CIMMYT Economics Program

Fifth Distinguished Economics Lecture

Changing Priorities for International Agricultural Research

Robert W. Herdt

CIMMYT®

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International Maize and Wheat Improvement Center

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Abstract: This paper examines the consequences of global changes for publicly supported agricultural research and its implication on research priorities of the CGIAR. The author asks whether the CGIAR has appropriately adjusted its activities in light of these changes and whether the technological and institutional changes of the past decade mean that germplasm conservation, intellectual property protection, and crop management research should be getting more support than varietal development. He discusses public goods and argues that the increasingly private nature of crop varieties, driven by the DNA revolution and extension of intellectual property rights to plant, increases the comparative advantage of private research in varietal development. On the other hand, crop mangement retains its public goods nature and there is little likelihood of this changing.

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Introduction

While the research priorities of the Consultative Group of International Agricultural Research (CGIAR) are constantly reviewed by the CGIAR, its Technical Advisory Committee, and each of its 16 research centers situated around the world, it is nevertheless a topic worth addressing for several reasons. First, the world is changing rapidly and research investment today is different from what it was a few years ago. Second, people may be so involved in the management of their organizations that they may find it challenging to see their role in the larger picture. Third, organizations change slowly and reluctantly and sometimes an outsider's voice provides the impetus for changes that may be too hard to make otherwise.

I will begin with a few preliminary observations followed by a review of some dramatic global changes of the past two decades that bear on food security. Then I will consider arguments for publicly supported efforts to enhance food security and the CGIAR's role in that effort. Finally, I ask whether, in the face of global changes, the CGIAR has appropriately adjusted its activities. In particular I ask whether changing global conditions mean that germplasm conservation, intellectual property protection, and crop management research ought to be receiving increased support compared to varietal development. In the process, I will pay some attention to policy and other categories of research, but I do not attempt a full analysis of priorities across all categories of international agricultural research.

I am not advocating abandoning any element in the CGIAR portfolio, nor am I suggesting that research productivity cannot be improved through better management of available resources. Neither will I suggest anything about any particular organizational form for international agricultural research – a topic that is the concern of the CGIAR's change design and management process.[1] Rather, I ask if technological and institutional changes of the past decade may have made the current balance between crop genetic research, crop management research, and other CGIAR enterprises outdated.

Global Food Security

Food security requires that every person have enough food every day to carry out normal activities. Over the past two decades world population grew by 1.6 billion. The number of people living in hunger fell by 150 million and although this continues to fall, the reduction is concentrated in East and Southeast Asia, while the number of food-insecure people has risen in many countries of Africa.

Short-run food crises that grab the headlines and media screens galvanize political action in developing and donor countries. Despite the best efforts of the World Food Programme and other relief organizations to focus attention on long-term needs as well as emergencies, when crises like the floods in Mozambique, the famine in Ethiopia or civil war in Indonesia occur, governments in the industrialized countries are impelled to respond and private citizens, in turn, increase their contributions to non-governmental relief and development organizations.

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1 *Some will recognize that I have voiced this concern earlier, most publicly at the CGIAR mid-term meetings in May, 1998 at Beijing, China and in May, 2000 in Dresden, Germany. While adjustments may have been made since then, it is not clear if they are enough to fit changing circumstances.*

The pattern is clear: the US and other advanced countries respond generously to disasters and emergencies from natural causes and war. However, resources for long-term development have fallen in real terms. Lancaster (2000) argues that an increasing amount of US foreign assistance is provided through government agencies like the Department of the Interior that have no apparent mandate for development assistance. But even including such sources, her data show that US foreign aid ranged from US$ 8-10 billion from 1986 to 2000, with no steady, perceptible rise or fall. In a world of inflation, this translates into a declining trend.

Data assembled by Evenson (2000) indicate that around a third of all new food crop varieties released between 1965 and 1995 were CGIAR releases or selected from CGIAR crosses, and another third were produced from crosses having CGIAR parent lines. While this may be a simplistic indicator, it does suggest how important the CGIAR centers have been for food production in a developing country—food production being a key requirement in the fight against poverty over the past three decades. While the UK government has taken the lead in highlighting the need to use development assistance to alleviate poverty (HMSO 2000), it seems unlikely that the pattern of official development assistance will change much. It seems equally unlikely that the CGIAR will receive a large increase in resources despite clear evidence of its productivity. Hence it is important to understand the dramatic changes in the world and how they may affect the optimal use of CGIAR research resources.

Global Changes

Rapid technological and institutional changes during the past several decades have been accompanied by dramatic biophysical changes in global climate resulting from land and water use by humans, the emergence of new infectious diseases, accelerated species extinction, and continuing changes in population growth. While these changes do interact, I will first review the technological and institutional changes, and then biophysical changes.

Institutions and Technology

The impact of changing geopolitical realities is inescapable. The broad recognition that planned economies failed to deliver what their proponents promised for decades led to the fall of the Berlin Wall and an avalanche of political and economic restructuring in Eastern Europe and the former Soviet Union. Economic restructuring and the embrace of markets as the solution for slow economic growth has been the basic thrust of World Bank policy for borrowing countries for the past two decades. The force of this Washington Consensus and the speed with which it has spread is one of the major factors conditioning the economic environment for agriculture in developing countries.

Communications and Information Technology

We are far enough into the electronic revolution to recognize its beginning, but probably are only vaguely aware of its ultimate impact. Telephones, computers, and related electronic technologies have reduced communications costs dramatically. In 1930 a three-minute telephone call from New York to London cost US$ 245, in 1960 it cost US$ 45, while in 1990 it was down to US$ 3.32 – almost a 99% decline in the cost of telecommunications (Ward, Bhattari, and Huang 1999). Today Internet voice communication has a zero variable cost. In the last few years, the development of the World Wide Web has enabled information to flow instantly to virtually any city and revolutionized the daily activities of the entire financial world, most of the business world, the US government, and science research. In low-income countries, finance, business, and science have either followed the leading edge of change quite rapidly or trailed behind so dramatically as to be almost completely left out.

Social and consumer sectors like primary and secondary education, medical practice, and agricultural production in high-income countries are participating in the electronic revolution, although at a slower pace than the leading business and finance sectors. In poor countries, social and consumer sectors lag far behind. At the same time, the electronics revolution has powered some surprising phenomena. Cellular telephones accelerated connectivity in some developing countries where land-based telephone service has long lagged. Education and business acumen have enabled computer entrepreneurs in India and other poor countries to compete in the global marketplace for software development and data services. Only five years ago, Bangalore became India's computer innovation center;today it is the Silicon Valley of India with Dell, Cisco Systems, and others investing hundreds of millions of dollars (Anthony 2000).

