



International Agricultural R&D:

Crop improvement for increased food security

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Readings (Open Access):

- 1) <http://www.sciencemag.org/content/300/5620/758.full>
- 2) <http://www.pnas.org/content/109/31/12302.full>

Introduction

The world population more than doubled between 1960 and 2010. In the same period agricultural production increased threefold, making more food available per world capita today than 50 years ago. The magnitude of the world's food insecurity today is appalling; 842 million people were undernourished in the world in 2013 according to the FAO, the UN's Food and Agriculture Organization. But the *proportion* of undernourished people has probably never been lower in human history. According to FAO statistics the proportion of hungry people in the world was reduced from 60% to 15% between 1960 and 2010. The key technological factor behind the impressive increase in agricultural production in this period was the result of crop improvement. By crop improvement I refer to breeding of crops to produce higher yields and become better adapted to the agroecological conditions targeted by the plant breeder.

My motivation for contributing this lecture to this series about promising practices in international development is that I believe the impact of past efforts and the potential of new initiatives in crop improvement is underestimated among many scholars of international development. The so-called Green Revolution that took place in Latin America and Asia in the 1960s and 1970s is subject to a highly polarized debate between those emphasizing the positive outcomes and those focusing on the negative consequences. Since crop improvement

was the core technology in the Green Revolution, it has been held hostage in this polarized debate, and has therefore been portrayed by some activists and scientists as part of a problematic approach to development.

Crop improvement has also experienced quite a bit of collateral damage from the GM-debate, as some participants in the debate apparently consider the activity crop improvement and the practice of biotechnology as synonymous. They aren't. The crop improvement and the yield increases caused by widespread adoption of improved varieties is a success story that everyone concerned with international development ought to know about, not only to be able to separate the wheat from the chaff in the debates about past experiences, but also because it is important to recognize the role crop improvement continues to play in the constantly evolving international efforts to achieve food security for all.

Crop Improvement and Food Security

Crop improvement is, simply described, crossing of different varieties of a crop species and selection of the plants that have the desired characteristics. Crop improvement has been part of agriculture since the beginning of farming. The first farmers selected and developed all the major crops in the world today. Starting in the 18th century, crop improvement also became a scientific undertaking. Knowledge in genetics and statistical methods for selection armed professional plant breeders with a faster and more trait specific crop improvement than traditional farmer selection. Universities, public agricultural research organizations and seed companies are the typical institutions performing such methodical crop improvement, but also NGOs and farmer organizations are involved in some crop improvement efforts, perhaps most notably in different forms of participatory plant breeding programs.

The success of crop improvement can be measured at two levels: impacts on production growth and impacts on food security. These levels are inherently hierarchical: Production growth is not sufficient to achieve increased food security, but it is a necessary prerequisite. I will return to talk about the impact of crop improvement on food security, but let's start with considering in what ways crop improvement has impacted on production growth.

In the period between 1960 and 2009 the world population increased from 3,1 to 6,9 billion and in the same period, cereal production increased from 900 million tons annually to 2,500 million tons annually, thus, almost a tripling of the production (Conway 2012)

Production growth can be the result of expansion of area cultivated and the result of increased production on existing agricultural land; yield growth. According to World Bank figures, the production growth in the 50 year period came about with only 30% expansion in agricultural land, meaning that most of the production growth was due to yield growth.

Evenson and Gollin (2003) distinguish between two aspects of yield growth: 1) the contribution of improved varieties and 2) the contributions of all other inputs such as fertilizers, irrigation, mechanization, and labor. Furthermore, they distinguish between an "early green revolution" period from 1961 to 1980 and a "late green revolution" period from 1981 to 2000. Using FAO data on national food production and area harvested, they present a regional analysis of how much of the production increase that can be attributed to the crop improvement work of international agricultural research.

