the turn of the century.

[10] The US average wheat yield around WWI was recorded as 1,140 lbs per acre, compared with Russia's yields in 1911-1915 of only 600 lbs/acre (Durand 1922).

What is more, by the 1940s roughly 100 percent of US farmland growing maize was under hybrid varieties.[11] It was hybrid maize that the US delivered to France in the late 1940s as part of the Marshall Plan. In the first year of aid (1948), 30 tonnes of seed were delivered and planted, achieving more than 5 tonnes per hectare instead of France's pre-war average of 1 tonne/ha. Its success led in 1950 to the delivery of 1,000 tonnes, which subsequently formed the basis of domestic breeding programmes by France's national agricultural research institute.

The US' successor to the Marshall Plan, the US Public Law 480 (the Agricultural Trade Development and Assistance Act, enacted in 1954), also played a role in distributing new varieties to producers as well as consumers. As large stocks of grain began to accrue in the US during the 1950s, the secretary of agriculture (Ezra Benson) spoke of "burdensome surpluses", which were expensive to store and in some cases contributing to depressed producer prices (McGovern 2001). Large amounts of grain were therefore distributed around the world with a view to promoting goodwill, supporting foreign policy priorities, and facilitating the opening of new markets for US grains. India was among the leading recipients of food aid in the world during the late 1950s and 1960s, most of it coming through the window of PL 480 donations.

In 1965, "all" the wheat that arrived in India through PL 480 was of a variety called Gaines, after E.F. Gaines (Swaminathan 1993). Gaines was a breakthrough variety. It was the first so-called semi-dwarf winter wheat suitable for commercial production, developed in Washington State and released in 1961. One of the parents (offering genetic material for) Gaines was a variety called Norin 10. Developed by G. Inazuka and S. Asanuma in 1935, Norin 10 seeds were forwarded to the US in 1946 by US researchers stationed in Japan during the US period of occupation. Norin 10 became a breeding parent for almost 100 new wheat cultivars because it had traits that led to short-statured (dwarf) plants that could be heavily fertilized for higher yields without collapsing, and had potential for good yields under both dryland conditions and under irrigation (Vogel 1977). It was the resultant new wheat breeds and their derivatives, including Gaines, that were taken up by Norman Borlaug at the International Maize and Wheat Improvement Center (CIMMYT) for adaptation to tropical conditions. Dr. M.S. Swaminathan (1993) read an article by Dr. O. Vogel in 1960 in the *American Journal of Agronomy* about the potential for breeding fertilizer responsive wheat varieties from Norin-10 material, including the Gaines variety. He contacted Dr Vogel with a request for samples of seeds, and was put in touch with Dr. Borlaug to obtain the right material (i.e. a spring rather than winter variant of the new wheat breed). Dr Borlaug sent those seeds, and the revolution had begun.

## "Everything else can wait but not agriculture." Jawaharlal Nehru, 1948[12]

The end of World War II ended neither war nor civil (intrastate) armed conflicts. But it did usher in a period of renewed attention to international public goods (the establishment of the United Nations), the importance of food to peace (the Marshall Plan, creation of new bilateral institutions to aid poor countries (including new mandates for KFW and USAID), and

[11] The Rockefeller Foundation, one of the main financial donors that underpinned agronomic research leading to the Green Revolution varieties in the 1960s, actually began its investments in agricultural research aimed at yield growth in 1942 (personal communication, Sir Gordon Conway, April 17, 2008).

[12] *Cit.* Swaminathan 1993, p. 1.

establishment of a ‘global ministry of agriculture’ in the form of the Food and Agriculture Organisation (FAO). It also focused national government attention on agriculture as an engine of economic growth and national stability. Countries like Japan, Germany, Italy and France invested heavily in the post-war years in agricultural ***re***construction, while many former colonies focused on agricultural development.

From 1965 to 2007, world cereal production more than doubled, rising from 1,006 million tons to 2,103 million tons. During the same period there was also a 106 percent rise in grain output in developing countries (MoEJ 1994). This monumental increase in output took place against a backdrop of an even more rapid escalation in the world’s population, rising from 2.5 billion in 1951 to around 6 billion in 2007. Importantly, much of productivity gain took place in developing countries where most of the increased demographic pressure was coming from.