The use of the Internet for business is just beginning, but growing rapidly. "Phone calls, faxes, and sales visits are replaced by mouse clicks. Buyers use the Internet to scan a universe of suppliers for the best price, while sellers connect to customers they never knew existed. Boring stuff, but the opportunities it creates for investors are tantalizing. B2B [Business-to-Business] e-commerce is already ten times larger than the more established consumer e-commerce and expected to grow much faster," (McLaughlin 2000). The use of the Internet for B2B deals is forecasted to reach US$ 1.3 trillion in 2003, compared to US$ 43 billion in 1998 (Fulcher 2000).

Although remote sensing has made significant contributions to mining and the military, its contribution to agriculture remains elusive. Perhaps this will be the next big technological impact on farming.

Biotechnology

It has become a cliché to say that biotechnology offers unlimited potential to agriculture. Indeed, genetically engineered crops are now a reality for many farmers in the US, Canada, China, and Argentina. An estimated 30% of the global area of soybeans, 14% of canola, 10% of cotton, and 8% of maize was planted to transgenic varieties in 1999 (James 2000). The controversies that have attended these developments and prevented the dissemination of the technology in Europe are well known (Nelson et al. 2000), although some farmers seem to see the advantages.

Soybeans with transgenic resistance to herbicide were introduced in the US in 1996 and by 1999 were planted to about 35 million acres or roughly 47% of the national area. Farmers like them because they get more complete, less complicated weed control with less crop injury. A comprehensive analysis of the data from trials and state-by-state statistics reveal no conclusive effect of genetically engineered herbicide tolerance on yields or net income, but farmers saved US$ 220 million in herbicide costs and made 16 million fewer herbicide applications compared to 1995 (Gianessi and Carpenter 2000).

For the developing world, biotechnology promises crop varieties that are genetically better suited for prevailing production conditions and stresses. For example, in China cotton varieties with built-in insect protection— Bt cotton— has become available over the past several years. A 1999 study of over 280 farmer-users in northern China showed that farmers growing Bt cotton sprayed insecticide 2 to 3 times compared with 12 or more sprays for farmers growing non-Bt cotton. This saved farmers an average of US$ 145/ ha on pesticide costs (Pray et al 2000). A recent report on collaborative research between the International Rice Research Institute (IRRI) and the Huazhong Agricultural University in China that compared transgenic hybrid Bt rice with non-Bt hybrids, showed a 28% yield increase for Bt hybrids under natural field infestations of yellow stemborers and leaffolders (Toenniessen, personal communication). These kinds of advantages would seem worthwhile for farmers. The adoption data will tell the story over the coming years.

Two major observations apply to biotechnology and the developing world: one, it seems unlikely that biotechnology will address the needs of the poor in the poorest regions without concerted public efforts; and two, it holds little promise of ever addressing some of the important needs of farmers. Multinational seed companies, the major players in plant biotechnology, will not turn this potential into reality in the poorest and most in-need developing countries, certainly not in the short run. There are simply too many more profitable opportunities for big companies to pay much attention to the poorest countries. While the markets for major crops in China and India have attracted their attention, markets for less important food crops and markets in Africa have not and likely will not. Even though they will not invest large sums, it is likely that these companies will cooperate with the CGIAR or other public-sector organizations to address the needs of smaller countries.

Likewise, big multinational NGOs will not help developing countries understand the potential risks and benefits of biotechnology as they have staked out a position that is in clear opposition to it. Developing countries themselves will have to acquire their own capability to understand the risks and intellectual property and international negotiating issues. Countries will need a solid base of conventional genetic improvement capability as well as national capability to understand the sciencitic and legal implications to negotiate wisely.

Some of the most important conditions for agricultural growth in developing countries cannot be addressed by biotechnology. Agricultural production requires good soil fertility, appropriate policies, markets for inputs and products, credit, and educated farmers. In Africa, better soil fertility is desperately needed for agricultural growth. On average less than 10 kg of nutrients are applied per hectare of arable land in Africa compared to 98 kg/ha globally (Gruhn, Goletti, and Yudelman 2000). Growing legumes in rotation with other crops contributes nitrogen and where the economics works out, is feasible. This practice is to be encouraged, but it is not what political leaders and the media envision when they talk of nitrogen-fixing crops. A biotechnology solution is a long way off. Some speculate on incorporating nitrogen-fixing capacity into cereals or other non-legumes; in reality very little concrete progress has been made toward that concept and probably would require resources to the order of US$ 10 million per year for ten years just to develop promising prototype genetic changes. Likewise, the needs for essential plant nutrients other than nitrogen seem unlikely to be addressed in a practical sense by biotechnology, certainly not in the short-run.

Like nitrogen fixation, there is widespread hope that science can make crops more drought-tolerant, and in the case of maize there appears to be progress. In rice, while the quest for some degree of drought tolerance has been considered intractable, many rice scientists, now believe that genetic improvement for this trait is possible given the recent advances in rice molecular biology and genetics (Cantrell 1999). However, the challenges, when enumerated, give one pause: "Variety characteristics that confer an advantage in some water stress environments may prove to be useless or may even be a liability in other environments....We do not yet know which alleles or even which loci confer an adaptive advantage in specific stress environments.... Many individual traits have been nominated as routes to improve rice performance under conditions of water deficit....Quantitative trait loci have been identified for all of these traits, but their adaptive value in various water stress environments remains unclear" (Lafitte 1999).

Drought-tolerant varieties will only be found with a carefully focused, long-term, comprehensive research program. There is no drought-tolerance gene to engineer into rice.

Thus even though biotechnology promises to contribute to improving food availability in a developing country and is one element of a comprehensive CGIAR investment portfolio, it is not a panacea.

Institutional Changes

Institutional change includes the rapid decline in acceptance of national socialized approaches to economic organization, its displacement by markets, globalization or the reduction of international barriers to trade and financial transactions, and, of special interest for this discussion, the application of private property rights in plants, genes, and short segments of DNA.

The pace of political change seems to have been accelerated by electronic communications that instantly bring visual images of political events thousands of miles away to millions of people. The dissatisfaction with the failure of socialized economies to deliver adequate performance has been an important factor propelling the political and economic repudiation of socialized economies. The triumph of the market and consensus that planned economies simply do not work the way they were envisioned is a change that is unlikely to be reversed.

It is also well recognized that the costs of gaining information about economic opportunities and negotiating contracts (transactions costs) may prevent some sales and purchases that might otherwise seem profitable. Indeed, if an economic unit does not know of an opportunity, it cannot act on that opportunity. Some believe that the electronic revolution will dramatically reduce these costs and improve productivity. How fast and how far this trend will prevail remains to be seen. Stories of farmers in remote districts of developing countries linking to markets in Europe or the US make the news precisely because they are unusual.

