Improving Agricultural Knowledge and Innovation Systems

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Foreword

The title of this conference on Agricultural Knowledge System (AKS) may be clear to its attendees, but not necessarily to the general public. In simplest terms, this meeting is about innovation and will address the ways in which innovation can help secure adequate supplies of food in agriculture, feed and fuel over the course of the coming decades, and how governments and policymakers can achieve this in a sustainable way.

In a sense, we would like to "get back to innovation," something we seem to have collectively wandered away from in recent years, which may not come as a surprise given the long period of steadily declining real prices for agricultural commodities. Today, however, we are entering a different era. Productivity growth rates have been slowing, demand has strongly accelerated, and there has been upward pressure on global prices; we expect continued strong prices, even in real terms, over the coming decade. However, amidst this surge in demand, we are faced with finite land and water resources, uncertain impacts from climate change, and increasing input costs – in particular, those related to energy. While farm profits have been squeezed for some producers, others have been doing particularly well recently; aggregate net farm income in many OECD member countries have reached record or near record highs.

From the standpoint of farmers and policy makers, then, "business as usual" is not a realistic option. Rather, it may be time to inject more urgency into the traditionally gradual process of farm policy reform. When analysing the role of innovation, we must take into consideration its regulatory, institutional, and financial aspects. Thus far, however, R&D, education, and the extension and transfer of technology have not received much government funding relative to other areas of support to agriculture.

These are issues that resonated during discussions at the 2010 Agricultural Ministerial Meeting at the OECD. More recently, these concerns have received unexpectedly strong attention within the context of France's presidency of the G20. Whether this amount of attention is translated into new actions, and a greater priority to agricultural productivity, remains to be seen. But innovation is clearly on the international policy agenda.

As we all know, the adoption of available technologies offers the potential, in and of itself, to increase productivity, output and income throughout significant areas of agriculture in developing countries. These results, however, are not guaranteed and much depends on increased investment – both private and public – in the sector. This in turn requires many developing countries to put in place the appropriate "enabling environment": peace and stability; effective governance systems and public institutions; clear property rights and effective rule of law; at least a degree of macroeconomic stability; effective structural policies (health, education, trade, investment); and coherent agricultural policies that enable well functioning input and output markets.

This is a topic that has received extensive attention within G20 discussions, and will likely continue to do so.

It should be noted there is a significant role for science to play. New technologies, including biotechnologies, can go a long way toward improving productivity, while allowing us to make better use of scarce resources. We hope to spend significant time discussing not only the development of science and new technology, but the mechanisms needed to transfer these developments from the lab to the farm.

In addition, we would like to address the importance of public communications as it relates to the adoption of new technologies since there have been some mis-steps in the past. New technologies will be more widely accepted if they are better understood, but this is an element of the technology transfer process that does not always receive sufficient attention.

Yet even amidst these concerns, this is a very good time to be in agriculture. Consumers, of course, have concerns over higher prices, but higher prices are a very good thing for producers. Higher prices point clearly to the opportunities arising from increasing supply in response to growing demand.

Today, there are two primary questions we hope to answer.

- How can we realign the policy set toward increasing agricultural innovation, helping producers to increase output via improved productivity, in response to clear growth in market demand?
- How can international collaboration help generate productivity growth in developing countries, while addressing the challenge of climate change and resource limitations?

Essentially, then, we aim to formulate policy advice we may offer to national governments, as well as international bodies. This policy advice should aim at improving productivity growth, while ensuring that key global challenges are addressed in a more collaborative manner than we have seen to date.

Ken Ash
Director
OECD Trade and Agriculture Directorate

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Acronyms

AgGDP	Agricultural Gross Domestic Product
AKS	Agricultural Knowledge Systems
AKIS	Agricultural Knowledge and Innovation Systems
ARD	Agricultural Research for Development
ASTI	Agricultural Science and Technology Indicators
AIS	Agricultural Innovation Systems
BMGF	Bill and Melinda Gates Foundation
BSE	Bovine Spongiform Encephalopathy
CAP	Common Agricultural Policy
CAS-IP	Central Advisory Service on Intellectual Property
CBD	Convention on Biological Diversity
CGIAR	Consultative Group on International Agricultural Research
CIAT	Centro Internacional de Agricultura Tropical (International Centre for Tropical Agriculture)
CIFOR	Centre for International Forestry Research
CIMMYT	International Maize and Wheat Improvement Center
CIP	International Potato Centre
CPVO	Community Plant Variety Office
CRP	CGIAR Research Programme
CSO	Civil Society Organisation
CWG	Collaborative Working Group
DNA	Deoxyribonucleic Acid
EC	European Commission
EPO	European Patent Office
EU	European Union
FAO	Food and Agriculture Organisation (UN)
FTE	Full Time Equivalent
GDP	Gross Domestic Product
GE	Genetically Engineered
GERD	Gross expenditure on research and development
GIS	Geographic Information System
GMO	Genetically Modified Organism
GOVERD	Government expenditure on research and development

IBRD (WB)	International Bank for Reconstruction and Development (World Bank)
ICARDA	International Centre for Agricultural Research in the Dry Areas
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
ICT	Information and Communication Technology
IFAD	International Fund for Agricultural Development
IFPRI	International Food Policy Research Institute
IICA	Inter-American Institute for Cooperation on Agriculture
IITA	International Institute for Tropical Agriculture
ILRI	International Livestock Research Institute
INNOVAGRO Network	Innovation Management in the Agri-food Sector
IP	Intellectual Property
IPR	Intellectual Property Rights
ISF	International Seed Organisation
ISNAR	International Service for National Agricultural Research
ISPC	Independent Science and Partnership Council
IRRI	International Rice Research Institute
IT	Information Technology
IT PGRFA	International Treaty on Plant Genetic Resources for Food and Agriculture
IWMI	International Water Management Institute
LINSA	Learning and Innovation Network for Sustainable Agriculture
NAIS	National Agricultural Innovation Systems
NARS	National Research Systems
NEPAD	New Partnership for Africa’s Development
NGO	Non-Governmental Organisation
OECD	Organisation for Economic Co-operation and Development
PBR	Plant Breeder’s Rights
PPB	Participatory Plant Breeding
PPP	Purchasing Power Parities
PPPs	Public-Private Partnerships
PVP	Plant Variety Protection
R4D	Research for Development
R&D	Research and Development
RD&E	Research, Development and Extension
RTTS	Research and Technology Transfer Systems
S&T	Science and Technology
SCAR	Standing Committee on Agricultural Research
SLO	System Level Outcome
SME	Small and Medium Size Enterprises
SRF	Strategy and Results Framework
SRO	Sub-regional Organisations
TFP	Total Factor Productivity
TRIPS	Trade-Related Aspects of Intellectual Property Rights

UNDP	United Nations Development Programme
UNESCO	United Nations, Educational, Scientific, and Cultural Organisation
UPOV	International Union for the Protection of New Varieties of Plants
WFS	World Food Security
WTO	World Trade Organisation
WAF	World Agroforestry Centre
WARDA	Africa Rice Centre (AfricaRice)
WFP	World Food Program
WFC	World Fish Centre

Executive summary

The conference provided a good opportunity to discuss a large range of experiences and approaches to Agricultural Knowledge Systems (AKS), considering in particular developments in institutional frameworks, public and private roles and partnerships, regulatory frameworks conducive to innovation, the adoption of innovations and technology transfers, and the responsiveness of AKS to broader policy objectives.

The conference demonstrated a wide diversity of approaches to AKS, with each responding to different agro-economic, social and institutional challenges, and each with a different history. Most strikingly, all of these approaches are currently evolving from a linear AKS to more integrated innovation systems. The question is whether these developments will successfully address the challenges identified at this conference — namely, those arising at the nexus of food security and climate change. Some speakers have emphasised public approaches, while others emphasised private. Many talked about co-development and networks, including the speakers who focused on biotechnology, and several speakers mentioned the importance of local traditional knowledge. Finally, many emphasised the shift taking place from research and development (R&D) to innovation in products and processes.

It emerged from the discussion that "no action is not an option": AKS throughout the world will have to adapt to meet future needs in food and agriculture, in a context of limited natural resources and additional pressure from climate change. Current evidence in many high-income countries points to a slowdown in the rate of agricultural productivity growth and to public under-investment in agricultural R&D — especially R&D oriented to enhancing farm productivity, despite estimated high rates of return. This underinvestment in high income countries is attributed, among other factors such as incomplete information, to long lags between making R&D investments and reaping the benefits at farm level.

Improving the effectiveness of AKS and reinforcing multidisciplinary co-operation at national and global levels is all the more important in the current context of budget austerity in many countries. The need to have a "wholistic" approach to innovation was mentioned. Examples of innovative approaches to increase the effectiveness of existing AKS include increased private sector involvement to leverage public resources through the provision of matching funds for agricultural R&D; the reorientation of public resources to areas with strong public goods elements and long-term benefits; the creation of centres of excellence to concentrate available R&D competency; the expansion of international collaboration to exploit synergies; and the use of information technologies. When discussing approaches to **secure long-term funding for R&D**, the use of levies charged on the value of agricultural output was presented as particularly relevant where the private benefits from research are high and the payoff to beneficiaries is rapid and highly visible. A better understanding of R&D benefits and future needs for innovation would also help.

Institutional design of AKS was also considered important. Experiences with AKS revealed a large diversity corresponding to different country contexts. At the same time, changes implemented in the last decade indicate a general movement from the traditional linear and top-down approach – from research to innovation to adoption – to an innovation systems approach, which is more reactive and interactive, and where agents contribute together to finding innovative solutions, while avoiding duplication of effort. The involvement of farmers and the industry was mentioned as crucial in terms of innovation creation and adoption. Networking and partnerships can play a vital role in leveraging scarce resources and in allowing for a continuous process of adaptation and reorientation. The suggestion was made that "innovation brokers" would help enable the adoption of innovation to develop customised solutions. The need for greater emphasis on the adoption of innovation, particularly as concerns developing countries and technology transfer, was a recurrent theme and the subject of a session, with large emphasis on developing countries and technology transfer (Part V).