The achievement of higher productivity in the developing world should not be ascribed to a single element. As in the US in the inter-war period, gains were made possible by a combination of improved seeds, application of new fertilizer (and pesticide) inputs, access to credit, investments in extension, and improved technologies in the realm of water control. According to the World Bank (2008) “Asia’s Green Revolution is a good example of how… technological advances can have a dramatic impact on development. Between 1970 and 1995, better agricultural technologies doubled Asia’s cereal production while increasing the land area devoted to growing cereal crops by just 4 percent. These technologies included pesticides, irrigation, synthetic nitrogen fertilizer, and development of high-yield varieties of maize, wheat, and rice. By the late 1990s it was clear that, on the positive side, poor people had benefited from higher incomes, cheaper food, and more demand for their labor.”

The core of the ‘package’ was new high-yielding seed. Average yields across developing countries in the 1960s were little more than 1 metric ton/ha. In India, for example, maize, wheat and rice yields in 1963/64 were 1.0, 0.8 and 1.0 tonne per hectare, respectively (Revelle 1966). This was at a time when maize yields in the US were already four times higher. Although India’s government had already in 1961 initiated the Intensive Agriculture District Programme (IADP) which sought to introduce a package of improved agronomic practices which included new approaches to irrigation, early results were disappointing due to a lack of seed that would respond appropriately to the application of higher levels of fertilizer under optimized water conditions. The search for higher-yielding cereals had been underway since the 1950s (with interaction among scientists across Asia, including China, Malaysia, India and the Phillipines), and the as crossing various *japonica* rice varieties with *indica* strains had already shown promise. But there were hurdles in that ‘tall’ varieties of wheat and rice with a potential to yield more tended were susceptible to lodging, and to falling over when fertilizer was applied.

Indian researchers searched extensively for genetic material that might help overcome such difficulties, leading to the contacts between Dr Swaminathan and Dr Borlaug. At the former’s invitation, Dr. Borlaug's visited India in March 1963 and travelled extensively in the wheat-growing areas in the Northern. Based on his observations, as well as the recorded performance of his wheat materials sent to Pakistan two years earlier, he sent a range of wheat seed material to India that were tested in multiple locations during 1963/64. Those early trials confirmed that semi-dwarf wheat varieties performed very well under conditions of good soil fertility and irrigation water management. According to Swaminathan (1993), "when small farmers, who with the help of scientists organized the National Demonstration Programme, harvested over five tonnes of wheat per hectare, its impact on the minds of other farmers was electric. The clamour for seeds began." The area under high yielding varieties of wheat rose from a demonstration plot of only 4 ha in 1963/64 to commercial production exceeding 4 million ha in 1971/72. As a result, wheat production in India jumped from 12 million tonnes in 1964 (the country's previous record output) to 17 million tones in 1968, to 50 million in 1990, and on to 74 million in 2006 (FAOSTAT).[13]

Looking backwards it is possible to locate the leap in developing country cereal yields around 1967 (see Figure 1). Average annual increase in cereal yields across south Asia between 1951 and 1963 had been a mere 0.9 percent--which was low even compared with West Africa during that same period, which had yield growth of 2.1 percent per annum (Revelle 1966). But between 1961 and 2000, average world cereal yields grew more than at any other time since humans have tended domesticated crops. Figure 2 shows the acceleration in yield growth globally from the late 1960s to around 1990. In India, for example, wheat yields grew almost 3.2 percent per annum between 1968 and 1990 (Swaminathan 1993).

Of course, as noted, it was a combination of the new seeds grown in optimal conditions with the application of pesticides, herbicides and fertilizer. Developing country use of fertilizer had lagged behind industrialized countries by more than 50 years…until around 1968. In 1960, developing country consumption was an almost invisible part of the world's 30 million tonnes used; yet by 1970, developing countries were accounting for roughly one third of global fertilizer consumption, rising to around one half by 1980 (MoEJ 1994). As shown in Table 3, by 2002/03 developing countries had overtaken the industrialized world (Hazell and Wood 2008).[14]

The result of this combined use of inputs was the large increase in food production referred to above. In 1950, global cereal output was 650 million tones; by 2007 it stood at 2.1 billion tonnes (FAO 2008b). In developing countries, from 1965 to 1990 there was a 106 percent rise in grain output, which represented an increase from roughly 560 kg per capita to over 660 kg per capita (MoEJ 1994). Of course uptake of the new practices and technologies was not uniform across developing countries. South and South-east Asia represented the hub of the Green Revolution advances, and Sub-Saharan Africa remained (and remains) far behind in terms of uptake and benefit. For example, Africa's consumption of fertilizer had remained largely unchanged over many decades (Table 3).