While there is broad recognition that markets do not solve the problems of equity, transactions costs, and externalities, there are many who believe that market solutions are best, even while some prominent economists hold that careful and limited intervention by the government is needed for development (Fishlow et al. 1994). Whether limited intervention or complete reliance on market forces will prevail remains to be seen.

Intellectual property rights have not been of much concern in crop variety development until the past decade when biotechnology enabled the incorporation of cloned genes into crops. Subsequently there has been a big increase in intellectual property rights on crop varieties. In the US four different forms of intellectual property protection are provided by law for plant-related inventions: utility patents (simply called "patents"), plant patents, plant variety protection, and trade secrets. Each operates differently. The US Patent and Trademark Office administers the first two, the US Department of Agriculture the third, and the fourth is controlled under US federal law (Peet 1999).

Each nation has its own form of intellectual property (IP) protection, and despite common perceptions to the contrary, IP protection granted in one country is not generally valid in another. That is, a patent granted in the US has no force outside of it. The invention must be patented in other countries to be protected there. However, nations have agreed through various treaties to respect certain rights related to IP in plants. Three international agreements are of particular concern: the FAO (Food and Agricultural Organization) International Undertaking on Crop Genetic Resources (IU), the United Nations Convention on Biodiversity (COB), and the Trade Related Intellectual Property Rights provision (TRIPS) of the World Trade Organization (WTO).

Prior to the IU, plant genetic resources and plant varieties were subject to few legal provisions. Movement of seeds and plants across national boundaries were governed largely by the desire to minimize plant diseases and insect pests (phytosanitary considerations). International agricultural research centers collected seeds of crops they were interested in for crop breeding. Plant breeders who were responsible for such collections made seeds freely available to plant breeding colleagues in both developing and industrialized countries. Gradually the centers and their donors recognized their obligation to systematically conserve the seeds and maintain them in trust, not as the property of the center but as part of the common heritage of humankind. Several concerns were voiced about the germplasm collections: that they might not be adequately cared for, that they might be kept from some legitimate crop breeders, and that the centers might claim intellectual property over them, betraying their trusteeship obligations.

An effort was made within the FAO to formalize the previously informal conditions under which the seeds were being held, resulting in the IU. The IU never attained treaty status, and some observers believe it is in conflict with other related international agreements (Petit et. al. (n.d.). The FAO Commission on Genetic Resources for Food and Agriculture is the forum where FAO member nations continue discussions on the IU.

The COB emerged from the United Nations Conference on Environment and Development held in Rio de Janeiro in 1992 as part of an effort to slow the rate of loss of biological diversity at the ecosystem, species, and gene levels. According to the Crucible II Group, the biodiversity convention is the legally binding umbrella for all levels and forms of biodiversity. Although most people recognize the centrality of COB, it is nevertheless viewed by some as being functionally more concerned with 'wild' (a contentious term) or 'not-yet-utilized' (no less contentious) diversity. Others see the FAO Commission as concerned with 'cultivated' or 'nurtured' diversity – that which is known to have 'value' (Crubible II Group 2000).

The COB has three primary objectives: the protection of biodiversity, the sustainable use of biodiversity, and the equitable sharing of the benefits arising from biodiversity. It confirms the concept of national sovereignty over germplasm by the country of origin, and some observers believe it was motivated largely by the idea that medical applications of natural plants might generate huge financial returns to nations of origin. Crop plants are now considered within the same convention by some, lending uncertainty to efforts to collect wild relatives or landraces for crop germplasm banks. While not mandating any intellectual property provisions, the COB does seem to add another impediment to free exchange of germplasm.

The WTO is an organization of nations who have agreed through a treaty to pursue certain goals, including the reduction of barriers to trade. Tariffs, the taxes that one nation imposes on goods imported from another, are one type of barrier being reduced within the framework of the WTO. Regulations other than tariff barriers are also within WTO jurisdiction. One provision in the WTO treaty requires that all member states have a system of trade-related property rights that provide for the protection of intellectual property. Crop varieties may be protected by patents or by other means like plant breeders rights, so long as some protection is available equally to all who wish to pursue commerce within the nation, whether domestic production or imports. This trade-related property rights or TRIPS provision has generated a good deal of attention from some who accuse WTO of compelling developing countries to institute a system of patents for crop varieties. While not strictly true, because the treaty clearly allows non-patent IP protection for crops, the US, presumably at the behest of domestic companies, has pressured developing countries to adopt patents both on a bilateral basis and through the WTO Secretariat.

Global Physical and Biological Changes

Climate change, the emergence of new infectious diseases, and the increasing appropriation of the earth's resources for human use are important biophysical changes affecting the globe. Each of these changes interacts with technological and institutional changes, and one of the effects of this interaction is the increase in the relative importance of agriculture's capacity to adjust crop production to changing environmental conditions.

Several global circulation models (GCM) that integrate the main climate change factors are available. Most projections show greater average temperature increases at higher latitudes than the tropics and distinctly different precipitation effects across regions. The impact of climate change on agriculture and the rest of society is, of course, a matter of much speculation, but it varies greatly across regions and locations because it derives from changes in temperature and precipitation as well as effects on plant growth from changing ratios of greenhouse gases.

"Generally, middle to high latitudes may experience some increase in productivity, depending on crop type, growing season, change in temperature regimes, and the seasonality of precipitation. In the tropics and subtropics where some crops are near their maximum temperature tolerance, and where dry-land, non-irrigated agriculture predominates, yields are likely to decrease," (Watson 1998). "While agriculture in some temperate regions may benefit from global climate change, tropical and sub-tropical regions may suffer. Even where the production potential will improve, the required adjustments may disrupt ecosystems and land-use patterns. Agricultural zones will shift toward high latitudes, while heat stress and increased droughts will reduce productivity in lower latitudes" (Rosenzweig and Hillel 1993).

The economic implications of climate change for the farm sector will depend on the speed and completeness of adjustment. That, in part, will depend on the extent of inter-regional and international trade as well as the availability of alternative technologies for crop production. Farmers, input suppliers, market agents, and consumers are always adjusting to all kinds of changes that generate price signals in markets. Because the effects of long-term climate change are so variable, they will generate a continuing series of short-term price changes as well as long-term price trends (Schimmelpfennig et al. 1996). Farmers with information, access to markets, and capital can shift resources toward activities that promise better economic returns, whether these returns are the result of anticipated changes in biological performance or anticipated price changes. On the other hand, farmers with limited access to markets and little information or capital are hampered in their ability to adjust to such changes. Developing country farmers may be doubly disadvantaged by limited opportunities to adjust through markets and by the direct effect of climate change on output.

Water

Along with the effects of climate change on water availability, changing patterns of water demand will have a major effect on agriculture, especially where irrigation and urban population concentrations compete for water. "Because irrigated farms typically get higher yields and can grow two or three crops a year, the spread of irrigation has been a key driver in this century's rise in food production…Worldwide, after a remarkable period of growth, the pace of irrigation's spread slowed substantially toward the end of the twentieth century. Between 1982 and 1994, global irrigated area grew at an average rate of 1.3% a year, down from an annual rate of 2% a year between 1970 and 1982" (Postel 2000).