There was shared understanding that with increasing demands upon scarce public resources in many countries, the **private sector** is to play a larger role in AKS, but that incentives need to be in place for this sector to generate, develop and diffuse new technologies. A key issue discussed was the protection of Intellectual Property Rights (IPRs) and the difficulty to define the scope and duration of IPR to provide enough incentive for private investment in AKS, without compromising the interest of society that knowledge is shared and further innovations are simulated. The two forms of Intellectual Property (IP) protection in plant breeding were discussed: patents and the International Union for the Protection of New Varieties of Plants (UPOV) system. The key role of public-private partnership was underlined to facilitate the transformation of public sector technologies into products commercialised by the private sector. Developments in IPR protection in plant breeding under UPOV were highlighted. The assessment of risk when new varieties are introduced was also discussed with two regulatory systems being presented. An important issue is how much regulation is needed and what criteria to apply so that the public is adequately protected, but the process of innovation is not slowed down.

A call for **policy coherence** among science, education, agriculture and development concluded the conference. The development and application of new technologies in agriculture and the food system in OECD countries takes place within the context of a set of existing agricultural policies which pursue a wide range of objectives. These include improving agricultural productivity and sustainability, the supply of food at reasonable prices, the improvement in farm competitiveness, and the preservation of natural resources, environmental quality and rural viability. Priorities, however, are changing over time. Other policies affect the agricultural sector and it is particularly important to ensure coherence between agricultural, innovation, environment, trade, and development policies. It will be a considerable challenge for the AKS to provide the innovations needed for agriculture to pursue the multiple objectives assigned to it.

Part I.

How well do Agricultural Knowledge Systems respond to new challenges?

1. Global and US trends in agricultural R&D in a global food security setting

Philip G. Pardey and Julian M. Alston[1]

In recent decades, we have witnessed in most countries a slowdown in the rate of growth in spending on agricultural Research and Development (R&D) — especially R&D oriented to enhancing farm productivity. This trend is most notable in the world's richest countries that have in the past been the primary drivers of global agricultural science and innovation. It has happened in spite of compelling evidence on the very large returns to public investments in agricultural R&D. Along with the slowdown in research investments we have witnessed a slowdown in agricultural productivity growth in most countries — China and Brazil are notable exceptions. These trends have potentially significant implications for global food security unless policy changes are implemented soon to rapidly reinvigorate investments in agricultural science and innovation, especially in view of the very long time lags between making investments in R&D and reaping returns in farmers' fields.

Introduction

Agricultural Research and Development (R&D) is at a crossroads. The close of the 20th century marked changes in policy contexts, fundamental shifts in the scientific basis for agricultural R&D, and shifting funding patterns for agricultural R&D in developed countries. Even though rates of return to agricultural research are demonstrably very high and productivity growth has flattened, we have seen a slowdown in spending growth and a diversion of funds away from farm productivity enhancement. Together these trends spell an extended period of slower farm productivity growth at a time when the market has, perhaps, begun to signal the beginning of the end of a half-century and more of global agricultural abundance. Slower farm productivity growth, combined with unabated growth in demand for farm output from the high- and middle-income countries, and other factors, may have dire implications for food security for the world's poor.

As they did in the past, the prospects for food security around the world in the coming decades will turn on the evolving global supply and demand balance for food commodities, which is a primary determinant of consumption possibilities for the world's poor. Growth in demand for agricultural commodities largely stems from growth in demand for food, which will be driven by growth in population and per capita incomes (especially the economic growth of the fast-growing economies of Asia), coupled with new demands for biofuels. Growth in supply of agricultural commodities will be driven primarily by growth in productivity, especially as growth in the availability of land and water resources for agriculture has become more constrained. Productivity improvements in agriculture are strongly associated with lagged R&D spending, as revealed in a large compilation of country-specific studies reported in Alston *et al.* (2000). Thus, the rate of growth of investments in agricultural R&D and the uses to which those research dollars are put will be a pivotal determinant of long-term growth in the supply, availability, and price of food over the coming decades.

In the past half-century, agricultural science achieved a great deal, contributing enormously to food security of the poor. Since 1960, the world's population has more than doubled, from 3.1 billion to today's 6.95 billion (6.78 billion by the end of 2009), and real per capita income has more than tripled (from USD 2 391 in 1960 to USD 8 390 in 2009, both in 2005 prices). Over the same period, total production of cereals grew faster than population, from 877 million metric tonnes in 1961 to over 2 494 million metric tonnes in 2009, and this increase was largely owing to unprecedented increases in crop yields.[2] The fact that the Malthusian nightmare was not realised over the past 50 years is attributable in large part to improvements in agricultural productivity achieved through technological change enabled by investments in agricultural R&D.

Looking forward, however, the prospects for the next 50 years do not appear as promising. Around the world we have seen a slowdown in agricultural productivity growth rates, which, coupled with increasing nonfarm competition for water and land, and competition from biofuels demand for agricultural capacity, spells slower growth in the supply of food. Meanwhile, based on their assessment of the most plausible population and per capita income growth projections, Rosegrant *et al.* (2009, p. 316) suggest that total demand for cereals for food uses is expected to grow by as much as 70% between 2000 and 2050. Such comparisons raise concerns about the implications for the world food equation, the price of food, and the incidence of poverty and malnutrition around the world over the next few decades. A natural and appropriate policy response would be to take steps to reinvigorate spending on agricultural science with a view to enhancing farm productivity in rich and poor countries alike. But only a few countries appear to be doing more than pay lip service to this imperative.

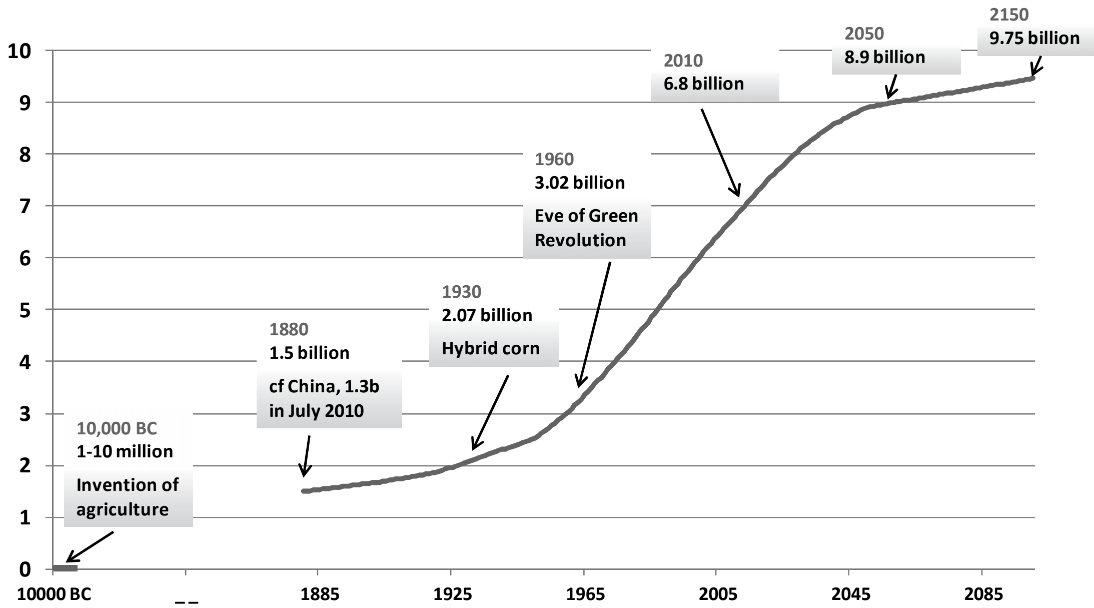
In this section, following a brief description of the links between agricultural R&D, productivity growth and food security outcomes, we briefly review the patterns of agricultural productivity growth in the United States, for which we have more-detailed data, and elsewhere in the world. The evolving developments in agricultural R&D investments and institutions are then presented, including developments in the public and private sectors. Agricultural R&D has some distinctive attributes that are critical to bear in mind, and especially so when thinking about the food security and general economic implications of that research. These dimensions are described briefly.

R&D-productivity-food security linkages

Agriculture was invented about 10 000 years ago when the world's population was no more than 10 million people, roughly equivalent to Belgium's population today (Figure 1.1). Since then, increases in agricultural production have been engendered through a combination of increases in resources devoted to production and increases in productivity, achieved through the application of improved methods and materials and changes in the scale and scope of farm enterprises. For much of human history agricultural productivity growth was relatively slow, and achieved mainly by informal processes of trial and error, tinkering and selection, by individual farmers. But in the past 200 years, increasingly productivity growth supplanted increases in the amounts of measured land and labour employed as a driver of increases in total availability of food and fibre, and this accelerating productivity growth was increasingly driven by public and private investments in organised agricultural science. As scientific crop breeding and modern approaches to agronomy, animal husbandry, and other agricultural R&D activities began to gather pace at the turn of the 20th century, the world's population stood at just 1.9 billion people. As population growth picked up, so too did the rate of agricultural innovation. Global population growth accelerated during the 1930s, 1940s and 1950s as waves of new technologies (including hybrid corn varieties and continuous streams of new varieties for many other crops with bred-in pest resistance and improved capacity to deal with a range of abiotic constraints) became available and spread over farmers fields — first, in the developed countries, and later by way of the Green Revolution and other (including private sector) means among important agricultural producers throughout the developing world.

In recent decades, on-farm productivity growth has been the main driver, and has contributed enormously to growth in supply of food and fibre. Over the past half-century and more agricultural productivity has generally fluctuated around a long-term average rate of between 1 and 2% per year, faster than productivity growth in the rest of the economy. Consider US agriculture, for which we have relatively detailed information, and which broadly represents patterns in many countries (Table 1.1). In 2007, US agriculture produced more than four and half times the quantity of agricultural output produced in 1910. The 1.58% per year increase in output over 1910−2007 was achieved with only a 0.16% per year increase in the total quantity of inputs. Consequently, in 2007 it required only 1.2 times the 1910 quantity of inputs to produce 4.6 times the 1910 quantity of agricultural output, a very significant increase in agricultural productivity.