This table is an excerpt of table 1 in the paper by Evenson and Gollin and provides a summary of the stats for all developing countries. We see that gains by improved varieties are increasing in the late period compared to the first period – a finding the authors attribute to the long-term impact of the crop improvement work that was started in the preceding two decades. In the late period, yield growth accounted for 86% of the increase in food production in developing countries and the improved varieties contributed almost 50% of the yield growth and 40% of the production growth.

The region in which yield growth and the contribution of improved varieties to increase yield was highest was Asia. The region where it was lowest was sub Saharan Africa.

Before we turn to look at the evidence for impact on the higher level, Food Security, in more detail, I will provide a brief historical overview of the Green Revolution. This part of my lecture draws heavily on Gordon Conway's book *One Billion Hungry* (2012).

The story of how crop improvement was introduced to developing countries is closely interwoven with the history of the Green Revolution. As defined on Wikipedia, the "Green Revolution refers to a series of research, and development, and technology transfer initiatives, occurring between the 1940s and the late 1960s, that increased agricultural production worldwide, particularly in the developing world, beginning most markedly in the late 1960s."

The beginning of the Green Revolution history starts with an agricultural development program that was a joint venture between the Mexican Ministry of Agriculture and the Rockefeller Foundation in 1943. The researchers in the program quickly realized that it was impossible to simply transfer the varieties of maize that were producing large harvest in the US as these varieties were not adapted to Mexican environmental conditions and performed poorly. What could be transferred however were the techniques and practices of crop improvement that had proven so successful in the US. By the 1960s over a third of Mexico's maize land was being planted to new high yielding varieties developed by crossing Mexican indigenous varieties with high yielding varieties. But the largest success came in the crop wheat. The wheat breeder Norman Borlaug was leading the wheat improvement efforts, and eventually solved two of the major challenges in Mexican wheat agriculture by developing varieties that were resistant to the devastating crop pest "stemrust" and by developing varieties that responded well to inorganic fertilizer without lodging (lodging means that the plants fall over because of the heavy grains). These varieties were so-called semi-dwarf varieties and were produced by crossing a traditional Japanese variety with a short sturdy straw with Mexican varieties and through an intensive system of breeding called "shuttle breeding", the programme developed wheat varieties that were well adapted to a range of growing conditions, responded well on fertilizer and yielded up to 7 tons per ha. The average yield of Mexican wheat agriculture in 1970 was four times higher than it had been prior to the efforts by Borlaug and his team.

The largest impact of crop improvement in Asia came when the success of developing semi-dwarf and fertilizer responsive varieties was deployed on rice –the main staple crop on the continent. Plant breeders in China and the Philippines developed semi-dwarf varieties of rice that revolutionized agriculture in the two countries and soon spread all over the region. The breeding efforts in the Philippines were done at the International Rice Research Institute. By 1965, IRRI was developing semi-dwarf, stiff-strawed, disease-resistant and fertilizer responsive plants that could double or triple yields.

In 1970 Norman Borlaug was awarded the Nobel Peace Prize in recognition of his contributions to world peace through increasing food supply.

The institutional underpinning of the crop improvement that made such impacts during the Green Revolution was first provided by two philanthropic foundations; the Rockefeller and the Ford foundations. The Rockefeller foundation was fundamentally important for the International Center in Mexico; the international maize and wheat improvement center,

known by its acronym CIMMYT. And the Ford foundation played a similar role for the establishment of the International Rice Research Center located in the Philippines.

This centre model for international agricultural research since expanded into a network of 15 centres in the Consultative Group of International Agricultural Research (CGIAR), a network mainly funded by the World Bank, national development agencies and philanthropic foundations.

The CGIAR has expanded into new work areas in environmental sustainability and poverty reduction, but as one recent review of the network puts it: crop improvement for agricultural productivity growth is still the “bread and butter” of the CGIAR (Renkow and Byerlee, 2009). The CG system has continued to churn out new improved crop varieties. In the eleven crops studied in the review by Evenson and Gollin more than 8000 improved varieties was released in 400 public breeding programmes as a direct result of crop improvement developed by international agricultural R&D. As is evident from this slide, most of the varieties were released in Latin America and Asia.