"After thousands of years in which water has been a plentiful resource in most areas, amounting to virtually a free good, the situation is now abruptly changing to the point where, particularly in the more arid regions of the world, water scarcity has become the single greatest threat to food security, human health and natural ecosystems" (Seckler, Molden, and Barker 1999).

Increasing competition for water between urban demand and irrigation will be a major ongoing theme through the coming decades. Water demand by households in developing countries is projected to double from 13% to 27% of total use between 1995 and 2020. But global aggregates mean little. The distribution of water across and within countries is a critical factor because it is so costly to move water over great distances and across challenging terrain. Today 28 countries with a total population exceeding 300 million face water stress; by 2025, that could increase to 50 counties with a total population of about 3 billion (Rosegrant, Ringler, and Gerpacio 1997).

Biodiversity

Biological diversity is reported to be rapidly declining at all levels. The cause of the decline is disputed, but includes the appropriation of land for agriculture and other uses, pesticide applications, climate change and changing atmosphere, and water quality. Reductions are reported in the worldwide diversity of species, the genetic diversity within species, and the diversity of agricultural ecosystems both across and within species.

Perhaps more important to agriculture is the loss of genetic diversity, the diversity of varieties grown by farmers, and the diversity available for future crop breeding. Loss of diversity of farmers' varieties may affect crop production stability in the short-run if pathogens overcome a large fraction of a single crop, as happened in the 1970s with southern corn leaf blight in the US. The corn leaf blight galvanized many plant breeders into incorporating diverse sources of resistance to known pathogens. The diversity available for plant breeding to protect potentially valuable alleles and gene complexes from genetic erosion is another long-term concern for genetic diversity. The importance of the CGIAR germplasm in providing a reserve of genetic diversity for crop plants is made more important by the decline in natural biodiversity.

Some link the adoption of modern crop varieties with the decline in genetic diversity in those crops. But the extent of genetic diversity incorporated in today's widely grown varieties is a matter of some misunderstanding because different varieties may or may not have greatly different genetic compositions. A large number of measures have been used to reflect genetic diversity within a crop (Meng et al. 1998). The number of varieties grown in a region, while straightforward, is a minimal reflection of genetic diversity because many varieties may be grown in a small area, giving little overall effect. An alternative measure, for example, the number of varieties that account for around 90% of an area, may be a better indication of diversity. This measure, while preferred to the former, does not account for genetic similarities among two or more varieties. To overcome this limitation, an index of species diversity based on the notion of genetic distance has been used to examine the potential association between diversity, average yield, and variability in yields within regions in China. A sophisticated quantitative analysis relating genetic diversity to yield variability failed to confirm any strong relationship (Widawsky and Rozell 1998).

Population Changes

The United Nations estimates that 2,000 years ago world population was about 300 million (www.popin.org/pop1998/4.html). It took 1,600 years for population to double to around 800 million in 1750. It doubled over the next 150 years to 1,650 million in 1900. Major growth was concentrated in Europe while the proportion of global population in Asia, Africa, and Latin America declined. Since then, global population growth has continued to accelerate, especially since 1950, and exceeded 6 billion in 2000. Another billion people will likely be added over the next 14 years, followed by another billion over the next 15 years. Thereafter a marked slowdown in growth rate is expected with an estimated 26 years required before the next billion is added.

Rapid growth in the demand for food and the need for employment and income have been major preoccupations of many concerned with global issues over the past 50 years. Indeed, it seems inevitable that global food production will have to double by 2020 and double again before there is any likelihood of population becoming stable in the late 21st century. Population growth today is most rapid in sub-Sahara Africa and South Asia, which are also the most food insecure regions. Significant continued efforts would be required to address these basic concerns over the next several decades. A new concern is the rapid changes in population demographics, such as the marked aging of populations. Japan and Western Europe are already experiencing this phenomenon, which endangers the competitiveness of labor-intensive activities like farming.

HIV/AIDS

Where HIV/AIDS has reached epidemic proportions it overwhelms other factors of change in terms of social impact, although ironically even in countries where it is at epidemic levels it has not led to significant reductions in population growth. HIV/AIDS incapacitates and adds a huge burden of care giving, but as the disease takes time to run its course, its impact on total population is limited.

Some 30 million persons are infected with AIDS worldwide. Of these, 26 million live in 34 developing countries, where 91% of all AIDS deaths in the world have occurred. In the 29 hard-hit

African countries covered in a recent UN study, "life expectancy at birth is currently estimated at 47 years, 7 years less than could have been expected in the absence of AIDS. In the nine hardest hit countries with an adult HIV prevalence of 10% or more, the average life expectancy at birth is projected to reach 48 years in 1995-2000, whereas it would have reached 58 years in the absence of AIDS. These countries include Botswana, Kenya, Malawi, Mozambique, Namibia, Rwanda, South Africa, Zambia and Zimbabwe (www.popin.org/pop1998/6.htm).

In eastern and southern Africa, farm production is threatened because AIDS is especially prevalent among young adults. In villages where the epidemic has struck, the very fabric of society is torn. AIDS incapacitates people for long periods; the healthy care for the dying and orphans, undercutting all normal activities. This commonsense observation is now being substantiated by empirical studies in rural areas (Pitayanon et al. 1998). Thailand and Uganda have moved aggressively and successfully to slow down the rate of spread of AIDS, but few other developing countries have, even where the epidemic is most advanced (Binswanger 2000). HIV prevalence exceeds 2% in many countries, including India, Brazil, and Cambodia, and unless effective steps are taken to curb the epidemic, it can rapidly progress to a crisis level.

Factors Determining Public Sector Research Resource Allocation

Political considerations motivate much of what is done in the name of international assistance. Those who have studied assistance by the US distinguish among four types, each with a different motivation (Gordon et al. 1996). One is support for the transformations underway in Eastern Europe and the former Soviet Union; and the transition to peace and regional security in the Middle East. This transitional assistance, driven by political foreign policy considerations, has more immediate drivers and receives a higher priority than long-term agricultural development. A second purpose is emergency relief in disaster and post-conflict situations. Although successful development can help avoid the need for emergency assistance, it is evident that emergencies will receive response, at times even requiring the shifting of funds from longer-term activities. A third type of assistance is designed to address global problems that affect developing and developed countries, such as climate change and international drug trafficking. The programming of these resources is handled by those charged with specific responsibilities for those issues.