Figure 1.1. Long-term world population — 10 000 BC to 2150



Source: Pardey (2011) and United Nations (1999 and 2004).

Table 1.1. Agricultural multifactor productivity growth in the United States and selected regions

	Average annual productivity growth rates[2]		
Regions[1]	1949−2007	1949−1990	1990−2007
		% per year	
United States	1.78	2.02	1.18
Northeast	1.72	2.16	0.67
Central	1.64	1.71	1.48
Northern Plains	2.04	2.32	1.38
Southern Plains	1.82	2.01	1.37
Southeast	1.96	2.49	0.68
Mountain	1.48	1.89	0.50
Pacific	1.82	2.02	1.33

1. The regions are as follows: Mountain – Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, Wyoming; Northern Plains – Kansas, Nebraska, North Dakota, South Dakota; Southern Plains – Arkansas, Louisiana, Mississippi, Oklahoma, Texas; Central – Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, Wisconsin; Southeast – Alabama, Florida, Georgia, Kentucky, North Carolina, South Carolina, Tennessee, Virginia, West Virginia.

2. The entries in this table are national (48 state) and regional and national (48 state) estimates of multi-factor productivity growth rates that account for changes in the use of 58 difference categories of inputs over the time periods examined. These include 32 categories of labour inputs, 12 categories of capital inputs (including seven physical capital categories and five biological capital categories) as well as 3 land categories, and 11 material input categories.

Source: Updated version of Alston *et al.* (2010, Appendix Table 5-3).

Such productivity gains can be measured in various ways. Conventional measures of productivity measure the quantity of output relative to the quantity of inputs. If output grows at the same pace as inputs, then productivity is unchanged; if the rate of growth in output exceeds the rate of growth in the use of inputs, then productivity growth is positive. Partial factor productivity measures express output relative to a particular input (like land or labour).[3] Multifactor productivity measures express output relative to a more inclusive metric of all measurable inputs (including land, labour and capital, as well as energy, chemicals, and other purchased inputs).

Measures of agricultural productivity growth for the United States — be they crop yields, other partial factor productivity measures (for example, measures of land and labour productivity), or indexes of multi-factor productivity − show generally consistent patterns in terms of secular shifts, including indications of a slowdown in growth since 1990 (Alston, Beddow and Pardey, 2009a and 2009b). The long-run evidence on US crop yields and productivity tells a consistent story: measurable but comparatively sluggish growth prior to 1950, historically rapid growth for the subsequent four decades 1950−90, and then a substantial slowdown from 1990 forward in the rates of growth for all of the crop yield and productivity series reported in this paper (Alston, Andersen, James, and Pardey, 2010). This slowdown reflects in particular the fact that productivity grew at historically high rates during the decades of the 1960s, 1970s, and 1980s.

Paralleling productivity developments in the United States, the evidence of a slowdown in crop yields throughout the world is quite pervasive (Table 1.2). In more than half the countries growing each crop, yields for rice, wheat, maize and soybeans grew more slowly during 1990−2007 than during 1961−90. Likewise, during 1990−2007 compared with 1961−90, land and labour productivity growth slowed considerably among the world's top 20 producers (according to their 2005 value of agricultural output), once the large, and in many respects exceptional, case of China is set aside (Table 1.3). Across the rest of the world (i.e. after setting aside the top 20 producing countries), on average, the slowdown was even more pronounced. For this group of countries land productivity grew by 1.74% per year during 1961−90, but only 0.88% per year thereafter; labour productivity grew by 1% per year during 1961−90, but barely changed over the period since then.

Table 1.2. Global yield growth rates for selected crops, 1961−2007

	Maize		Wheat		Rice		Soybeans	
Group	1961−90	1990−07	1961−90	1990−07	1961−90	1990−07	1961−90	1990−07
	% per year							
World	2.20	1.77	2.95	0.52	2.19	0.96	1.79	1.08
North America	2.20	1.40	2.23	0.01	1.67	1.54	1.05	0.04
Western Europe	3.30	1.81	3.31	0.63	0.38	0.55	1.64	0.05
Eastern Europe	1.91	0.97	3.18	-1.69	-0.41	1.07	1.90	2.29
High Income	2.34	1.48	2.47	0.06	1.07	0.54	1.14	0.02
Middle Income	2.41	2.12	3.23	0.85	2.54	0.81	3.21	2.08
Low Income	1.07	0.65	1.32	2.15	1.46	2.16	2.63	0.00

Source: Updated version of Alston *et al.* (2010, Appendix Table 5-3).

Table 1.3. Growth in agricultural land and labour productivity worldwide, 1961−2005

Group	Land productivity		Labour productivity	
	1961−90	1990−05	1961−90	1990−05
World	2.03	1.82	1.12	1.36
Excluding China	1.90	1.19	1.21	0.42
Excluding China and USSR	1.91	1.57	1.13	0.73
Latin America	2.17	2.83	2.15	3.53
Asia	2.56	3.01	1.83	2.72
Excluding China	2.45	1.83	1.69	1.24
China	2.81	4.50	2.29	4.45
Africa	2.18	2.21	0.68	0.90
Low income countries	2.00	2.39	0.46	1.03
Middle income countries	2.35	2.30	1.51	2.02
Excluding China	2.18	1.37	0.39	0.81
High income countries	1.61	0.72	4.26	4.18
Top 20 producers	2.11	2.16	1.17	1.77
Excluding China	1.98	1.38	1.33	0.63
Other producers	1.74	0.88	1.00	0.07

Note: Labour is measured as economically active workers in agriculture. Land is the sum of area harvested and permanently pastured areas. Output is a value of production measure developed by the authors by weighting a time series of country specific commodity quantities (spanning 155 crop-related and 30 livestock-related commodities) with an unpublished 1999−2001 global average of commodity-specific international prices developed by FAO.

Source: Alston, Pardey and Beddow (2010).

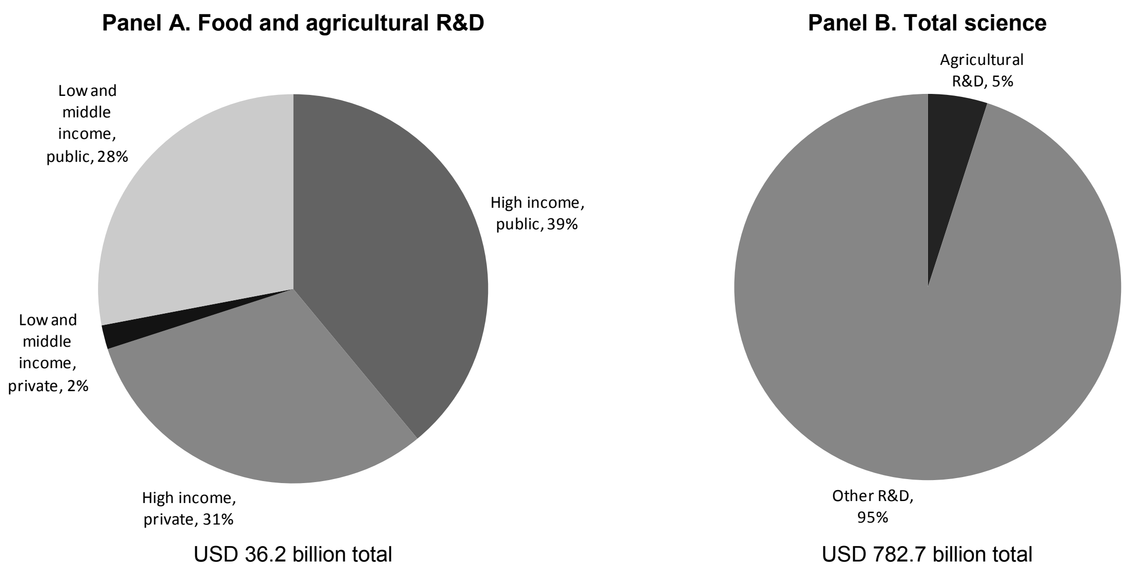
Agricultural R&D investments and institutions

Many factors may have contributed to the slowdown in agricultural productivity growth. Changes in weather or climate, land degradation, shifts or expansion of the location of production into less favourable environments, farmer responses to resource scarcity or higher prices of inputs, changes in public institutions, and evolving pests and diseases may all have contributed. Agricultural R&D is an important element of the story, a critical policy instrument that governments can affect to influence the path of agricultural productivity. Understanding the changing patterns of investment in agricultural R&D in the United States and elsewhere in the world is essential for understanding likely prospects for food security. The lags between investing in agricultural R&D and realizing a productivity enhancing return on that investment are long — a matter of decades not years — ,which dictates taking a very long-run perspective on R&D spending trends.

A global overview of current science spending

To appreciate and understand the sources of innovation in food and agriculture we must consider the magnitude and changing nature of total investments in R&D, given the significant interdisciplinary and cross-sectoral spillovers between food and agricultural R&D and research done by other sciences and in other sectors. Figure 1.2, Panel B, shows that in 2000, R&D oriented to food and agriculture accounted for only 5% of the estimated USD 782.7 billion invested in all forms of R&D worldwide (increasing to USD 970.6 billion in 2006). Collectively, the high-income countries (whose average per capita incomes exceeded USD 11 906) accounted for 85% of the world's R&D spending in 2000 (80% in 2006). The developing-country share of the world total grew from 5% in 1980 to 15% in 2006 (Dehmer and Pardey, 2011). Notably, China, India and Brazil account for a growing and now dominant share of this developing-country total — 61% of the developing world's total R&D spending in 1980, increasing to 83% in 2006.