That said, food supply per capita in developing countries increased by 12 to 13 percent between 1960 and 1990 (rising between 0.5 and 1 percent per year per capita since the 1970s), while population nearly doubled. The amount of food energy available from all sources (worldwide) rose from 2,255 kilocalories per person per day (kcal/cap/day) in 1961 to around 2,800 kcal/cap/day in 1998; that level is expected to reach 3,015 kcal/cap/day by 2020 despite

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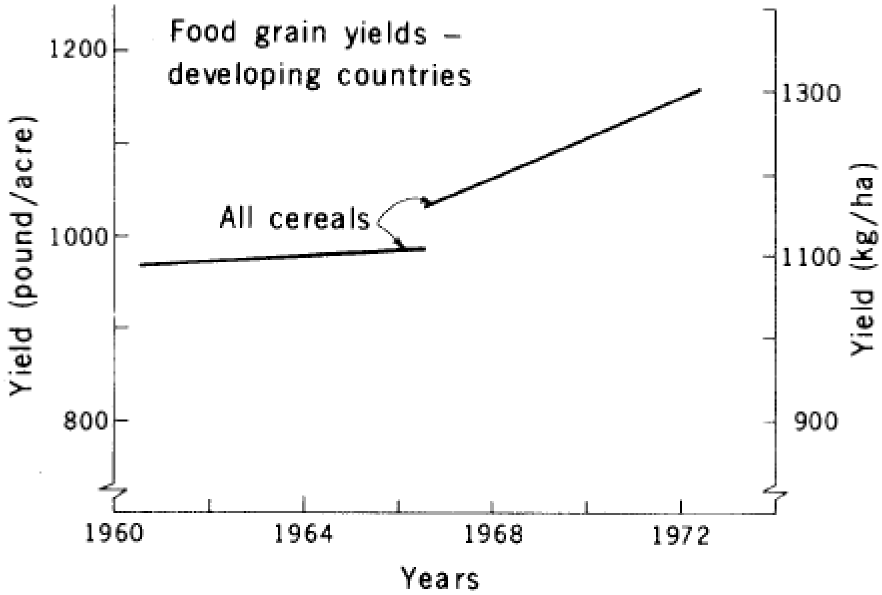
[13] As per the title of Swaminathan's (1993) book, the Green Revolution was originally known at the "Wheat Revolution". The term Green Revolution is attributed to former USAID director William Gaud, from a speech made in 1968.

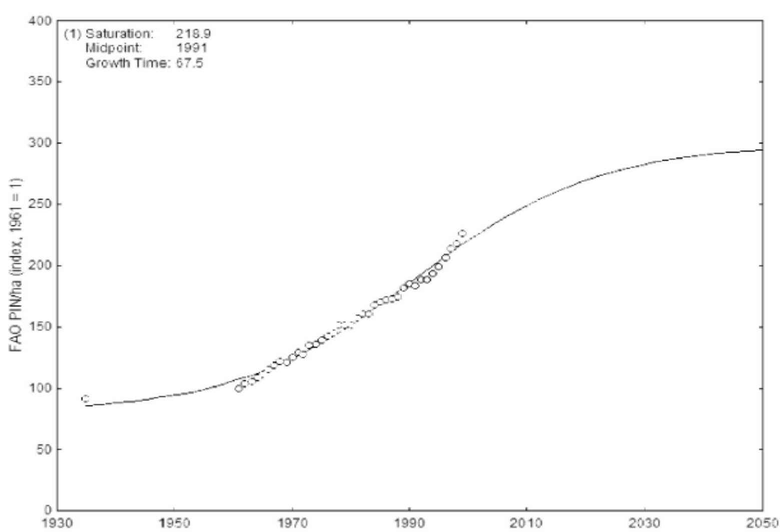
[14] Global consumption has continued to rise, such that it reached 160 million tonnes 2006/07 (Heffer and Prud'homme 2007).