General economic development, the fourth goal of international assistance, is directed at the long-term processes of change to improve the lives of people in developing countries. These core development assistance activities are directed at the poorest people in the poorest countries and motivated by the desire for a more equitable world. Development assistance agencies are appropriately focused on situations where market-driven economic activity does not address basic human needs either because of equity failures (situations where fairness argues for actions that meet the needs of the poor) or because of market failures (situations where economic actors cannot capture all the returns or are able to avoid some of the costs deriving from their possible actions). The particular case of market failures and public goods has attracted considerable attention within the CGIAR context.

Market Failure

Recognizing market failure is not simple, and recent popular discussions suggest there is confusion about the meaning of the term "market failure" as well as its relationship to externalities and public goods. Market failures exist when the price and quantity of goods or services in a market differ from the price and quantity that would exist if that market had many independent buyers and sellers, unfettered entry and exit, full information by all buyers and sellers, and no buyer or seller having the power to determine prices or quantities. A monopoly is a classic, extreme case of market failure.

Situations where a person needs a product but does not have the income to purchase it are sometimes called market failures but may also be viewed as equity failures. When the cost of drugs exceeds the purchasing power of an individual who needs them, that might be considered either a market failure or an equity failure. One may argue that the lack of income, by itself, is not a market failure, although it is a cause for public concern and action on equity grounds.

The failure of markets to address all economic needs is starkly illustrated by the lack of foreign investment in sub-Saharan Africa and South Asia during the 1990s. The wealthy world invested a total of US$ 130 billion in foreign direct investment in the developing world in 1998, with about 7% in South Asia and sub-Saharan Africa (Lancaster 2000). By contrast, these two regions together accounted for almost half of the absolute poor in the developing world.

Even when private companies do invest in the poorest countries, they invest in proven markets. For example, most African countries which had restricted seed production and sales to a government or parastatal company after independence, opened these markets to private companies following structural adjustment in the 1980s. However, companies that invested in seed markets concentrated only on hybrid maize and produced little or no pearl millet, sorghum, groundnut, or pigeonpea seeds. This, despite the observation from a study of seed systems in Kenya, Malawi, Zambia, and Zimbabwe that "in any given year at least 20-25% of seed will be acquired off-farm in most African farming communities" (Tripp 2000). The need for maize seeds is not necessarily greater than the need for other seeds, but because more maize is sold in well-functioning markets and because hybrid techniques protect hybrid seed from being copied, companies concentrate on producing hybrids and do not use scarce capital to invest in what they see as the lower profit potential of other seeds. Thus, there appears to be a market failure in the case of non-hybrid seeds in sub-Saharan Africa.

Public Goods and Externalities

Public goods are products or services characterized by two conditions – first, that persons cannot be excluded from consuming a product or service, and second, that one person's use of a product or service does not diminish another person's ability to use it. Economists have called these two key characteristics of public goods non-excludable and non-rival, respectively. The classic public good is national defense. No one in a society can be excluded from receiving the benefits of national defense and the addition of more members to society does not reduce the service that national defense provides to the whole society. Another way of thinking about the non-excludable nature of public goods is the inability of the producer to find a way to make people pay for consuming the product or service. Public goods can be national, but alternatively can have a sub-national, global or international nature.

The term "public goods" has begun to be used by non-economists in a different way. Sometimes the context suggests that any product or service that advances public well-being is a public good, for example, providing more reliable electricity service. In rigorous economic terms, reliable electricity service is not a public good because the person receiving it generally must pay to use it (i.e., it is not non-excludable), and the use of it by one person means that another person cannot also use that same electricity (i.e., it is not non-rival).

Another point of potential confusion between economists and non-economists is the desirability of public goods. There is no doubt that most people believe that improving the general public welfare is something positive, but not all public goods are good for the public. They may have negative as well as positive effects on public welfare. Global greenhouse gases are a public good because no one can be excluded from consuming them and one person's consumption is not reduced by another person's.

Many products and services have some elements of a public good nature without being pure public goods. That is, persons may be excluded from their consumption under certain conditions or their consumption is partly rival. Quasi-public goods or impure public goods have both of these characteristics in part. Cornes and Sandler (1996) provide a comprehensive analysis of the theory of externalities and public goods.

Open-pollinated and self-pollinated crop varieties (in contrast to hybrids) have characteristics of public goods. Once a variety exists and is in common use, it is difficult to make a farmer pay the plant breeder for it or to prevent another farmer from planting it. Nature makes copies of the original variety and farmers can purchase seeds from a friendly neighbor who has excess grain to sell. It is difficult to exclude farmers from using grain thus produced for seed. In this case the variety is a non-excludable good. Likewise, one farmer growing the variety does not prevent another from growing it too.

However, a newly developed variety is not a pure public good because for some time after its development potential users can be excluded from growing it – they must obtain the seed from one of the few producers who have seed of the new variety. After several seasons, seeds are plentiful and use of the variety is non-rival and non-excludable and becomes very nearly a public good. Hybrids by contrast are not public goods because their seeds must be obtained from a producer who crosses two (generally secret) parent lines in a specialized process. Unlike ordinary varieties the grain produced by a hybrid does not produce more of the same, at least not of the same quality.

It is also notable that crop varieties may be non-rival and non-excludable after they have been available for some time and hence old varieties are public goods while newly developed varieties are private goods. On the other hand, the seeds of any crop that one farmer plants that cannot be used simultaneously by another, are clearly private goods. Their private goods nature is confirmed by the common practice of selling seeds – they simply are not available without payment. By definition, public goods are.

Changes in Market Failure and Public Goods

Market failures are not fixed. They change continually and new markets emerge as technology and institutions change. Prior to the mid-19th century there was no market for rights to the electromagnetic spectrum. But after radio was invented the electromagnetic spectrum became the subject of a series of international treaties governing its use. In 1865 the International Telegraph Union was created with the adoption of the first Convention by 20 countries.[2] The invention of the telephone in 1876 was followed by an agreement on its use in 1885; the first voice radio transmission in 1902 was followed in 1906 by the Berlin International Radiotelegraph Conference; the first broadcast radio in 1920 by international agreements on its use in 1927; and so forth through to television, the launching of Sputnik, communications satellites, cable TV, and cellular telephone.[3] It would be difficult to argue that the electromagnetic spectrum is a public good today although the laws of physics that determine its use are unchanged. What have changed are the technologies available to exploit electromagnetic waves and the laws society has enacted to regulate their use.

Little thought was given to property rights in plants until the invention of DNA-based technologies which made it possible to identify biological organisms with virtually any desired degree of

[2] *http://www.itu.int/itudoc/about/itu/history/landmrks_e_5517.txt.*
[3] Ibid.

precision. Until then the incentive for private companies to invest in developing new plant varieties other than hybrids was limited because of their quasi-public goods nature. Plant varieties were identified by the way they looked in the field and it was impossible to prove that any particular plant was or was not any particular variety. Today DNA-markers make it possible to pick out the presence of a gene if it appears in as little as 1% of maize grains in a truckload of grain. Varieties can be identified with absolute legal certainty from the DNA in the seed or from a small piece of leaf. Where property rights in plants are recognized, DNA-based identification and property rights protection have changed crop varieties and their seeds from being quasi-public goods to being nearly private goods, and private firms have responded with growing investments in their production and sale.