Figure 1.2. Structure of global research, 2000



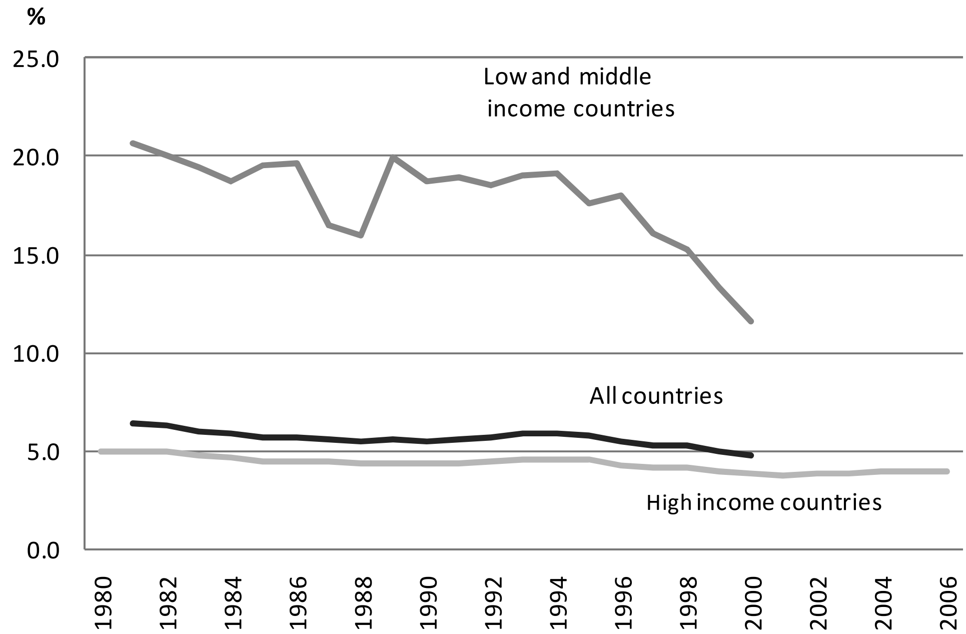
Note: All data denominated in 2005 international prices using purchasing power parity indexes. Former Soviet Union and Eastern European countries excluded for lack of data.

Source: Pardey and Chan-Kang (2011, beta version) for private and public food agricultural R&D series for high-income countries; Beintema and Stads (2008) for public food and agricultural R&D series for developing countries, and Dehmer and Pardey (2011) for total science spending estimates for all countries.

The dynamics between food and agricultural R&D and science spending generally are likely to continue changing in future years, most notably for those low- and middle-income countries with growing science sectors. Figure 1.3 shows that, for the past several decades at least, spending on food and agricultural R&D in high-income countries has been less than 5% of total science spending. On average, research directed toward food and agricultural R&D in the low- and middle-income countries was around 20% of the total (public and private) research conducted in that part of the world during the 1980s, but by the mid-1990s that share started to decline and now averages nearer 10%.

The United States is a significant element of the global total in both all science and agricultural science. As well as being important in its own right, the United States is representative of broad patterns in other high income countries, and we have comparatively detailed data on the US investments, so we discuss these before turning to the global patterns and the contrast between the world's richest versus poorest countries. Pardey and Alston (2011) provide a more-detailed discussion of the US trends, and their implications. From which the following discussion is drawn.

Figure 1.3. Food and agricultural R&D share in total R&D across all fields of science



Note: Former Soviet Union and Eastern European countries excluded for lack of data.

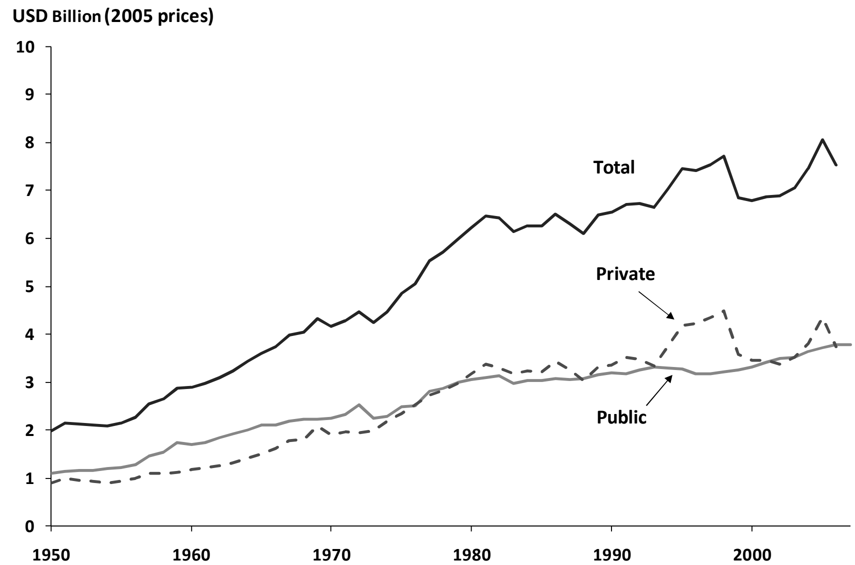
Source: Pardey and Chan-Kang (2011, beta version) drawing on Beintema and Stads (2008) for public food and agricultural R&D series for developing countries, and Dehmer and Pardey (2011) for total science spending estimates for all countries.

Public sector — US trends

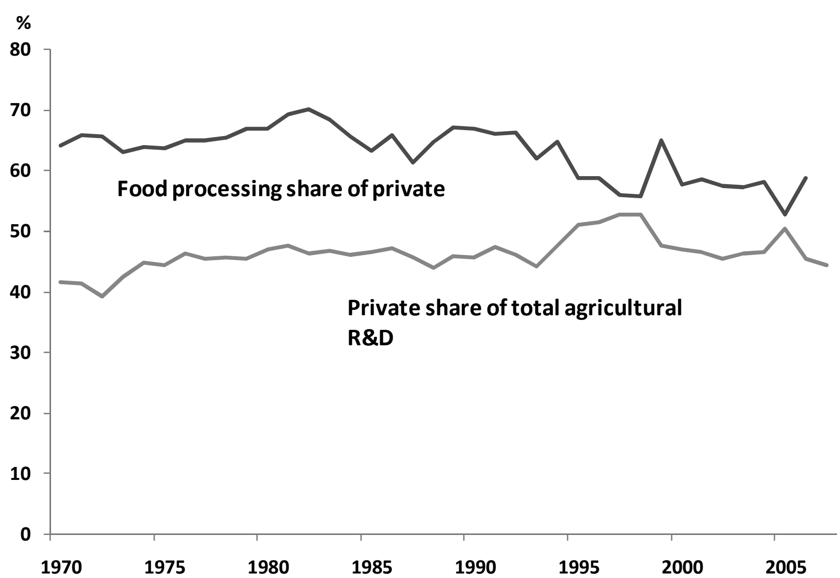
The history of agricultural R&D in the United States is one of jointly evolving state and federal, public and private-sector roles. The public-sector role developed mainly over the past 100 years (Figure 1.4). In 1889, shortly after the Hatch Act was passed, federal and state spending appropriations totalled USD 1.12 million. Over a century later, in 2009 the public agricultural R&D enterprise had grown to USD 5.15 billion (net of forestry), an annual rate of growth of 6.9% in nominal terms and 3.7% in real (i.e. inflation-adjusted) terms. Intramural USDA and state agricultural experiment station (SAES) research accounted for roughly equal shares of public research spending until the early 1940s, after which the SAES share grew to almost 67% of total public spending on agricultural R&D by 2009.

Figure 1.4. US private and public agricultural R&D, 1950–2009

Panel A. Public, private and total US agricultural R&D, 1950–2009



Panel B. Private research in the United States, 1970–2006

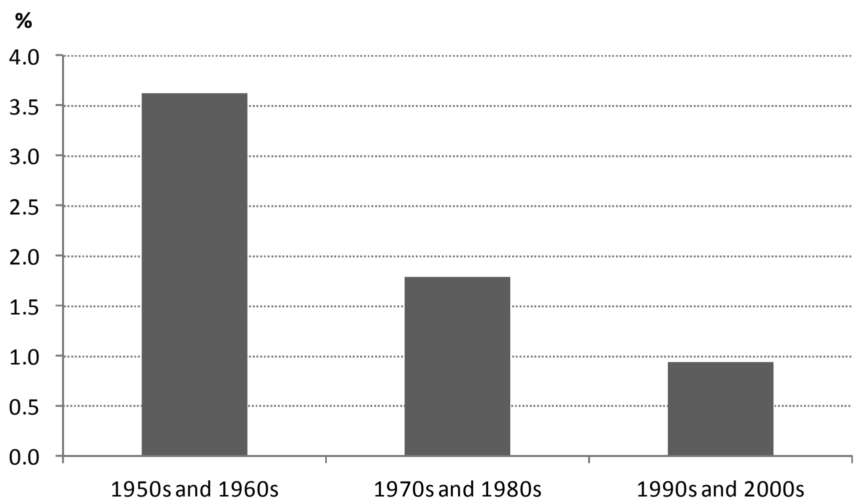


Note: Private agricultural R&D series ends in 2006.

Source: Public agricultural research series (excluding forestry) are from USDA sources cited in Alston *et al.* (2010, Appendix III) and for more recent years from USDA, CRIS (various years). Private food and agricultural research series (also excluding forestry) are and the beta version of data reported in from Dehmer and Pardey (2011). Estimates were deflated using an agricultural R&D deflator from Pardey *et al.* (2011).

The substantial growth in public agricultural R&D developments over the long haul masks important details: notably a marked slowdown in the growth of spending in recent decades and a shift in the focus of the research away from growing more food and feed and towards other policy priorities. The pace of growth in real (inflation-adjusted) investment slowed considerably over the past several decades: from 3.63% per year during the 1950s and 1960s, to 1.79% per year during the 1970s and 1980s, and slowing still further to just 0.94% per year during the years 1990−2009 (Figure 1.5). Moreover, research funds have been redirected away from farm productivity towards other concerns such as the environmental effects of agriculture, food safety and other aspects of food quality, and the medical, energy, and industrial uses of agricultural commodities. For example, in 1976, an estimated 65% of all research conducted by the SAESs in the United States was directed to maintaining and enhancing farm productivity; by 2009 this share had slipped to 56%.

Figure 1.5. Slowing growth in US agricultural research spending



Note: Public agricultural R&D includes SAES and USDA intramural spending, exclusive of forestry research. The series was deflated using an agricultural R&D deflator from Pardey *et al.* (2011). Average annual growth rates are calculated using the exponential growth rate method (which assumes continuous growth) described in World Bank (2009).

Sources: Public agricultural R&D series (excluding forestry) is from USDA sources cited in Alston *et al.* (2010, Appendix III) and for more recent years from USDA, CRIS (various years).