**Figure 1: Slope of developing country grain yield trends derived from linear regression**




Source: Reproduced from Chancellor and Gross (1976)

**Figure 2: Index of world cereal yield growth (1961=100). 2000-2050 projections based on logistic regression.**




Source: Reproduced from Kemp-Benedict (2003) continued population growth (FAO 2007). The gains in world average food consumption predominantly reflect those of developing countries, given that developed countries already had fairly high levels of per capita food consumption in the mid-1960s. That represents a success by any measure.

**…But a Qualified Success**

The increased output and yield gains within developing countries from the mid 1960s through to the turn of the 21st century were surprisingly rapid, urgently needed, and widely shared across countries of Asia. That said, several important caveats need to be made: First, not all parts of the developing world benefitted directly from this agronomic revolution; second, not all foods gained (mainly cereals), which has implications for the net quality of diets; and third, there are many questions about the sustainability of past gains (required natural and financial resources), which have implications for meeting the continued and future challenge of rising food demand.

Not all parts of the World

Sub-Saharan Africa has been, and remains, the exception. Africa's yield growth and resultant rate of growth in food output has been lower than most other regions (Table 4). Indeed, per capita production of all staple foods (grains combined with soy and vegetables) was still lower in Africa in the late 1980s than it had been in the 1960s (MoJE 1994). As a result, Africa has consistently lagged behind not only Asia, but also Latin America and even North Africa and West Asia.

It has proven to be a major challenge to introduce into Africa the package of products and practices that worked well elsewhere. The continent generally has a low population density, low effective demand, lack of irrigation, poorly connected markets, under-funded research and extension systems, and a tradition of growing crops other than cereals which have not lent themselves to the same kinds of yield gains as cereals. For example, Africa's consumption of fertilizer in 2003 was barely above its levels for the 1980s, and only 20 percent or so that of Asia (and less than a third of the consumption in Latin America) (FAOSTAT). Africa's consumption of pesticides did double between 1990 and 2000 (reaching 106,000 tonnes), but not only was that much lower than for Asia (862,000 tonnes) its use has been concentrated in a few Africa countries like Egypt, Algeria and South Africa where export crops, such as cotton, are important sources of revenue (FAO 2005). Similarly, in the early 2000s, less than 4 percent of Sub-Saharan Africa's arable land was irrigated, compared with an average of 26 percent for all developing countries and over 40 percent for South Asia . In other words, the enabling conditions in Africa have been unfavorable, the infrastructure and processes for achieving dissemination of inputs and services are weak, and markets for products (particularly links to global markets) are severely constrained. This does not mean that gains cannot be made in Africa, rather that different kinds of approaches may be needed to achieve the productivity enhancements that were seen in the rest of the world.

**Table 3: Fertilizer Consumption to Arable Land Ratio**

| Region/Country | 1980/1981 | 1990/1991 | 2002/2003 |
| --- | --- | --- | --- |
| | (kg nutrients/ha) | | |
| East/Southeast Asia | 120 | 180 | 231 |
| South Asia | 37 | 77 | 107 |
| Latin America/Caribbean | 59 | 59 | 89 |
| North Africa/Near East | 45 | 67 | 73 |
| Sub-Saharan Africa | 8 | 10 | 9 |
| WORLD | 87 | 99 | 101 |
| Developed countries | 120 | 112 | 82 |
| Developing countries | 56 | 87 | 115 |

Source: FAO 2005

**Table 4: Average Annual Rate of Growth of Food Production**

| World/Region | 1970-1980 | 1980-1990 | 1990-2000 | 2000-2003 |
| --- | --- | --- | --- | --- |
| | (percent growth) | | | |
| East and Southeast Asia | 3.3 | 4.4 | 5.2 | 4.0 |
| South Asia | 2.7 | 3.8 | 3.3 | 1.3 |
| Latin America/Caribbean | 3.6 | 2.5 | 3.4 | 3.7 |
| North Africa/ Near East | 3.1 | 3.5 | 2.9 | 3.4 |
| Sub-Sahara Africa | 1.1 | 2.9 | 3.1 | 1.9 |
| WORLD | 2.5 | 2.4 | 2.5 | 2.0 |
| Developed countries | 2.0 | 1.0 | 0.2 | -0.3 |
| Developing countries | 3.0 | 3.6 | 4.0 | 3.2 |