Challenges for Agriculture

The broad changes influencing the earth and the human species in the 21st century have innumerable interconnected implications for agriculture and nutrient management. Some interactions of socio-economic changes with biophysical and technological changes seem clear from this vantage point, while others will surely catch us by surprise. It seems certain that it will be necessary to produce a lot more food on the same amount of land with less water and less labor. It also seems certain that over the long run society will demand similar environmental standards from agriculture as it demands from other sectors. This means that externalities will increasingly be internalized or regulated in some way. Other, as yet difficult to envision changes will influence developing country agriculture.

Experience has shown that raising agricultural productivity in poor countries can be achieved and is a key element in ensuring food security. The relative success in reducing the proportion of hungry people in many developing countries over the past 20 years is quite an achievement, in light of the dire predictions of the 1960s. Some countries performed better than others. Smith and Haddad (2000) analyzed the experience of 63 developing countries in reducing child malnutrition between 1970 and 1995. In 1970 about 46% of developing country children under five were underweight for their age; this dropped to 31% by 1995. By comparing the differences across countries the analysis measured the effect of four direct determinants and two underlying determinants of malnutrition.

"Improvements in women's education have contributed by far the most, 43%. This contribution is the combined effect of both the strong effect of the determinant and a fairly large increase in it over the period...Improvements in food availability have contributed around 25% of the reduction in child malnutrition, not only because the effect of this variable is strong but also because increases have been substantial, rising from 2,092 kilocalories per capita in 1970 to 2,559 in 1995" (Smith and Haddad 2000). In sub-Saharan Africa, "Changes in food availability have played a very large role overall. However, the role was not always positive. Substantial improvements in the later 1980s and early 1990s were outweighed by deterioration, for the most part during the 1970-85 period," (Smith and Haddad 2000). Thus local food production that contributes to food availability is especially important in combating child malnutrition where overall levels of food availability are low. In countries where food availability is relatively high, such as East Asia, West Asia, North Africa, and Latin America, national food availability and improving women's education were not as important as local food production and improved food availability.

A key requirement for increasing national food availability in many countries is increasing agricultural productivity and income. History shows that the key requirements for increasing agricultural productivity are productive small-scale farms, well-functioning markets, adequate economic incentives, available inputs, and dynamic technology. Every country that has progressed from a poor, rural condition to a sustained higher income level has based that process on dynamic, small-scale farms. The US was a nation of small-scale farmers until about 1930 when the trend to off-farm migration and larger farms became well established. By that time only about 30% of the population was dependent on farming for a living and incomes reached a moderately high level (Wilcox, Cochrane, and Herdt 1974). Most of Europe followed a similar path later. Japan and Taiwan also built their development on small-scale farms, and still have few large farms (Barker, Herdt, and Rose 1985). After the communists came to power the Soviet Union imposed a policy of large-scale, collectivized farming that only continued with substantial state subsidies. Russia is still suffering the aftermath. China's experience with large-scale, collective farms was so dismal that pragmatic forces brought in the responsibility system in the mid-1980s, and China returned to the small-scale farm base which, with appropriate policies, unleashed dynamic agricultural output growth.

Well-functioning markets are needed for growth because without them farmers cannot deliver products or obtain inputs. A key element in a well-functioning market is timely, accurate prices so farmers know prices in various markets and can direct output accordingly. Modern communications technology in the form of cell telephones is making an important contribution to the flow of market price information in some places. Another element in well-functioning markets is accurate, enforced grades and standards. Without reliable grades that are understood, information on prices and availability of goods is incomplete. Enforceable contracts are yet another element in well-functioning markets because if a buyer fails to pay with impunity, sellers will trade only with those they know and the market will become inefficient. A good transportation system is, of course, needed for a well-functioning market. The government has several important roles in ensuring well-functioning markets including the institution or supervision of grades and standards, legal enforcement of contracts, and provision of good roads. Well-functioning markets transmit price signals that lead farmers to increase production in response to demand, if inputs are available and technology makes such a response possible.

Innovations in farm production technology include not only genetic innovations but also crop management innovations. The importance of crop management innovations is illustrated by many studies that compare the yields of varieties when grown on experiment stations and nearby farmers' fields. In sub-Saharan Africa, typical yields on farmers fields are in the range of 1-2 t/ha while on nearby experiment stations 4-6 t/ha are common. Reasons for differences include a whole complex of crop management practices that experiment stations follow as compared to farmers: land preparation, crop establishment methods, time of planting, water management, pest management, fertilization, weed control, and so forth. Even when effort is made to duplicate experiment station practices on farmers' fields as closely as possible, the yields are typically much lower at early stages of development. By contrast, in advanced countries, farm yields are typically higher than experiment station yields because farmers have superior knowledge of their particular fields and how to manage crops optimally.

Implications of Global Change for Public International Agricultural Research

The rest of this discussion teases out the consequences of global changes for publicly supported international agricultural research, and specifically the implications for allocations among genetic improvements, crop management, and policy improvements.

Biotechnology and Institutional Change

The combination of changes in biotechnology with changes in property rights have led to an explosion of private investment in research directed at crop genetic changes over the past 20 years (James 2000). This investment is now bearing fruit in the form of new seeds in farmers' fields in the US, Canada, China, and Argentina. Despite the opposition of some, the technology, largely driven by private investment, seems destined to find its way in the world. To the extent that it is directed at developing country crops or has spillover effects on those crops, the developments generate increased opportunities for private research activities to produce genetically changed crops for developing countries.

These same developments attenuate the public goods nature of newly developed crop varieties by increasing the ability of the developer to identify with legal certainty products of the developer's efforts (through DNA fingerprinting). Where the legal regime permits, the developer can exclude non-payers from using those innovations (or enforce the requirement of a payment on users). As already noted, seeds themselves are not non-rival because the seeds one individual plants cannot be planted by another. DNA fingerprinting and property rights now have created the possibility of charging users who plant the progeny of protected lines. In other words the second requirement of a public good, non-excludability, has been lost through the combination of DNA and property rights. Of course, in jurisdictions where property rights in plants are not recognized, that element of the public good nature of crop varieties remains.

It is precisely on this last point where the TRIPS provision of the WTO comes into play. By 2005, all countries must have in place a provision to protect property rights in biological organisms like seeds. The precise kind of property rights adopted will make a considerable difference. If plant variety protection is adopted, it may be possible to use new varieties as the basis for further plant breeding and farmers may be able to save seeds from their own harvest to use in planting subsequent crops. If patents are adopted as the property rights protection regime, both these practices will be prohibited. In both cases, however, the public goods nature of crop varieties will have been lost. If the strong property protection afforded by patents is adopted, then the public goods nature of seeds also will have been lost.