The shifting focus of the research conducted by the SAESs is coincident with a substantial shift in the sources of (federal) support for that research. In 1970, over 74% of the federal funds flowing to the SAESs were administered by the USDA. By 2009 that share had fallen to about 50%. The remaining half of the federal funds flowing to the SAESs is provided through agencies such as the Departments of Defence, Health and Human Services (especially the National Institutes of Health), Energy and Homeland Security along with the Environmental Protection Agency, National Science Foundation, National Aeronautics and Space Administration and so on, no doubt carrying with them the mission objectives of each of these agencies.

The form of the federal funds flowing to the SAESs has changed substantially as well. Historically, and until relatively recently, the majority of the federal funding to the SAESs was allocated to each SAES by means of a formula. Common perceptions notwithstanding, this is no longer the case. Formula funding as a share of total USDA support to the states shrank from 86.6% in 1970 to 35.2% in 2009: less than 20% of the total federal support to the SAESs in that year, given the substantial decline in the USDA share of federal government funding to the SAESs over this same period. Other forms of funding have grown in importance. Even so, by 2009, only 18.5% of the USDA spending on agricultural R&D was allocated by competitive grants (compared with almost 75% of the funds spent by the National Institutes of Health). As a share of USDA and total support, most of the increase in competitive funding occurred in the early years of the programme, which was launched in 1977, with little upward trend in the share of competitively disbursed funds after the mid-1990s. Notably, earmarked or special grants funding increased in absolute and relative terms. Federal funds allocated by means of Congressional earmarks are now equivalent to those allocated by competitive, peer review processes. Funds allocated by way of formula or as grants and contracts to collaborating institutions still account for 70% of USDA research funding to the states, but only 38% of all the federal funding to the states for agricultural research.

Public sector — global trends

Worldwide, public investment in agricultural R&D increased by 35% in inflation-adjusted terms between 1981 and 2000, growing from an estimated USD 14.2 billion to USD 20.3 billion in 2000 international USD.[4] It grew faster in developing countries (from USD 5.9 billion to USD 10.0 billion, a 53% increase), and the developing world now accounts for about half of global public-sector spending — up from an estimated 41% share in 1980. However, developing countries account for only about one-third of the world's total agricultural R&D spending when private investments are included.

Public spending on agricultural R&D is highly concentrated, with the top 5% of countries in the data set (i.e., 6 countries in a total of 129) accounting for approximately half of the spending. The United States alone constituted almost 20% of global spending on publicly performed agricultural research. The Asia and Pacific region has continued to gain ground, accounting for an ever-larger share of the world and developing country total since 1981 (25.1% of the world total in 2000, up from 15.7% in 1981). In 2000, just two countries from this region, China and India, accounted for 29.1% of all expenditure on public agricultural R&D by developing countries (and more than 14% of public agricultural R&D globally), a substantial increase from their 15.6% combined share in 1981. In stark contrast, sub-Saharan Africa continued to lose ground — its share fell from 17.9% of the total investment in public agricultural R&D by developing countries in 1981 to 11.9% in 2000.

The intensity of agricultural R&D — that is, agricultural R&D spending relative to the economic size of the agricultural sector it serves — is also much lower in developing countries. In 2000, developing countries spent just USD 0.50 on public agricultural R&D for every USD 100 of agricultural output, compared with USD 2.36 for developed countries as a group (in this case, agricultural R&D spending expressed as a percentage of agricultural gross domestic product, AgGDP). The public agricultural R&D intensity in developed countries grew from USD 1.62 per USD 100 of output in 1980 to USD 2.33 per USD 100 of output in 1991 but has barely risen since. In contrast, the overall agricultural R&D intensity was static in developing countries over the entire period.

Private sector — global and US trends

The private sector has continued to emphasize inventions that are amenable to various intellectual property (IP) protection options such as hybrid crops, patents, and more recently, plant breeders' rights and other forms of IP protection. The private sector has a large presence in agricultural R&D, but with dramatic differences among countries. In

2000, the global total spending on agricultural R&D (including pre-, on-, and post-farm oriented R&D) was estimated to be USD 33.7 billion. Approximately 40% was conducted by private firms and the remaining 60% by public agencies. Notably, 95% of that private R&D was performed in developed counties, where some 55% of total agricultural R&D was private, a sizeable increase from the 44% private share in 1981.

This rich-country trend may well continue if the science of agriculture increasingly looks like the sciences more generally. In the United States, for example, the private sector conducted nearly 55% of agricultural R&D in 2000, compared with 72% of all R&D expenditures in that same year (Dehmer and Pardey, 2011; NSF, 2008). These increasing private shares reflect increasing industry R&D by the farm-input supply and the food processing sectors. However, around the general trend was much country-specific variation. Compared with the United States, Japan conducted a slightly larger share of its agricultural R&D in the private sector whereas Australia and Canada — both reliant on privately developed, technology-intensive imports of farm machinery, chemicals and other agricultural inputs — had private-sector shares of agricultural R&D spending of less than 35% in 2000 (Pardey, Beintema, Dehmer and Wood, 2006).

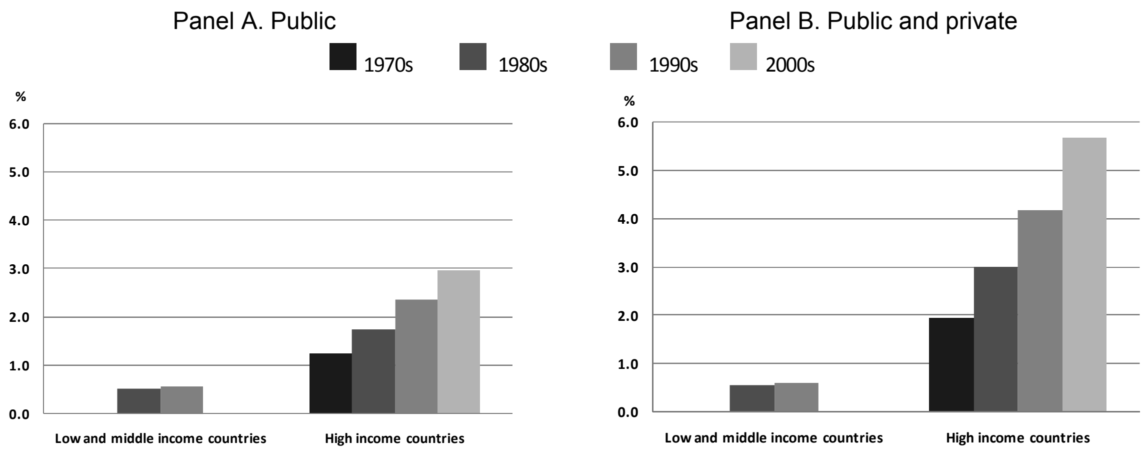
In developing countries, only 6.4% of the agricultural R&D was private, with large disparities in the private share among regions of the developing world. In the Asia and Pacific region, around 9% of the agricultural R&D was private, compared with only 1.7% of the R&D throughout sub-Saharan Africa. The majority of private agricultural R&D in sub-Saharan Africa was oriented to crop-improvement research, often (but not always) dealing with export crops such as cotton in Zambia and Madagascar and sugarcane in Sudan and Uganda. South Africa carried out approximately half of the total measured amount of private agricultural R&D performed throughout sub-Saharan Africa.

The more limited private-sector participation in agricultural research done in or for developing countries stems from several factors, many of which are likely to persist for some time in most countries (with some likely exceptions, such as Brazil, China and India). A significant share of food produced in developing countries is consumed within the household where it is produced. Even when commodities enter the marketing chain, in less-developed countries they are less often purchased in highly transformed forms with food more-often prepared and eaten at home. Consequently, a much smaller share of the food bill in developing counties accrues to post-farm food processing, shipping and merchandising activities; areas where the incentives for private innovation are relatively pronounced. Likewise, on the supply side, purchased inputs (such as herbicides, insecticides, improved crop varieties or animal breeds, and all sorts of agricultural machinery) constitute a comparatively small share of the total costs of production in many parts of the developing world.

While these characteristics of the production and consumption of food, feed, and fibre commodities are likely to change as incomes rise and infrastructure improves, the pace of change will be gradual in the poorest areas where (semi-)subsistence farming still predominates and infrastructure is often lacking. The cost of doing business in places characterised by small and often remote farms subject to poor market access, lack of farm credit, and limited communication services also undercuts private participation in these agri-business sectors, in turn reducing the private incentives to invest in R&D targeted to these markets. Finally, a plethora of regulations, often inefficiently enforced, make it difficult for local and multi-national private interests to penetrate agricultural markets with new seed, chemical or other agricultural technologies in substantial parts of the developing world.

The rich-country: poor-country disparity in the intensity of agricultural research noted above is magnified dramatically if private research is also factored in (Figure 1.6). In 2000, in developing countries as a group, the ratio of total agricultural R&D spending to agricultural GDP was 0.54% (i.e. for every USD 100 of agricultural GDP, just 54 cents was spent on agricultural R&D). In developed countries the comparable intensity ratio was 5.28% (i.e USD 5.28 per USD 100), almost ten times greater.

Figure 1.6. Food and agricultural research intensity ratios



Note: Intensity ratios indicate public and total (i.e., public and private) food and agricultural R&D spending expressed as a percentage of agricultural gross domestic product for each period. Former Soviet Union and Eastern European countries excluded for lack of data.