Source: FAO 2005

Non-Cereal Foods

Good nutrition is achieved not only through consumption of an adequate amount of energy (kilocalories), but also through a balance of all nutrients required for health and growth. The balance can only be achieved through dietary diversity, which is itself a key element of dietary sufficiency. Already at the very dawn of the Green Revolution some analysts were pointing out that large scale increases in cereal yields and output were coming, "at the expense of animal and vegetable protein and "protective" foods, such as fruits and vegetables….Cereal production tends to be emphasized at the expense of other crops in the underdeveloped countries, because it is a relatively efficient way of producing food energy for human consumption." (Revelle 1966)

For example, it has been argued that the new focus on wheat in countries like Pakistan and India led to a long-term decline in the cultivation of legumes (pulses) (Spitz 1987). That trend has been blamed for contributing to the high price of legumes in the 2000s, leading to "a decline in pulse consumption in all the income groups." (Ramachandran 2008) Protein consumption has also been declining in rural India. Some argue that higher incomes derived from much higher cereal output should enable rural consumers to enhance the quality of their diets. The problem is that overall energy consumption in a country like India appears to have been falling over time (dropping from just under 2,300 kcal/capita/day in the early 1970s to under 2,100 kcal/capita/day in 2004/05) (Ramachandran 2008). And this relates to the third caveat—sustainability of the gains made in past decades.

Sustainability

There are several issues to be dealt with under this rubric. Globally, per capita cereal production peaked in the late 1980s, while the rate of food output overall hit its high during the 1990s (Figure 3 and Table 5). The subsequent stagnation, and in some cases decline, has causes alarm, not least because of the food price crisis of 2008 and projections that high prices may persist, challenging the long-term trend (World Bank 2008). The average annual rate of growth in the world's cereal production was 2.7 percent in the 1970s, falling to 0.5 percent in the 1990s, and only 0.3 percent in the early 2000s (FAO 2005). At the same time, the average annual rate of growth of *per capita* food production fell from 2.3 percent in the 1990s to 1.6 percent in the years 2000-2003—roughly the same level that pertained in the 1980s (FAOSTAT). Even South Asia's growth in wheat production was been negative after 2000 (FAO 2005).

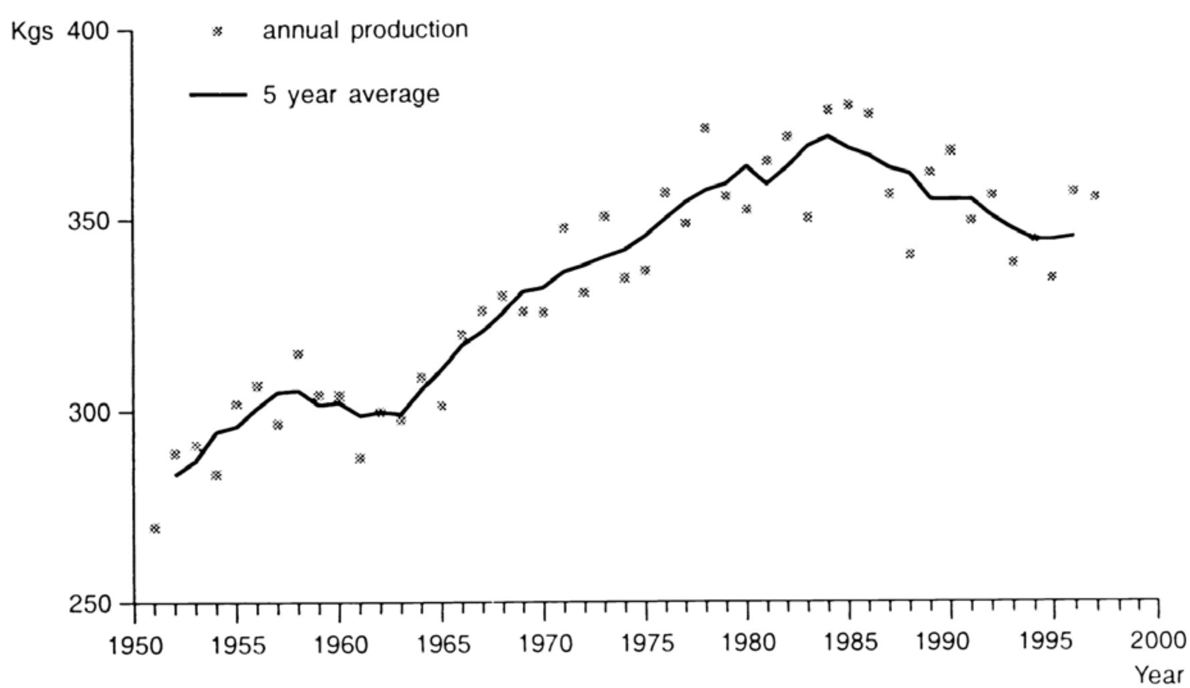
Sustained success is challenged on a number of fronts. First, natural resource conditions. From the mid-1990s, the environmental costs of productivity agriculture were widely recognized as a potential threat to longer-term replication of South Asia's agronomic revolution. High-input/high-output agriculture was widely condemned as compromising the environment and poor people's lives through its over reliance on chemicals and biotechnology, and by its displacement of traditional biomes and methods. Farming had come full circle and was increasingly seen as part of the problem of hunger, no longer the solution. As noted by UNESCO (2008) "systems are needed that enhance sustainability while maintaining productivity in ways that protect the natural resource base and ecological provisioning of agricultural systems. Options include improving nutrient, energy, water and land use efficiency; improving the understanding of soil-plant-water dynamics; increasing farm diversification; supporting agroecological systems, and enhancing biodiversity conservation and use at both field and landscape scales." In other words,