Several consequences follow from this set of developments, implying the need for greater public research investment outside of traditional germplasm improvement. First, CGIAR institutions will have to devote more resources to understanding the intellectual property regime and more resources to protecting, in the public interest, genetic resources that have been obtained with public funds. Second, over time private companies will produce and sell more seeds in developing countries, thereby reducing the need for public seed development and sale. The speed of these developments will vary across countries with private companies seeking to serve first large markets like India, China, Brazil, and Mexico, and later smaller, less developed markets. In any case, international public sector crop variety development efforts will need to focus more sharply on crops and markets that private firms do not address.

Global climate change presents a pervasive, global challenge to agriculture. All three elements – genetics, management, and policy — will have to be brought to bear in adjusting to global climate change over the coming century or two. It seems difficult to argue in the abstract that any one of the three research categories is inherently more important for adjusting to global climate change than any other. It does seem likely that research that facilitates adjustment to violent, short-run changes will have increasing value, and all three areas might be seen to contribute.

Crop Management and Labor Productivity

It is now clear that the rate of population growth is slowing in most countries although the absolute growth in global population will continue to be nearly a billion people every 15 years over the next few decades. Producing the food needed for people in the developing world will be a challenge. The effects of high levels of HIV/AIDS are more immediate. This is especially true in sub-Saharan Africa, although it may become as great a challenge in other countries that do not give high priority to preventing its spread in the coming decades. If such places are not to become even more dependant on the outside world for food, they will need to increase food production with attenuated labor availability and minimal capital. No currently developed region has been challenged with a shortage of both labor and capital at the low income level current in sub-Saharan Africa. A new kind of agricultural intensification will be required, one that uses small amounts of capital and labor together with genetic and crop management knowledge to increase production per unit of land and per unit of labor. Gordon Conway (1997) calls this a "Doubly Green Revolution".

Genetic improvement, both generated conventionally as well as through biotechnology, has a role in the Doubly Green Revolution. However, a radical increase in crop management research for a deeper understanding of the processes under tropical conditions may be the primary new requirement. The processes of nutrient supply from organic matter, the identification and optimal integration of legumes in grain-based cropping systems, the interactions of plants, soils, and water, the relationship of plant physiology to insect and disease attack, and other detailed interactions of plants and environmental factors will have to be understood much better than they now are if techniques for managing crops for sustainably higher yields in the tropics are to be developed. The general area of crop management research will thus have to receive a much higher priority by international agricultural research organizations in the future compared to the past. This is not routine applied research on optimal fertilizer rates or timing, or the killing power of specific pesticides on insects, but rather research to understand the basic biological processes that underlie the mineralization of nutrients from biological sources, the biological soil processes active in different circumstances, the interactions of plants with soils and water, the options for legume-grain systems, and the agroecology of crop production in the tropics, including the role of pests and pathogens.

A comprehensive understanding of these phenomena, developed with the deliberate objective of devising more productive ways to grow crops in the tropics, should yield results. Such knowledge, if developed, is unlikely to be associated with a product or process that can be protected with property rights and hence will be a public good. Existing systems of intensification appear not to be sustainable in the tropics and even though impressive examples of alternatives to conventional intensification appear to offer extraordinary opportunities for productivity gains, they are being ignored by crop management research establishment. For this reason the international agricultural research establishment has a growing comparative advantage in such crop management research and should increase its relative investment in such research.

Falling Productivity

Stagnating yields in the rice-wheat system in the Punjab of India and Pakistan more than a decade ago led to an organized international effort to understand those changes (Hobbs, Giri, and Grace 1997). Declining yields on the IRRI experiment station where rice was continuously cultivated raised questions 20 years ago that remain unresolved. In fact, after a review of the evidence, two accomplished analysts conclude: “Particularly disturbing is the complete lack of long-term experiments on irrigated rice systems which document that it is even possible to produce sustainable increases in rice production over time" (Cassman and Pingali 1995).

These challenges seem associated with loss of soil quality and increased soil health problems. A recent comprehensive quantitative analysis of the factors that affect crop yields in farmers'fields in the Punjab indicates that the effects of controllable production factors like varieties, fertilizer, pesticides, and quantity of irrigation water are being offset by deterioration in the quality of soil, water, and other biotic stresses (Murgai 1999, Ali and Byerlee 2000). A similar analysis for China has linked several indicators of soil stress to reduced productivity (Huang and Rozelle 1995). But there are also worrying observations when one closely examines trends in controlled long-term experiments even in temperate areas.

For example, in many situations, crop yields decline over time when inputs are held constant and increase only with application of increasing amounts of inputs or genetic improvements, and complete offset is not always possible. "Development of higher yielding varieties which are more water efficient and disease resistant appears to be unable to overcome the decline in biological sustainability in the semi-arid Pacific Northwest" (Duff, Rasmussen, and Smiley 1995). In Missouri, an analysis of long-term trial data from the Sanborn Field indicated that the continuous culture of wheat without the use of fungicides and insecticides was not sustainable even when adequate nutrition was supplied (Brown et al. 1995). These results suggest that even in temperate regions maintaining yield and long-run productivity requires continuous adjustment in cultivars and cropping practices, generally with more inputs per unit of output.

Thus, the dark side of intensification is beginning to emerge from experiments as well as farmers' experiences and their recognition is becoming more widespread. "It is now clear that agricultural intensification can have negative local consequences, such as increased erosion, lowered soil fertility, and reduced biodiversity; negative regional consequences such as pollution of groundwater and eutrophication of rivers and lakes; and negative global consequences, including impacts on atmospheric constituents and climate" (Matson et al. 1997).

Extraordinary Productivity Gains

At the same time as these challenges to conventional intensification are appearing, reports of extraordinary productivity using unconventional approaches are surfacing. However, in many cases the crop management establishment seems reluctant to pursue these reports with proper research – an almost anti-science attitude. Each of the systems described below has either been ignored or ridiculed by the mainstream international agricultural research establishment. But each provides a challenge to our understanding of conventional crop management.