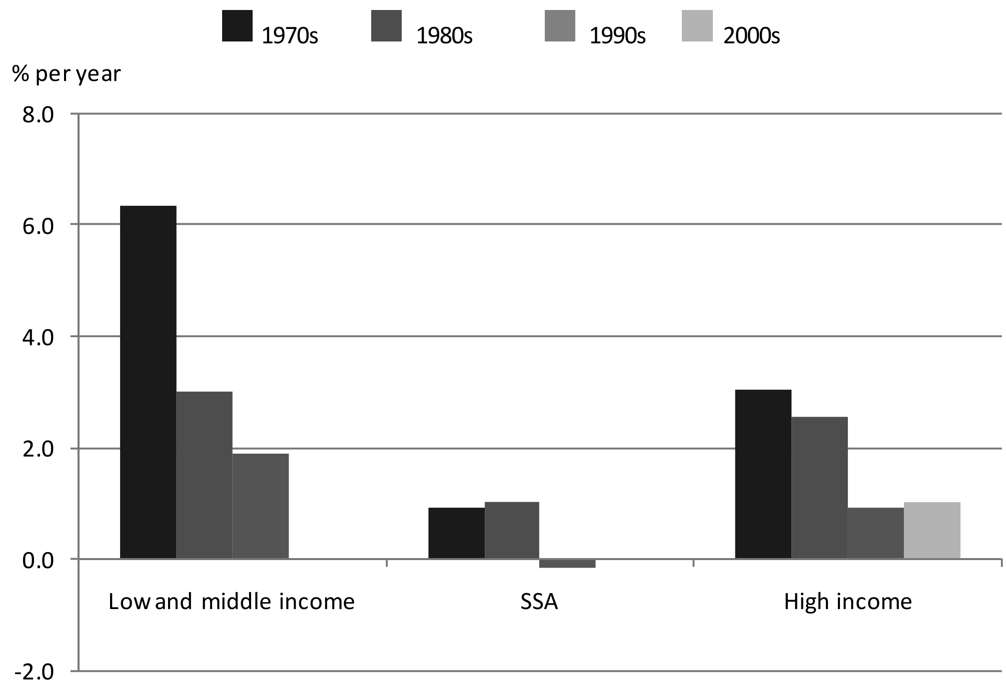
Source: Pardey and Chan-Kang (2011, beta version) drawing on Beintema and Stads (2008) for public food and agricultural R&D series for developing countries, and Dehmer and Pardey (2011) for total science spending estimates for all countries.

Rich versus poor countries — a growing scientific and knowledge divide

Collectively, the US and global agricultural R&D trends point to two disturbing developments: first a pervasive slowdown in the rate of growth of agricultural R&D spending, and second, a growing rich-country: poor-country divide in the conduct of and thus the innovations emanating from (agricultural) R&D (Figure 1.7). To the extent the R&D spending slowdown is a widespread phenomenon it will serve to slow or reverse the long-run decline in staple food and feed prices and add to the dismal tally of hungry and malnourished people worldwide. To the extent that agricultural R&D conducted in rich countries increasingly targets income-elastic attributes of food and fibre production, the technological divide between rich- and poor-country agriculture will widen. Only a few developing countries (including Brazil, China and India) show signs of closing in on the larger amounts and higher intensity of investment in agricultural R&D typically found in the rich countries. Meanwhile, large numbers of developing countries are either stalling or slipping in terms of the amount spent on agricultural R&D, the intensity of investment, or both.

A comparison of agricultural R&D realities in sub-Saharan Africa (a region consisting of 42 contiguous countries plus 6 island nations), India (a nation of 28 states and 7 union territories, 21 and 5 of them contiguous, respectively), and the United States (a nation of 50 states, 48 of them contiguous) makes more concrete the nature of this technological divide. The arable agricultural areas in these three parts of the world are similar, but Indian and African agriculture uses far fewer hectares per worker than in the United States. Moreover, land and labour are still dominant components of the cost of production in sub-Saharan Africa and India, whereas in the United States the combined cost share of these two inputs fell considerably during the past 50 years at least. Purchased inputs now constitute 38% of the total cost of production in US agriculture, compared with 23% in 1949.

Figure 1.7. Growth rates in public food and agricultural research expenditures



Note: Growth rates calculated by regression. SSA denotes Sub-Saharan Africa.

Source: Pardey and Chan-Kang (2011, beta version) drawing on Beintema and Stads (2008) for public agricultural R&D series for developing countries.

Not only is the structure of agriculture dramatically different, so too is the structure of agricultural R&D. For most measures, the starkest contrast is between the United States and sub-Saharan Africa, with India usually somewhere in between. Africa has almost 30% more public agricultural researchers than the United States and 50% more than India, but the training of these researchers continues to lag well behind those in the United States (and well behind those researchers working elsewhere in the developing world). Approximately 25% of research full-time equivalents (FTEs) in sub-Saharan Africa have PhDs, compared with 100% in the United States and 63% in India. Accounting for the "quality" of the researchers, in terms of their educational status, the quantity of effective scientific labour going into agricultural R&D in Africa is significantly less than the quantity in India and the United States.

African public agricultural research agencies are heavily skewed to the small end of the size distribution, with three-quarters of these agencies employing fewer than 20 researchers, whereas one-third of the public agencies in India and almost all the public agencies in the United States employ more than 100 researchers. The small size of many research agencies in India and particularly in sub-Saharan Africa makes it difficult to exploit the economies of scale that increasingly characterize the production of much new knowledge. Moreover, a dominant share (68%) of public research in the United States is now performed by universities, while the average university share is less than 20% in sub-Saharan Africa and approximately 45% in India.[5] Crucially, real spending per researcher in the United States is more than double its counterpart in India and more than four times its counterpart in sub-Saharan Africa; and the gap is growing. The long-run trend continues to be an increase in spending per scientist in the United States while inflation-adjusted spending in sub-Saharan Africa in 2000 had shrunk to less than half what it was in 1981.

These measures suggest the immensity of the challenge of playing catch-up in countries like India, and the seeming impossibility of catching up in sub-Saharan Africa. The measures also underscore the need to transmit knowledge across borders and continents and to raise current amounts of funding for agricultural R&D while also developing the policy and infrastructure needed to accelerate the rate of knowledge creation and accumulation in the developing world over the long haul. Developing local capacity to carry forward findings will yield a double dividend: increasing local innovative capacities while also enhancing the ability of local research agencies to tap discoveries made elsewhere. It is also essential to increase complementary investments in primary, secondary, and higher education if the generation and accumulation of knowledge is to gain the momentum required to put economies on a path to lift people out of poverty.

In addition to these broad trends, other aspects of agricultural R&D funding that have important practical consequences are also of concern. For example, variability in R&D funding continues to be problematic for many developing-country research agencies. This is especially troubling for agricultural R&D given the long gestation period for new crop varieties and livestock breeds, and the desirability of long-term employment assurances for scientists and other staff (Pardey, Alston, and Piggott, 2006). Variability encourages an over-emphasis on short-term projects or on projects with short lags between investment and outcomes, and adoption. It also discourages specialisation of scientists and other resources in areas of work where sustained funding may be uncertain, even when these areas have high pay-off potentials.

Policy relevant realities of agricultural R&D

Innovation in agriculture has many features in common with innovation more generally, but also some important differences. In many ways the study of innovation is a study of market failure and the individual and collective actions taken to deal with it, notably investing in agricultural R&D. Like other parts of the economy, agriculture is characterised by market failures associated with incomplete property rights over inventions. The atomistic structure of much of production agriculture means that the attenuation of incentives to innovate is more pronounced (and particularly so in many of the poorest parts of the world where the average farm size is small, and getting smaller) than in other industries that are more concentrated in their industrial structure. On the other hand, unlike most innovations in manufacturing, food processing, or transportation, many farm technologies have a degree of site specificity because of the biological nature of agricultural production, in which appropriate technologies vary with changes in climate, soil types, topography, latitude, altitude, and distance from markets.

Benefits are difficult to appropriate

The partial public-good nature of much of the knowledge produced by research means that research benefits are not fully privately appropriable. Indeed, the main reason for private-sector underinvestment in agricultural R&D is because some research benefits are not appropriable: the firm responsible for developing a technology may not be able to capture (i.e. appropriate) all of the benefits accruing to the innovation, often because fully effective patenting or secrecy is not possible or because some research benefits (or costs) accrue to people other than those who use the results. For certain types of agricultural research, the rights to the results are fully and effectively protected by patents or other forms of intellectual property protection, such that the inventor can capture the benefits by using the results from the research or selling the rights to use them; for instance, the benefits from most mechanical inventions and developing new hybrid plant varieties, such as hybrid corn, are appropriable. Often, however, those who invest in R&D cannot capture all of the benefits — others can "free-ride" on an investment in research, using the results and sharing in the benefits without sharing in the costs.[6] In such cases, private benefits to an investor (or group of investors) are less than the social benefits from the investment and some socially profitable investment opportunities remain unexploited. The upshot is that, in the absence of government intervention, investment in agricultural research is likely to be too little.

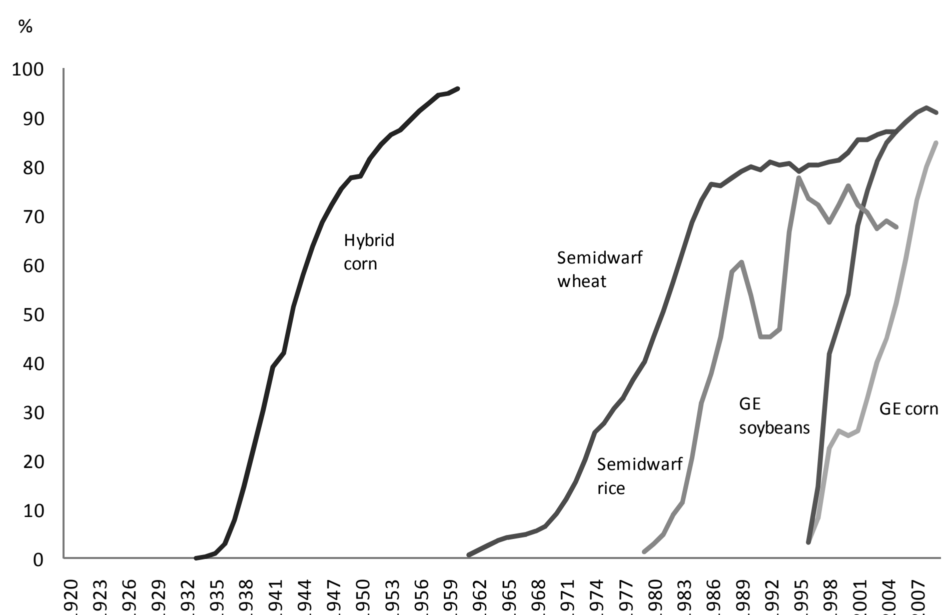
The types of technology often suited to less-developed country agriculture have hitherto been of the sort for which appropriability problems are more pronounced — types that have been comparatively neglected by the private sector even in the richest countries. In particular, until recently, private research has tended to emphasize mechanical and chemical technologies, which are comparatively well protected by patents, trade secrecy, and other intellectual property rights; and the private sector has generally neglected varietal technologies except where the returns are appropriable, as for hybrid seed. In less-developed countries, the emphasis in innovation has often been on self-pollinating crop varieties and disembodied farm management practices, which are the least appropriable of all. The recent innovations in rich-country institutions mean that private firms are now finding it more profitable to invest in plant varieties; the same may be true in some less-developed countries, but not all countries have made comparable institutional changes.