**Table 5: Average Annual Rate of Growth of Per Capita Food Production**

| World/Region | 1970-1980 | 1980-1990 | 1990-2000 | 2000-2003 |
|---|---|---|---|---|
| | | (percent growth) | | |
| East/Southeast Asia | 1.4 | 2.7 | 3.9 | 3.0 |
| South Asia | 0.4 | 1.5 | 1.3 | -0.4 |
| Latin America/Caribbean | 1.1 | 0.4 | 1.7 | 2.2 |
| North Africa/ Near East | 0.3 | 0.7 | 0.7 | 1.3 |
| Sub-Sahara Africa | -1.7 | -0.1 | 0.4 | -0.5 |
| WORLD | 0.6 | 0.6 | 1.0 | 0.7 |
| Developed countries | 1.2 | 0.3 | -0.3 | -0.6 |
| Developing countries | 0.7 | 1.5 | 2.3 | 1.6 |

Source: FAO 2005

**Figure 3: Per capita cereal production, 1950 to 2000**




Source: Dyson (1999)

from this viewpoint, 'sustainability' of agriculture requires attention not just to increasing output of single crops but to protecting, conserving and enhancing entire crop and livestock systems.

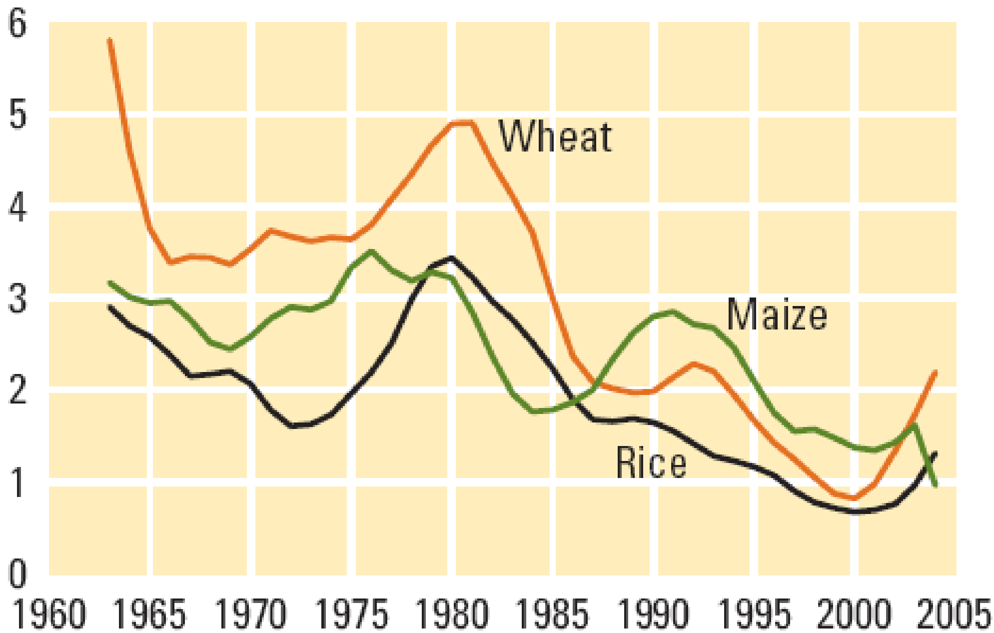
Many different problems have been pointed to over the years, including loss of biodiversity due to heavy pesticide and herbicide use, water pollution due to fertilizer residue in irrigation drainage, exposure to key pests or diseases due to increased mono-cropping, and more recently output decline as soils taxed by intensive cropping over several decades are becoming depleted of nutrients and organic matter. For example, intensive irrigation of rice leads to soil zinc deficiency even when that may not have been the case prior to irrigation (Broadly et. al. 2007). Nayyar et. al. (2004) for example, argue that zinc deficiencies started emerging in the Indo-Gangetic plains of India and Pakistan with the Green Revolution. They propose that "with intensive cropping, zinc deficiency appeared initially, and subsequently the deficiencies of iron." Thus, the World Bank (2008) concludes that, "lessons from the Green Revolution…caution us that technological progress can have unintended effects."