The first system is the System of Rice Intensification developed by Tefsay Saina, a non-governmental organization in Madagascar (de Laulanie 1993), and "discovered" by Norman Uphoff, a political scientist at Cornell. In this system rice seedlings as young as eight days rather than the usual 21 to 30 day-old-seedlings are transplanted; seedlings are spaced 25 cm apart, which is considerably wider than normal; one seedling per hill is transplanted compared with the usual practice of 5-9 seedlings per hill; the paddy fields are saturated for transplanting and allowed to dry periodically through the season, but standing water is avoided. If it does not rain, water is added to a depth of one or two cm and fields allowed to remain dry for several days before water is added again. The first weeding is done 8 to 10 days after transplanting and 3 or more times thereafter with a rotary push hoe; composted manure is applied. The plants tiller profusely and produce yields in the range of 8-10 t/ha in areas where most farmers get less than 2 t/ha (Uphoff 1999). Questions abound about this system: does it use more or less water than the old? Do production gains more than offset its labor use? Does its yield advantage persist in other soils? What is the source of nutrients?

A second example of an unusual technique providing apparently high efficiency is growing maize in "pits" in the Njombe District in the southern highlands of Tanzania. The dominant soil is red kaolinitic clay with moderate natural fertility and medium to high water holding capacity. Under conventional tillage this soil type degrades quickly through compaction, and plant rooting is shallow. Apparently developed by a local farmer, the technique "involves digging pits 60-120 cm in diameter, 30-60 cm deep, and 75-100 cm apart. Crop residues and manure (one bucket of 20 liters) are put into each pit and mixed with topsoil, 20-25 maize seeds are then sown in each pit and later thinned to 15-18 plants depending on the size of the pit. He top-dresses the pits with a mixture of manure slurry from the kraal floor and urine collected with his piped system" (Temu et al. 2000). The farmer harvested 20 bags/acre with the technique as compared to 5 bags/acre when planted the conventional way. A quick survey of farmers in several villages of Njombe District in June 1999 found that 71 farmers had already adopted or were adopting the innovation. Does this system work equally well in other soils? What are the long-term effects of such practices?

Deliberate mixing of species or genotypes in one crop field is a mark of traditional farming often thought to be a risk aversion strategy to combat yield variability. It may also promote greater output by reducing pests and pathogens. A recent report of a large-scale experiment to test the idea provides dramatic evidence supporting this hypothesis. Farmers, researchers, and extension personnel in five townships in Yunnan, China, cooperated to compare monocrop rice production (single variety) and mixed-variety stands (Zhu et al. 2000). Hybrids normally are planted on over 95% of the fields and yields commonly approach 10 t/ha.

Foliar fungicide application is common. Glutinous or sticky rice varieties are highly valued for their use in specialty foods, but they are highly susceptible to the blast disease. One row of blast-susceptible sticky rice was planted between four rows of blast-resistant hybrid rice. In 1998 farmers followed the procedure on 812 ha and in 1999 it spread to 3,342 ha. Land equivalent ratios "indicate that an average of 1.18 ha of monoculture crop land would need to be planted to provide the same amount of hybrid and glutinous rice as were produced in 1 ha of a mixture," (Zhu et al. 2000). By the end of the two-year program fungicidal sprays were no longer used. Research to understand the extent to which such biological control methods work on other cropping systems is woefully lacking.

Achieving food security for people in developing countries requires biological and physical technology as well as systems that generate incentives for farmers to use the technology, in the form of income, or if not income at least from rising asset values. In Malawi, where hybrid maize and fertilizer spread fairly rapidly during the late 1980s and early 1990s, it was evident that production of hybrid maize with fertilizer application rates of around 50 kg of nutrients per hectare produced significantly more maize than local varieties without fertilizer (Smale et al. 1991). Local production reached a level about adequate to meet local consumption needs, and as maize is the local staple, this is an important national objective.

The Washington Consensus mandated structural adjustment and the elimination of all government subsidies in Malawi, including subsidies on fertilizer in the mid-1990s. Fertilizer use declined sharply along with maize production. The Malawi government was unable to meet import needs and appealed to donor governments for food assistance. In 1997, a starter pack with small quantities of fertilizer, legume seed, and maize seed was developed for distribution to individual farmers. The starter pack idea was converted into a national program and in 1999 reached 2.6

million households cultivating less than 1 hectare of maize, increasing maize production dramatically. In this case, a small quantity of free fertilizer that was imported and distributed made the importation of a much larger quantity of food unnecessary.

The challenge for the government and donors in Malawi is to develop a set of policies and procedures that can function on an ongoing basis, in the face of the global consensus of market reliance. International agricultural research has the opportunity to illuminate the policy choices for decision makers, if adequate resources are put into such research.

Conclusion

Should the CGIAR change its allocation of resources among research activities? The generalizations are easy: public expenditures should offset inequity, offset market failures, and produce public goods. Table 1 shows how CGIAR allocations of research funds have changed over the past five years.

Resources for germplasm enhancement and plant breeding remained essentially constant from 1995 to1999. Resources for germplasm conservation and maintenance have also been about constant. In contrast, resources for production systems have declined by about US$ 10 million over the five-year period, while resources dedicated to environmental protection have increased substantially. The biggest changes have been in policy research and

Table 1: Allocation of CGIAR research funds, 1995-99

	US$m		
Activity	**1995-96**	**1997**	**1998-99**
Germplasm enhancement and breeding	62	64	61
Production systems	70	69	60
Environmental protection	50	57	66
Germplasm conservation and maintenance	33	35	36
Policy research	32	37	43
Strengthening NARs	61	70	75

Source – Consultative Group on International Agricultural Research: Financial Report. 2000.

strengthening NARs, which increased by US$ 11 million and US$ 14 million, respectively, from 1995 to 1999.

The global changes reviewed earlier have the effect of increasing the comparative advantage of private research in varietal development and of increasing the comparative advantage of public research in crop management. This follows from the increasingly private goods nature of crop varieties, driven by the DNA revolution combined with the extension of intellectual property rights to plants. No comparable changes have taken place on the crop management side. There, knowledge of cropping systems, nutrient management, pest management, water management, and the whole complex area of crop agroecology retain their public goods nature. If anything, that public goods nature is enhanced by the exploding availability of computer-based communications and information.

Public research institutions will need the ability to deal with a world of increasing property rights for crops, and will have to increase their investment in Intellectual Property Rights (IPR) management capability. They must also continue to protect and make available germplasm resources held in gene banks in the public interest. However, variety development is increasingly being done by private companies and the CGIAR should recognize its declining comparative advantage in that area by sharply focusing plant breeding on developing specific traits valuable for regions and crops the private sector neglects. On the other hand, there is nothing on the horizon of changes that suggest the public goods nature of crop management will change. Questions about the long-term effects of the current style of crop intensification and the possible opportunities offered by non-conventional approaches increase the need for crop management research in the public sector. The CGIAR seems to have reduced its investment in this critical area just when it should have increased its investment.

Without the knowledge of how to increase productivity it will be impossible to protect the environment, so substituting the environment for productivity in the CGIAR research portfolio is bound to fail. Without focused attention on increasing the basic knowledge of crop management in the developing world, a Doubly Green Revolution is not likely to become a reality. That would be a grave situation for the developing world.

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