Agricultural R&D lags are very long

The lags between investing in R&D and realizing a return from that investment are long, often spanning decades, not months or years. The dynamic structure linking research spending and productivity involves a confluence of processes — including the creation and destruction of knowledge stocks and the adoption and disadoption of innovations over space and time — each of which has its own complex dynamics. That science is a cumulative process, in which today's new ideas are derived from the accumulated stock of past ideas, influences the nature of the research-productivity relationship as well. It makes the creation of knowledge unlike other production processes. The evidence for these long lags is compelling. One form of evidence is the result of statistical efforts to establish the relationship between current and past R&D spending and agricultural productivity. The dozens of studies done to date indicate that the productivity consequences of public agricultural R&D are distributed over many decades, with a lag of 15−25 years before peak impacts are reached and continuing effects for decades afterwards.[7]

The statistical evidence linking overall investments in aggregate agricultural R&D to agricultural productivity growth are reinforced by the other evidence about research and adoption lag processes for particular technologies, especially crop varieties about which we have a lot of specific information (Figure 1.8). For example, hybrid corn technology, which took off in US farmers' fields in the 1930s, had its scientific roots in focused research that began in 1918 (and arguably before then, back at least to the early 1890s). Thus the R&D or innovation lag was at least ten years and may have been 20−30 years. The time path of the adoption processes extends the lag lengths even further. Iowa had 10% of its corn acreage planted to hybrids in 1936 (with 90% of its corn acreage so planted just four years later), while it took until 1948 before Alabama — a state with distinctive agro-ecological attributes compared with the principal Corn Belt states — had 10% of its corn acreage under hybrids. By 1950, 80% and by 1960, almost all of the corn grown in the United States was hybrid corn. Looking across all the states, the technology diffusion process was spread over more like 30 years, reflecting the envelope of adoption processes that were much more rapid in any individual state. Taking the entire research, development, and adoption process for hybrid corn as having begun as late as 1918, the total process that had been accomplished by 1960 took place over a period of at least 40 years and possibly decades longer.

Figure 1.8. Share of US acreage planted to various varietal innovations



Source: Adapted from Chan-Kang and Pardey (2011) and Alston *et al.* (2010).

Has modern (bio-) technology materially sped up this research-innovation-adoption process, as is commonly suggested? Genetically engineered (GE) corn was first planted on US farmers' fields in the mid-1990s. The adoption-cum-diffusion process for GE crops is not yet complete, the technology itself is continuing to evolve, and the maximum adoption rate has not yet been achieved, but by 2008, 80% of US corn acreage was planted to GE varieties. Like hybrid corn, biotech corn has been adopted at different rates in different states, but perhaps for different reasons. This, as yet incomplete, process over less than 15 years represents only part of the relevant time lag. To that we must add the time spent conducting relatively basic and applied research to develop and evaluate the technology, and the time (and money) spent after the technology had been developed to meet the requirements for regulatory approval by a range of government agencies.

Compared with the adoption-cum-diffusion process for hybrid corn within the United States, the process for biotech corn appears to have been a little faster. The main difference may be that all states began to adopt together, without the slower spatial diffusion among states that characterised hybrid corn, possibly because of improved communications and farmer education, perhaps assisted by public extension services. Thus biotech corn achieved 80% adoption within 13 years compared with 19 years for hybrid corn. However, other elements of the process may be getting longer. For instance, the process of regulatory approval may have added a further 5−10 years to the R&D lag (and this regulatory approval lag for biotech crops appears to be getting longer). Given a range of 10 to 20 years spent on R&D to develop the technologies that enabled the creation of biotech crops, and then the time spent to develop the initial varieties and improve them, the overall process of innovation in the case of biotech corn may have taken 20 to 30 years so far.

Agricultural R&D spillovers contribute to underinvestment

Underfunding of agricultural R&D in developing countries is clearly problematic, and the stage is set for the problem to worsen. In addition to the distinctive features of developing countries described above, the inadequacy of agricultural knowledge stocks may be exacerbated by changes occurring in developed countries. While the most immediate and tangible effect of the new technologies and ideas stemming from research done in one country is to foster productivity growth in that country, the new technologies and ideas often spill over and spur sizable productivity gains elsewhere in the world. In the past, developing countries benefited considerably from technological spillovers from developed countries, in part because the bulk of the world's agricultural science and innovation occurred in rich countries.[8] Increasingly, spillovers from developed countries may not be available to developing countries in the same ways or to the same extent.

Decreasing spillover potential is caused by several related market and policy trends in developed countries. First, the types of technologies being developed may no longer be as readily applicable to developing countries as they were in the past. As previously noted, developed country R&D agendas have been reoriented away from productivity gains in food staples toward other aspects of agricultural production, such as environmental effects, food quality, and the medical, energy, and industrial uses of agricultural commodities. This growing divergence between developed-country research agendas and the priorities of developing countries implies fewer applicable technologies that would be candidates for adaptation to developing countries.

Second, technologies that are applicable may not be as readily accessible because of increasing intellectual property protection of privately owned technologies and, perhaps, more importantly, the expanding scope and enforcement of biosafety regulations. Different approaches may have to be devised to make it possible for countries to achieve equivalent access to technological potential generated by other countries.

Third, those technologies that are applicable and available are likely to require more substantial local development and adaptation, calling for more sophisticated and more extensive forms of scientific R&D than in the past. The requirement for local adaptive research is also likely to be exacerbated as changes in global and local climate regimes add further to the need for adaptive responses to those changed agricultural production environments. In some instances developing countries may also have to extend their own agricultural R&D efforts farther upstream, to more fundamental areas of the science. These new pressures for self-reliance in agricultural research are coming at a time when many developing countries, along with developed countries, are finding it difficult to sustain the current rates of investment in agricultural research.[9]

International initiatives

Beginning in 1971, the United States and other agencies financed a collectively conceived international undertaking called the Consultative Group on International Research (CGIAR). The CGIAR system has captured the attention of the international agricultural R&D and aid communities because of its scientific achievements and its pivotal role in the Green Revolution. The main priorities of the CGIAR system are to overcome, to some extent at least, the global agricultural R&D underinvestment problem and to help the food-poor. In 2008, the CGIAR conducted research in 15 international research centres located throughout the world and spent USD 542 million. The CGIAR is important, but only one of several options for leveraging national agricultural R&D capacity and funding worldwide. In recent years, new international initiatives supported by US-based entities [including the Bill and Melinda Gates Foundation (BMGF), the Warren Buffet Foundation, and the Rockefeller Foundation] have directed significant funding and effort to revitalizing productivity growth in sub-Saharan Africa and South Asian agriculture. Creative co-financing or other options could be used to achieve multiplier effects from the targeted deployment of public and private monies. The BMGF is pursuing an evidenced based approach, directing the funds to areas with the likely highest productivity and development payoffs. Preserving flexibility and seeking new, perhaps sometime experimental ways of doing business will be key to success. Recognising that science for development funding is quite different in scope and mode of action from most other forms of development, placing oversight of CGIAR funding in the hands of science agencies with experience in large collaborative international R&D undertaking [such as the National Science Foundation (NSF)] might engender better outcomes than routing it through economic development agencies [such as the United States Agency for International Development (USAID)] as is typically the case.

Conclusion

Revitalised funding and improved institutional and evidence-based oversight of the disbursal of funding for agricultural R&D would go a long way toward redressing the productivity slowdown that is apparent in recent years. However, the lags between investing in agricultural R&D and realizing a social return on these investments are long (typically several decades or more). Thus a sustained (but managed and flexible) commitment is warranted, at least for the key strategic research that is required. If history is any guide to the future, that persistence will be rewarded with high and life-changing payoffs globally, and to national agricultural and international development interests in particular. Among policies to enhance food security of the world's poor in the coming decades, substantially enhanced investment in agricultural R&D focused on sustainable, broad-based farm productivity improvement, will be one of the most cost-effective and potentially powerful, especially if used in conjunction with appropriate other policy instruments, each used with a view to its particular comparative advantage

Notes

1. Philip Pardey is a professor in the Department of Applied Economics at the University of Minnesota, and Director of the University's International Science and Technology Practice and Policy (InSTePP) Center. Julian Alston is a professor in the Department of Agricultural and Resource Economics and Director of the Robert Mondavi Institute Center for Wine Economics at the University of California, Davis, and a member of the Giannini Foundation of Agricultural Economics. This work draws heavily on Pardey and Chan-Kang (2011) and the CSIS Report by Pardey and Alston (2010), but we have updated some information presented in that report, and the emphasis here is different

2. Obtained from United Nations FAO, FAOSTAT online database, found at *faostat.fao.org.* Accessed September 2009.

3. Crop yields represent a particular partial productivity measure wherein the physical output for a particular crop is expressed relative to land input.

4. Year 2000 is the last year for which internationally comparable data on agricultural R&D investments are presently available.

5. Notably, government agencies accounted for over half the publicly performed agricultural R&D in the United States through to the mid-1900s, but the university share has grown steadily since then (Alston *et al.,* 2010).

6. For instance, an agronomist or farmer who developed an improved wheat variety would have difficulty appropriating the benefits because open-pollinated crops like wheat reproduce themselves, unlike hybrid crops, which do not. The inventor could not realize all of the potential social benefits simply by using the new variety himself; but if he sold the (fertile) seed in one year the buyers could keep some of the grain produced from that seed for subsequent use as seed. Hence the inventor is not able to reap the returns to his innovation.