The challenge is how to limit and reverse the recent decline in yield growth that set in since the 1980s (Figure 4). While yields of wheat and rice did recover after 2000, maintaining the upward trajectory, and reversing the decline in maize yields are important priorities. Which brings up the second issue in 'sustainability'—that of sustaining funding for the agronomic research, extension and agricultural packages that laid the foundation for past growth.

Agriculture has be largely ignored for many years by international donors and many developing country governments alike—as seen in low recurrent budget allocations and low overseas development assistance (ODA) to this sector. For example, the share of total ODA to agriculture fell from around 15 percent in 1980 to less than 4 percent in 2005—a significantly smaller share of a much larger pie over time. Similarly, the allocation of ODA to Asia fell from more than $4 billion in 1980 to $1.5 billion in 2004…roughly the same level as received by Africa, which also saw its ODA to agriculture fall from more than $3 billion in the late 1980s (World Bank 2008).

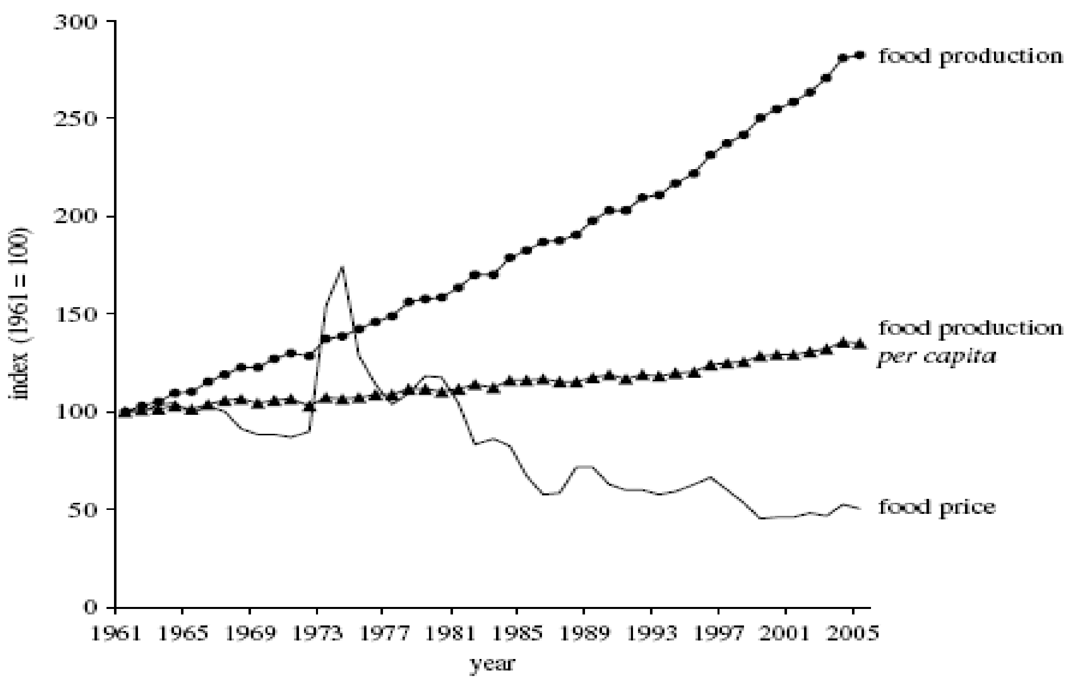
This lack of external funding has in part been influenced by the long-term downward trend in prices (Figure 5), and in part by signals from some donors (not all) that African governments should not seek to generate national income from agriculture. The International Monetary Fund, for instance, has made explicit recommendations in many countries, including Niger, the Democratic Republic of Congo and Angola, that governments should promote rural income diversification (i.e. out of agriculture), and focus agricultural investment on enhanced productivity—particularly through irrigation and/or emphasis on crops for export (IMF 2007; IMF 2007b; DRC 2007). Similarly, in India the IMF recently stated that "there is a need, particularly in the poorly performing states, to diversify the economic production base away from agriculture" (Purfield 2006).

