Agricultural Education, Science and Modern Technology’s Role in Solving the Problems of Global Food Resources in the 21\textsuperscript{st} Century\textsuperscript{*}

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I. Introduction

The growth of agriculture output over the past 200 years has been phenomenal. When Malthus wrote in 1798, he perceived limits on agricultural production as serious and imminent. Since then world population has increased by six-fold and global agricultural production has more than kept pace. Falling real grain prices for most of the 20\textsuperscript{th} Century are cited as evidence. The sources of the increase in food production, however, have been quite different and have come in distinct waves. For most of the 19\textsuperscript{th} Century, increased output came from expanded land area in production. Science-based agriculture is really a post-Mendel phenomenon.

In the 20\textsuperscript{th} Century, new technology came in different forms. First, mechanical technology, particularly the tractor, made possible cultivating more acres and freed enormous areas used for producing fuel for draft animals, for food production. Improvements in breeding and agronomy in the middle part of the century opened the possibility of substantially increasing yields per unit of land through the use of chemical fertilizers and pesticides. A large part of the increased output in the 1950s, 60s and 70s came from increased input use on more responsive

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plants, e.g., the Green Revolution. In the latter part of the 20th Century, land area expansion became less and less important as a source of production increase. However, altering the intensity of land use through greatly expanded irrigation played a significant role throughout much of the 20th Century. But in general science and technology have played an increasingly important roles in meeting world food needs in the 20th Century.

As we look to the 21st Century, this conference is asking a critical question about the role of knowledge, science and technology in meeting future global food needs. It is that question I will attempt to address today. To give you a preview, I will argue that integrated knowledge, based on many strands of science, will have to be the source of almost all food supply increases in the next century. Therefore, how we train agriculturalists is absolutely central to solving the problems of global food resources in the 21st Century.

Let me begin by reviewing the challenge to the global food system that lies ahead. Then I want to set that challenge in the broader context of the radically changed global setting in which the global food system will operate. Next I will ask what the implications of these two sets of factors will be for food and agricultural systems in the 21st Century. Finally, I will draw out what the implications are for agricultural science, technology and education.

II. The Challenges Facing the Global Food System

The challenges facing the global food system begins with the demand challenge – how much food is needed? But meeting food needs, or food security as I call it, has three dimensions: (1) availability – can enough food be produced? (2) access – will all people have the necessary income or support to have continuous access to sufficient food to lead a
productive life?; and (3) nutritional security – will people have the knowledge and live in a healthy enough environment which allows effective utilization of food to achieve nutritional security. I will focus most of my attention on the demand and supply (availability) dimension with only brief comments on the access challenge. But remember, adequate supplies are a necessary but not sufficient condition for food security.

A. The Demand Challenge

In less than two years, we will enter the 21st Century. By the end of the first quarter of that 21st Century, 2025, world population will approach 8 billion people, an increase of 2-1/2 billion from the 1990s. Recent projections suggest something less than 8 billion but still project a more than 2 billion increase. Nearly all of this increase will be in developing countries. The population of sub-Saharan Africa will for example more than double.

But the increase in the number of mouths to feed is only part of the challenge. Income growth also drives the demand for food. With modest income growth, food needs in the developing countries could double in the next 30 to 40 years. Further, in this same period, population in developing country cities will increase by about the same number, 2-1/2 billion people. With rising incomes and urbanization, the composition and characteristics of food demand will be significantly different.

These developments described on the demand side raise fundamental questions. Can the world produce enough food to feed 7-1/2 to 8 billion people and at the same time hopefully reduce the number of undernourished to below the current level of 800 million? If so, where will it be produced? Will we break away from the mind set of equating food security with national food self-sufficiency and ask where the food should be produced? Can the food
system of the future meet the challenge of processing, distributing and storing a nutritious food
supply for billions more people in the next century? And finally, does the world have a trading
system that will allow increasing quantities of food to flow from surplus to deficit areas?

B. The Supply Challenge

There are widely differing views on the difficulties of meeting food needs in the 21st
Century. Those using economic projection or simulation models, based significantly on history,
tend to project sufficient global supplies until at least 2010 (Agcaoili and Rosegrant, 1995;
Those projecting on the basis of resource availability and environmental constraints (perhaps
these should be called ecological modelers) are generally much more pessimistic. The most
extreme view combines resource constraints with biological yield pessimism and foresees
serious problems ahead, as do Brown and Kane, for example. The very nature of projections
using compounding growth rates of population and income compared to compounding growth
rates in yield means that food gaps grow rapidly if the growth rate of demand exceeds the
growth rate of supply. On the other hand, if supply growth rates exceed demand growth rates,
food prices fall. The latter has been the predominant outcome in the 20th Century.