Scholars and practitioners today commonly recognize three to four components of Food Security: Availability, Access, Utilization and Stability (The stability dimension covers risks to price volatility etc.). It is common to credit the Harvard economist Amartya Sen for contributing the seminal work on the important role of access. Sen has documented a number of famines in which overall shortage of food either was absent or played a relatively minor role, while the cause of hunger was failure of the market and government mechanisms involved in food distribution. Sen’s work has been highly influential on the development of the concept of Food Security as it was formulated in the Rome Declaration on World Food Security from 1996:

“A situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life.”

This concept is a valuable as a goal for which the world should strive. It is, however, not a concept that provides easily measurable indicators.

The statistics on undernutrition at country and regional levels are based on the FAO data reported in the annual report State of the World’s Food Insecurity (SOFI). Hunger is by FAO defined as inability to acquire enough food to meet dietary energy requirements and the number of hungry people in the world is by FAO reported as the indicator “prevalence of undernourishment” (PoU) (the probability that a randomly selected individual consumes an amount of calories insufficient for conducting an active and healthy life). This probability estimate is not based on a headcount, it is (simply stated) an aggregate of national level calculations of the total number of calories available in a country (based on national statistics on production, trade and stocks) divided by the number of people (distributed by age and sex), factoring in a coefficient for distribution of the food supply (FAO 1999). This FAO estimate is the data used by the UN to keep track of the Millennium Development Goal 1C: *Halve, between 1990 and 2015, the proportion of people who suffer from hunger*. While the figure

still is at a stunning 842 million people (2013 estimate) by the latest account, the current estimates show that the MDG is almost within reach at the global level.

- The proportion of undernourished people in developing regions has decreased from 24 per cent in 1990–1992 to 14 per cent in 2011–2013.
- In 2012, a quarter of all children under the age of five years were estimated to be stunted—having inadequate height for their age. This represents a significant decline since 1990 when 40 per cent of young children were stunted.

One cannot infer causality between the reduction in hunger and the use of improved varieties. However, it is striking that the regions with the highest use of improved varieties also are the regions with the highest reduction in the prevalence of hunger: Asia and Latin America.

FAO's hunger indicator is criticized for mainly being an indicator of calorie availability, not accounting well for access and ignoring the utilization aspect of food security. Utilization is about the way the body makes use of the nutrients and achieves an acceptable nutritional status. Pingali (2012) reports some statistical evidence for the association between the use of improved crop varieties and increased nutrition. A 10 year study from southern India found that increased rice production resulting from the spread of improved varieties accounted for about 1/3 of the substantial increase in energy and protein consumption of both farmer and landless workers. Another study from Bangladesh found that the fall in rice prices from 1992 to 2000 translated into greater expenditure on foods that diversified people's diet, leading to a significant improvement in child nutrition status.

In its broadest sense food security is a question of economic and social development. Macroeconomic studies show that the agriculture sector is important for spurring further economic growth and development. Figures cited by Pingali shows that in Asia each 1% increase in crop productivity reduces the number of poor people by 0,48%. Furthermore Pingali reports studies showing that agricultural growth is the most important economic sector for poverty reduction. For low income countries in general, he reports, the impact on poverty is 2,3 times larger from agricultural growth than equivalent growth in other sectors and in Sub Saharan Africa agriculture's contribution was estimated to be 4,25 times the contribution of equivalent investment in the service sector.

Since the story of crop improvement in many ways is the story of the green revolution it is important also to mention the negative consequences and the limitations of the green revolution. The green revolution had negative environmental impacts and the social impacts were mixed, with some groups benefiting more than others. There were many negative environmental impacts such as unsustainable use of water resources, loss of agrobiodiversity (including loss of traditional varieties, known as genetic erosion), soil degradation, and chemical runoff from inorganic fertilizer and pesticides. It was not the improved crop varieties *per-se* that causes these problems, but they came as a result of policies and incentives promoting overuse of agrochemicals and unsustainable agronomic practices.