**Figure 4: Growth rates of cereal yields (average annual percentage)**




Source: World Bank (2008), p.87

**Figure 5: Trends in Food Production and Prices, 1961-2006**




Source: Reproduced from Hazell, P. and S. Wood. 2008.

The result of stagnant or declining support to agriculture in target countries is, of course, reduced revenues from that sector which supports the view that resources should be focused elsewhere. According to the World Bank (2007), the importance of agriculture to most growing economies "will shrink to boutique niches", such that just a few resource-rich regions and countries will in future supply more than 50 percent of the worlds' grain. Needless to say, most donors still do not believe that Africa will be one of those regions. As a result, the capacity of Zambia's Ministry of Agriculture, for example, to provide appropriate services and inputs to small farmers has seriously eroded. Zambia has devoted roughly 6 percent of its annual budget to the agricultural sector in recent years, but of this, less than 4 percent was allocated to agricultural researchers and extension agents, while 75 percent went to salaries of ministry of agriculture administrators. As Govereh et. al. (2006) put it, public sector agricultural extension "has come to a standstill in Zambia."

**Conclusions**

The specter of famine no longer casts a long a shadow over humanity at the start of the 21st century. But food shortages, hunger and the threat of famine have not disappeared. As noted by Hazell and Wood (2008), "there remain large, persistent and, in some cases, worsening spatial differences in the ability of societies to both feed themselves and protect the long-term productive capacity of their natural resources."

The challenge to agriculture for the coming decades will therefore be huge—of the same caliber as the challenge that faced the world in the 1960s. Even with a *relative* decline in population growth rates there will need to be a very large *absolute* increase in food supply in coming years—from around 2 billion metric tons of grains in 2000 to almost 2.5 billion tons in the year 2020—due to increase food demand linked largely to poverty reduction and the rapid urbanization (and changing dietary habits) of most of the world's population. How this *additional* quantity of at least 500 million tons can be met in the face of a fixed, possibly eroding, stock of natural resources is a serious question. Gains on such a scale will have to be secured with continued improvements in agricultural productivity, reduced poverty (resulting in enhanced purchasing power that encourages higher productivity), and considerable public investments in health, education and market infrastructure, alongside greater attention to natural resource enhancement, protection, and conservation.

The lessons of the second half of the 20th century point to a need for continued (indeed raised) investment in the agriculture sector, continued agronomic research that raises productivity, a focus on the nitrogen fixation by plants (particularly legumes, but perhaps also cereals) to bypass some of the rising costs and potential deleterious effects of fertilizer applications, research on nutrient density traits or drought resistance rather than only yield maximization, and a renewed attention to minimizing losses (pre- and post-harvest), such that the burden of feeding more people should not rest solely on the plants. The caveats that apply to the agronomic revolution of the 1960s take away none of its achievements. It was a remarkable moment in human history. But, the challenge 50 years later is to apply those lessons in ways that can recreate such achievements in sustainable ways, with fewer environmental side-effects.

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