How can these economic optimists on one hand and the ecological pessimists on the
other hand reach such different conclusions in projecting food supply potential to the future?

In my judgment the optimists are too optimistic and the pessimists are too pessimistic.
Reality suggests that feeding 2 to 2-1/2 billion more people will be an enormous challenge.
Growth in agricultural output in the long term must come primarily from rising biological yields,
rather than from area expansion or intensification through irrigation. Why? Because most fertile
land is under cultivation and the really suitable and low cost areas for irrigation have already
been exploited. With population growth and urban expansion, there will be rising competition
for land and water from urban and industrial uses. Therefore, doubling yields in complex
farming systems without damaging the environment is an enormous challenge.

Because of the projections of urbanization and income growth, the composition of output
will clearly change. IFPRI projections, for example, forecast a 180% increase in meat demand
in developing countries. Where will the feed come from? Will China, for example, expand feed
grain production to produce its own meat or will it import meat directly? New demands for
fruits and vegetables will also shift cropping patterns. Overall, there could be significant shifts in
the location of global production.

The challenge ahead is worldwide and is both technological and political/economic in
nature. We require a new technology that allows the development of new high productivity and
environmentally sustainable production systems. It cannot be more of the same, with
purchased-input-intensive monoculture. And the political/economic challenge can only be met if
international and domestic policies, institutional frameworks, and public expenditure patterns are
conducive to sustainable agricultural development.

C. The Access Challenge

But supply is only one part of the food security challenge. The second part of food
security challenge is about access to food. Here the issue is clearly the reduction and elimination
of poverty. In the developing world, in which the World Bank mainly operates, that remains a
predominantly rural challenge. (World Bank, 1997) Seventy percent of the poor people in the
developing world still live in rural areas. For this challenge to be met, it will require improving the productivity and profitability of millions upon millions of small farmers.

To do this, farmers will need new, appropriate technology. Here the role of biotechnology should be critical if it can be applied to the crops of complex farming systems in the tropics and subtropics. As we break away from the heavy focus on basic food crops - rice, wheat, maize - to more diversified production systems involving all crops, animals and trees, research needs are likely to be very large.

Profitability will come from increased market orientation as farmers produce food and fiber for domestic and international markets. Here the critical issues are appropriate policies and incentives.

If we can meet the challenge of improving the well being of farmers, we will also have the additional benefit of encouraging farmers to be more effective stewards of the world’s natural resources. Virtually all of the arable land in the world is managed by farmers and most of the fresh water in the world is used by farmers. Therefore the issue of improving the welfare of rural communities, by improving the profitability of agriculture, is a triple win situation. It contributes to poverty reduction, it contributes to food security, and it contributes to improved natural resource management.

III. The Changing Global Context

Let us review the context within which the last doubling of the food supply occurred – 1960-199. In the 1960s there were dire predictions of famine. Yet the world did remarkably well in providing adequate global supplies of cereals. In the period 1960-1990, global cereal
production doubled, per capita food availability increased 37%, per capita calories available per
day increased 35%, and real food prices declined 50%. But even with these good indicators of
overall global performance, there were substantial regional differences. Average calories
available per day increased significantly in the Near East and North Africa, East Asia and Latin
America to levels of 2700 calories per day or higher. South Asia grew more slowly and still is a
region with significant undernutrition, but in the same period per capita food availability in sub-
Saharan Africa decreased, as a result of a combination of high population growth rates and slow
and sometimes negative growth rates in agricultural production.

These results came from the Green Revolution and rapidly expanding production in
developed countries based on conventional genetic improvement and intensified monocultures
using high levels of fertilizer application. The policy environment in most countries was
protective and inward looking. Farmers in rich countries were subsidized, receiving high
guaranteed prices which encouraged intensification. Farmers in poor countries were taxed
(Schiff and Valdes). The GATT trading system for agriculture was highly distorted and world
trade in grains stagnated.

How different is the world going to look in the 21st Century? Vastly different. Why?

Let’s start with global mega political and economic trends that will profoundly affect the
world food system. Let me simply list a few.

- **Globalization** – integrated capital and financial markets will link domestic economies’
  monetary and finance sectors like never before.

- **Trade Liberalization** – the new WTO, and in particular the agricultural accord, will
  link more countries, more intimately than ever before.
• The Decline of Socialism and the Ascendancy of Markets – there are fundamental changes in national economic paradigms, influencing the process of development.

• Changing Public/Private sector roles and the drive for privatization.