As I said the social impacts were mixed. A rural household where members are farmers, paid workers, and net buyers of food would often both experience gains and losses at the same time as a consequence of the decreasing prices on grains.

But can the fact that not everybody gained equally be used as an argument to say that the poor would have been better off without the Green Revolution? Evenson and Gollin report the results of a so-called “counterfactual” study – what would have happened if developing countries did not have access to improved varieties and were constrained to use the technologies available in 1965? These are two of their most striking estimates:

- Crop yields in developing countries would have been about 20% lower
- Crop prices would have been 35-65% higher on world market than they are today (prices actually fell 40% in the period)

Thus, despite the negative consequences, I think it is useful to do as Pingali does and remind about the big picture: *“The GR contributed to widespread poverty reduction, averted hunger for millions of people, and avoided the conversion of thousands of hectares of land into agricultural cultivation.”* But, as he goes on to say *“At the same time the GR also spurred its share of unintended negative consequences, often not because of the technology itself, but because of the policies that that were used to promote rapid intensification of agricultural systems and increase food supplies.”*

Conclusion

One important lesson from the green revolution is that public funding is needed for creation of public goods. The Asian governments consistently spent 15% of the annual budget on agriculture during the green revolution. This is much more than most developing countries today spend on the agricultural sector. However, change is underway. The African governments have in their official policies reintroduced agriculture as a major sector to achieve development. The Comprehensive Africa Agriculture Development Program (CAADP), the agriculture program of the New Partnership for Africa’s Development (NEPAD) of the African Union declares that investment in agriculture should increase to a minimum of 10 per cent of their national budgets. It is telling that two of the most successful emerging economies, China and Brazil, have prioritized agricultural R&D, including crop improvement in their highly successful public agricultural research systems (EMBRAPA in Brazil and CAAS in China).

While a critical perspective on technology and production growth is warranted, it is important to acknowledge the crucial role of crop improvement and agricultural development for increasing the availability of food. If the critique of the production growth focus leads to a decrease in funding for agricultural R&D it might actually undermine food security.

All agricultural development strategies, whether they are centered on conventional agriculture, organic farming or so-called agroecological farming, is dependent on development of new varieties adapted to changing environmental conditions. One of the lessons from the green revolution is that crop improvement for increased food security needs to target the marginal

environments where many of the poorest live. Crop improvement in the green revolution typically targeted the agricultural land with the best growing conditions and this is part of the reason why better-off farmers benefitted more than the poorest from the improved varieties developed in the early stages of the green revolution in Asia and Latin America. The need to target marginal areas is made all the more urgent by climate change which is projected to shift many crop climates towards the extreme end of the normal distribution in today's conditions. Adapting to the adverse effects of climate change will require increased crop improvement efforts.

As a part of the targeting of the marginal environments more emphasis needs to be put on other crops than the big three cereals wheat, rice and maize. One of the reasons why the impact of crop improvement never created a green revolution in Africa is that there was very limited breeding for African cropping environments during the green revolution. It was not until the 1980s that more suitable varieties of maize based on research specifically targeting Africa became available. In the recent years we have seen more progress in crop improvement in crops such as sorghum, millet and cassava crops of great importance for food security in Africa.

One exciting development in crop improvement the last years is referred to as decentralized participatory plant breeding. By including farmers in the breeding process such models of crop improvement allow for adaptation to local conditions and preferences. To enable this we need to ensure conservation and access to genetic resources –the raw material for crop improvement.

The emphasis in my lecture has been on the science and technology of crop improvement. But I also hope I have been able to convey that achieving food security for all will require the creation of a more socially just and sustainable global food system with a reduced environmental footprint. Finally, it is important to keep in mind the crucial role of policies and institutions as emphasized by several of my co-lecturers in this course. Successful and sustained effect of improved crop varieties and other agricultural inputs designed to increase yield depends on well functional institutions and policies for agricultural development.