• Democratization – in Latin America, Eastern Europe, Asia and some of Africa, democratic forces are on the ascendancy.

• The Rise of the Civil Society and growing focus on decentralized, participatory approaches to development.

• Fiscal Conservatism leading to expenditure constraints on the public sector, a particularly crucial issue for the agricultural sector.

• The End of Bipolar Global Politics but a precipitous rise in regional and national armed conflicts, and in global terrorism.

All of these trends, plus more, taken together radically alter the environment of the world food system. But there are more big differences, more specific to the food system:

• Biology is still in the early stages of applying the incredible advances in molecular biology through biotechnology;

• Global warming – evidence strengthens yearly that long-run global temperatures are rising and that weather variation is increasing (El Nino);

• We are in the midst of a revolution in information technology which has already radically changed the way we see each other, do business and do science;

• Environmental concerns are still increasing, not just because of global warming. Concerns with pollution, loss of biodiversity, deforestation, health and sustainable resource use – have and will continue to impact on agricultural production systems;
• Resource competition – rising population, urbanization, industrialization and environmental demands will all increase competition for agriculture’s historical virtual monopoly on arable and land fresh water.

Again, I could go on but you get the flavor. The global food resource system in the 21st Century will evolve in a very different environment and will face very different challenges than the past 50 years.

IV. Impact on Global Food System

I have argued that the global food system faces unprecedented challenges in the 21st Century. Can these challenges be met? On the production side, I believe we can do it, but there are four BIG IFs:

1. IF we can develop sustainable production systems capable of doubling output; this requires attacks on all fronts, ecology, soils, agronomy, breeding, farm management, pest management, etc.: all in a systematic way which increases the productivity of complex farming systems. We cannot focus only on increasing the yields of single commodities grown in monoculture. It is an unprecedented challenge for agriculture and biological science.

2. IF we have in place domestic and international policies and institutions that do not discriminate against agriculture and provide appropriate incentives to hundreds of millions of farmers around the world; we must do away with policies that tax agriculture, e.g., over-valued exchange rates, industrial
protection, and low-priced food requisitions, as well as policies which distort farmers’ incentives. (Schiff and Valdes)

(3) **IF** we continue in invest in public agricultural research such as through the CGIAR; and build stronger partnerships with the private sector to tap the enormous potential of modern molecular biology for the small and poor farmers around the world.

(4) **IF** we stay the course with removing distortions to freer agricultural trade. The Marrakech Agreement of 1994 put agriculture under rules of GATT/WTO for first time. It requires: (1) tarification of all non-tariff barriers (NTBs); (2) reductions in domestic support; (3) reduced import barriers; and (4) lower export subsidies. This will make a more level playing field for developing countries. This is critical because as countries move away from self sufficiency, they must be able to use world markets. They must be assured of access and should expect reasonably stable markets. Therefore the agricultural negotiations scheduled for 1999-2000 should focus on reducing levels of protection in OECD countries thereby providing improved access for developing countries.

These will all help in making food supply available.

But there are several critical questions.

(1) **What can we assume about the rate of the increase in biological yields?**

Economic modellers point to 2-3% increase in production in 1960-1990 but even projecting lower rates of 1.5-1.7% per year in the future still produces more rapid supply growth, as the population growth rates assumed have fallen even more rapidly.
They are optimistic about the potential of biotechnology. Ecological modellers point to yield increases in 1990s of less than 1%, yield stagnation in intensive irrigated systems, e.g. triple cropped rice in the Philippines (IRRI), and a decline in yields in rice/wheat systems in South Asia. They are very skeptical about biotechnology solving all problems.

(2) **How much land will be added to or lost from agricultural production over the next 30 years?** Area expansion contributed significantly to output increases in the past 30 years. Modellers continue to assume some increases but less than in the previous period. Ecologists and Lester Brown argue that land lost to urban and industrial use, plus degradation of existing land, means less available land than in the past. They argue that any new land brought into production would be ecologically fragile and environmentally sensitive.

(3) **How much land can be subjected to increased intensification through irrigation and/or changed cropping patterns?** This had a big impact in past 40 years as irrigated acreage in developing countries doubled. Cropping intensity increased as shorter duration varieties were bred to allow 2 instead of 1 crop per year, or 3 instead of 2 crops per year. This, combined with irrigation, had a significant impact. The economic modelers project continuance of this trend though at lower levels. Ecologists argue that there will be no more new irrigation, increased competition for water and significant land degradation.

(4) **And what will be the impact of environmental degradation on food production capacity?** Modellers tend to ignore this issue. Ecologists see it as a big issue - land
loss, through erosion and water pollution, will be constraints. Water quality will decline.

Range lands are over grazed and fisheries are depleted. In their mind this will be a major constraint to future production growth.

The bottom line is that virtually all of the increase in production globally will have to come from knowledge-based intensification, using modern science and biological technology – genetics, agronomy, pest management, resource management and improved capacity to deal with biotic and abiotic stresses. Land expansion and intensification through capital-intensive irrigation are simply not going to make significant contributions to output. In fact we may have to do it with less land and less water and do it in a resource friendly way.

But there are additional challenges. Let us begin with the fact that less than 12% of world grain production enters international trade and about 10% of global food supplies are traded internationally. And these percentages have been essentially constant for the past 40 years. IFPRI projections to 2020 (Rosegrant, M.W. et al 1995) suggest significant increases in trading volumes but relatively little increase in the share of food needs traded.

The same can be stated another way. In the next quarter century, about 90% of food production likely will be consumed in the country where it is produced. This has two critical implications. First, North-South trade is not going to come anywhere near meeting the growth in food demand in developing countries. And second it means that the most rapid increases in food production will have to occur in the humid, sub-humid and semi-arid tropics and subtropics. These areas (basically between the Tropics of Cancer and Capricorn) are characterized by complex farming system (about which we know too little), fragile soils and
significant weather variability. They are also the regions most likely to be negatively impacted by global warming.

These are daunting challenges indeed and they will need to be met in a vastly different global environment. Given the global trends listed above what are the specific likely impacts in the global food system?

1. The role of government will be significantly different and possibly diminished.

   Markets will play a much larger role, as will citizens at the local and regional levels.

   This will lead to freer trade, internally and internationally, in both inputs and outputs.

   It will lead to less expenditure on subsidies to inputs, price supports, export subsidies and on public sector research.

2. The molecular biological revolution and its application through biotechnology, coupled with changes in intellectual property rights, has given rise to massive increases in private sector research investment and in proprietary science.

3. Globalization and the information revolution means that science and technology are truly global and therefore national agricultural science strategies (characteristic of FSU and Eastern Europe) are less and less viable. Human capital, investment dollars and scientific knowledge are globally fungible. It means a country is either part of the global knowledge system or it gets left behind.

4. Economics and politics both nationally and internationally will have to be factored into decisions about agricultural science, technology and education.

5. The agricultural science system will have to change. Isolated agricultural universities, dominated by the faculty and scientists, simply will not survive: – the complexity of the
challenge requires access to disciplines far beyond traditional agriculture; the changing role of civil society, participation and decentralization will radically alter the clientele of universities and change the demands on them; and the role of proprietary private sector research will almost certainly increasingly dwarf public sector investments.

V. Implications for Agricultural Science, Technology and Education

Let me begin my concluding section with a stylized characterization of the Global Agricultural Science System as it evolved in the 2nd half of the 20th Century. Clearly it is oversimplified and not exactly true in every country but it is, I argue, characteristic of many, many developing and transition economies.

The traditional system is divided into three domestic parts – teaching, research, and extension which have very little interaction. It has a very small international dimension.

- **Agricultural schools and universities** in most countries are separate from general universities, are administered by Ministries of Agriculture rather than Ministries of Higher Education. The primary outlet for graduates is in public sector research and extension operations or in Ministries of Agriculture.

- **Agricultural research** is dominated by National or Federal Research Institutes through highly centralized and top-down research coordination units or Academies of Agricultural Science. There is a limited role of universities and producer-oriented research bodies. Funding generally comes from a single public sector source. They are separated from the rest of the science establishment both public and private.
• **Agricultural extension services**, usually focused and funded at the state or province level are generally disconnected from the research and education establishments. Extension agents are increasingly poorly trained for modern farming reflecting outdated training in agricultural universities.

• **Weak international linkages except through the CGIAR.**

While I have perhaps overdrawn the case, I believe I am not far wrong. The basic question is can such a system evolve rapidly enough to adjust to the enormous changes in the external environment that we have discussed.

Let me recapitulate what those changes portend specifically in terms of challenges for the agricultural science system.

1. **Increased complexity of the research, education and extension challenge.** There are many dimensions of that complexity:
   
   • The need to understand more complex farming systems and their linkages to surrounding ecologies;
   
   • The need to tap the power of rapidly evolving science, particularly molecular biology, and systems and information sciences;
   
   • The need to understand the social and environmental consequences of changed farming systems;

2. **Pluralism and a Multiplicity of Actors and Stakeholders**
   
   • The rising role of the private sector in proprietary science and its implication for the public sector system.
• The rise of civil society and NGOs concerned with the negative externalities of modern agriculture – displacement of small farmers, environmental pollution, impact on habitats and on biodiversity.

• Farmers as demanders and payers for research who will set the research agenda.

3. A Broader Research Agenda

• Crops, animals, trees and fish – how do they interact?

• How do you improve the productivity of a farming system as opposed to increasing the yield of a commodity?

• Resource management – water, soils, natural habitats, biodiversity, etc.

• Agriculture interfaces with ecological systems - river basins, coastal zones, estuaries, lakes.

• Social impacts and equity issues.

• The role of agricultural research in poverty reduction.

4. Globalization:

• Global knowledge systems – either you are part of them or you are left behind;

• A global trading system and open markets – world prices drive the system more than domestic choices, which have to be seen as parts of the bigger picture;

• International financial flows influence investment decisions;

• Trade creates new requirements for standards, safety and sanitary control.

In my view the typical agricultural science system cannot meet these changed demands in its current form. What changes must occur? It must be integrated into the broader science
establishment at all levels. But before it can be integrated with others, it must itself be integrated. Therefore the future requires 4 levels of integration.

Level 1 - Integration of teaching (education), research and extension (TRE). I must confess that I worked in the U.S. Land Grant System for 28 years and I am a great admirer of its success to date. But it developed slowly. It evolved to an integrated system of over a 50 year period [1862 (Morill Act) – 1914 (Smith-Lever Act)]. I believe it is still the right model with teaching, research and extension integrated into a single institution.

Level 2 - Integration of TRE into the broader science establishment on campus and off (not all parts of the Land Grant System have achieved this yet).

Level 3 - Integration at the national or federal level into the policy environment and interaction with the multiplicity of interested actors – public sector, private sector, NGOs and civil society.

Level 4 - Integration into the global agricultural science system which itself is a component in an integrated global science system.

For countries who want to be part of the global community (as I believe all must), these are not options but imperatives. Thus we come to the bottom line. What should happen to agricultural higher education?

Many of you belong to an agricultural university. I ask you to think about what your new curriculum should look like at the Bachelors, Masters, and Doctorate levels. I close by sharing a few thoughts about these questions.
First, let’s recognize that the research agenda should ideally drive the education agenda and I believe I have outlined clearly what the research challenge facing agriculture in the 21st Century is. The extension agenda should be driven by the research and public policy agendas.

**Bachelors level.** I would focus on intensified production systems with two tracks. One with a biological-physical emphasis, one with a social-economic emphasis. All students would be well grounded in fundamentals – mathematics, chemistry, physics, biology, history and philosophy and logic, as well as modern information systems in the first two years of curriculum.

Those on the biological/physical track would take a third year of molecular, cellular, physiological and systems biology; biochemistry; genetics; and anatomy and morphology.

Those on the economic/social track would take a year drawn from anthropology, sociology, economics, political science, history, statistics and quantitative analysis.

Following the third year, all students would begin the process of integration by a course of study focused around ecological and social systems. Using integrated production systems as a model – the program should focus on cross-cutting themes such as:

- Conservation tillage
- Integrated pest management
- Integrated nutrient management
- Conservation barriers – ecology, biodiversity, etc
- Risk management and marketing

In addition, they would focus on farmer-farming system interactions and on farmer-village-social system interactions. All students would require an understanding of the importance of policy and institutions.
I would have all students do a fifth year field project as well as learn a foreign language.

My Masters curriculum would build on the field project allowing the students to focus more in depth on critical components of the cross-cutting themes.

I would leave the Doctorate level basically focused at the discipline level. I would not have an interdisciplinary doctorate because the doctorate should remain a research degree. Research results come from focusing the power of a discipline on a critical problem.

There are three things about my curriculum deserving notice. First, to deliver it, the College of Agriculture needs to have access to the full range of disciplines, i.e., it should be part of a comprehensive general university. Second, it recognizes the critical importance of disciplinary foundations and disciplinary research once the interdisciplinary diagnosis has identified critical constraints. It is like a sandwich. It begins disciplinary and ends disciplinary. The filling in the sandwich is interdisciplinary. Third, it defines the rural/agricultural challenge much more broadly than traditional production agriculture.

In sum, the global food challenge ahead is enormous. Science and technology must provide virtually all the solutions to the global food challenge. Is the global agricultural science establishment as currently constituted, ready to meet that challenge? In my view the answer is a resounding NO! Can it change to meet the challenge? Possibly, but only if radical changes are initiated now, new partnerships, particularly with private sector, are initiated soon, and if the agricultural establishment gets out of its isolationist shell and joins the global science community. The agricultural education establishment can and should lead but will we?
REFERENCES