7. Alston *et al.* (2010) reviewed the prior literature. They also developed their own estimates using newly constructed US state-level productivity over 1949–2002 and US federal and state spending on agricultural R&D and extension over 1890–2002. Their preferred model had a peak lagged research impact at year 24 and a total lag length of 50 years.

8. Developed countries have also benefited substantially from spilling of R&D done in or directed toward the developing world. Alston (2002) reviewed work by economists in quantifying these benefits. For example, Pardey, Alston, Christian and Fan (1996) quantified the substantial economic benefits to the United States from selected research conducted in the international research centres.

9. The CGIAR (Consultative Group on International Agricultural Research) is an institutional innovation designed, in part, to correct for the global underinvestment in agricultural research arising from cross country spillovers. See Alston, Dehmer and Pardey (2006) for more details.

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2. Agricultural Knowledge and Innovation Systems in transition: Findings of the SCAR Collaborative Working Group on AKIS

Krijn Poppe[1]

This section presents the intermediate results of the review by the EU Standing Committee on Agricultural Research (SCAR) to identify agricultural knowledge structures in Member States (as well as other countries involved in the European Research Area). The Collaborative Working Group on Agricultural Knowledge and Innovation Systems (AKIS) of this Committee was created in response to the need for increased co-ordination between research and higher education systems. In discussions on innovation policy, two views have emerged: the macro-economic view which stresses market failure and research policy, and the institutional economics / systems of innovation view which stresses systematic institutional failure and innovation policy. The AKIS thinking is grounded in the second view.

Introduction

Introduction to the SCAR

The Standing Committee on Agricultural Research (SCAR) was established in 1974 by a Regulation of the Council of the European Union.[2] It is composed of representatives of EU member states and presided over by a representative of the Commission. The SCAR has a mandate to advise the Commission and member states on the co-ordination of agricultural research in Europe. Its mandate was renewed in 2005 with a view to playing a major role in the co-ordination of agricultural research efforts across the European Research Area. Today, the SCAR is composed of 27 EU member states, with representatives from candidate and associated countries as observers. A total of 37 countries are represented.

On the occasion of an informal Council of the Ministers of Agriculture in May 2006, under the Austrian Presidency, the Ministers recommended “that, in the framework of the Lisbon Strategy, the Standing Committee on Agricultural Research (SCAR) should invite EU member states to include questions of advisory services, education, training and innovation in their discussions.”

In October 2008, the French Presidency of the European Union organised in Angers a SCAR workshop entitled “Strengthening the links between knowledge and agricultural innovation in Europe.” The workshop concluded that European farming and agro-industry need knowledge from many different sources in order to compete with quality products in a globalised world. Climate change mitigation and adaptation, and recent fears related to food security are new challenges that required an integrated approach for optimal farm management in order to comply with new standards concerning the environment, food safety, animal health and welfare.

Farming is more diverse than in the past and is often combined with other activities. New knowledge is generated by farmers, researchers (basic and applied) and private companies. The old linear model of technology transfer (from scientists to users) is therefore outdated and should be replaced by an interactive model of networking systems which integrate knowledge production, adaptation, advice and education. The Angers workshop provided an opportunity to identify the key features of a European Agricultural Knowledge and Innovation System (AKIS) and to analyse how shared experience from important reforms in several European countries can lead to potential “best practices.” It highlighted the stakes linked to the need for proper AKIS in Europe:

- How to maintain a sufficient technical and scientific level among actors to enable them to respond to global and local changes and to improve their entrepreneurial skills.
- How to orient development work and link it to continuous education.
- How to conceive a new CAP supported by strong innovation systems in agriculture.

The conference on “The Knowledge Triangle: Shaping the Future of Europe,” organised by the Swedish Presidency of the European Union on 31 August – 2 September 2009 in Gothenburg focused on the importance of a well-functioning knowledge triangle (education-research-innovation) for Europe in a situation where the European Union’s research and higher education system is perceived as fragmented, and called for intensified interaction between policy areas, notably for higher education, research and innovation. A European modernisation agenda is stimulating universities to develop their missions and to develop to new models for the ways they operate. Innovation and entrepreneurship must be integrated in the core activities of education and research. The need to develop a European society based on knowledge places strong pressure on universities as central actors of the knowledge triangle. The complex problems facing agriculture need approaches that look beyond traditional agricultural boundaries and that incorporate inter- and even trans-disciplinary approaches.

The SCAR and Agricultural Knowledge and Innovation Systems (AKIS)

In line with the extended SCAR mandate, the 2008 Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions entitled "Towards a coherent strategy for a European Agriculture Research Agenda" indicates that "the Commission intends to make use of SCAR to identify agricultural knowledge structures in each Member State, with a view to eventually creating a corresponding Collaborative Working Group (CWG)."

The SCAR plenary meeting of December 2008 endorsed the proposal that "the SCAR-Working Group will look into the possibility to set up a CWG on this issue (i.e. on the links between knowledge and agriculture innovation in Europe)". The same idea was expressed during the SCAR plenary meeting of June 2009, when France and the Netherlands expressed their commitment to explore a possible follow-up of the Angers workshop in the form of an *ad hoc* CWG.

The new SCAR-CWG on agriculture knowledge and innovation systems in Europe seeks to contribute to fulfilling the SCAR mandate as described in the preceding section. It can serve as a starting point to establish a European system to monitor the AKIS structures and their evolution in order to design and evaluate AKIS policy formation and implementation with the perspective of meeting the challenge to feed the world's population in the long run in a sustainable way.

In addition, since advisory and extension services will likely play a significant role in the development of any future European agricultural knowledge and innovation system, the findings of the CWG could be interesting to the Commission, in particular in view of the Farm Advisory System, a policy instrument of the Common Agricultural Policy.

AKIS background

A key message of the first SCAR foresight exercise, widely disseminated by a June 2007 Conference in Brussels, indicated that the mounting challenges facing the agri-food and rural sectors in Europe called for a review of the links between knowledge production and its use to foster innovation. The role of research would be stronger role if different actors (farmers, advisory services, consumers, private sector, civil society, policy makers) were better integrated in the actual agenda setting and became part of the research process through their actions in innovative networks.

The second SCAR foresight exercise shed a harsh light on the current state of Agricultural Knowledge Systems in Europe, which was described as "*currently unable to absorb and internalise the fundamental structural and systemic shifts that have occurred. The remaining publicly funded AKIS appear to be locked into old paradigms based on linear approaches and conventional assumptions.*" The report stressed the need for renewed political attention to the effectiveness, relevance and scale of Europe's AKIS and to redefine AKIS. Although many share this opinion, more evidence-based analysis is needed to develop adequate policy actions.

This issue has since become more relevant. The European economy has seen a changing policy context: the financial and food crises, the EU 2020 strategy: “Smart, sustainable, inclusive growth”, the European Innovation Partnership initiative, and the discussions on the Common Agricultural Policy (CAP)-post 2013 (including the role of innovation) have influenced the discussions in the CWG.

Working methods of the CWG

The CWG is a network of civil servants from member states and the European Commission. The European Commission made available a small budget for some experts to write a methodological state of the art paper. A reflection paper was written on the AKIS concept (Dockès *et al.*, 2011) as was a briefing paper on the significance of social innovation in the context of agriculture and rural development (Bock, 2011). The CWG established and discussed an inventory of national issues and structures. However, it did not undertake any research.

The work is organised as a project with five working packages: a reflection paper on the state of the scientific literature on AKIS, AKIS policy, social innovation, management of complexity and porosity, and country cases.

Theory

Some theoretical notions on innovation policy

The thinking on AKIS is based on the so-called Systems of Innovation thinking concerning innovation policy. Smits *et al.* (2010) distinguish two views on innovation policy: the systems of innovation approach *versus* the macro-economic approach (Table 2.1).

The macro-economic view tends to see innovation as a linear process from (basic) research via Research and Development (R&D) to a commercial application. The main rationale is market failure and the main policy instrument is science or research policy. As there is also a risk of government failure, the choices on the direction of innovation should be left to the market as much as possible; the market organises the allocation of resources. This leads to a fairly clear policy that can be monitored by trends in science-based indicators.

The systems of innovation view is a more complicated approach to innovation and innovation policy. The focus is more on interaction between different stakeholders in the innovation process. The main rationale here is that there are systemic (network) problems in the system and with the creation of new innovation systems. Therefore, an innovation policy is needed that makes choices and is much more context specific. This more holistic approach is difficult to implement and monitor.

Table 2.1. Two views on innovation policy

	Mainstream macro-economics	Institutional and evolutionary economics: Systems of innovation
Main assumption	Equilibrium Perfect information	Disequilibrium Asymmetric information
Focus	Allocation of resources for invention Individuals	Interaction in innovation processes Networks and frame conditions
Main policy	Science / Research policy	Innovation policy
Main rationale	Market failure	Systemic problems
Government intervenes to:	Provide public goods Pitigate externalities Reduce barriers to entry Eliminate inefficient market structures	Solve problems in the system Facilitate creation of new systems Facilitate transition and avoid locks-in Induce changes in the supporting Structure for innovation: create Institutions and support networking
Main strength of policies designed under this paradigm	Clarity and simplicity Analysis based on long-term trends of Science based indicators	Context specific Involvement of all policies related to innovation Holistic approach to innovation
Main weaknesses of policies designed under this paradigm	Linear model of innovation (Institutional) framework conditions are not explicitly considered	Difficult to implement Lack of indicators for analysis and evaluation of policy

Source: Smits *et a*l. (2010).

The macro-economic view is linked to equilibrium thinking in economics, as elaborated by economists such as Ricardo, Marshall, Walras, Coase, Hayek and Friedman. However, innovation is much more about bringing the economy into disequilibrium. Several great economists have contributed to this view, including Schumpeter with his thinking on the role of the entrepreneur, creative destruction and business cycles. He builds on work by Karl Marx (on the role of the capitalist) and Friedrich List (the infant industry argument). Other thinkers are Ken Arrow on market failure and Oliver Williamson on institutional economics.

In the systems of innovation view, a well developed knowledge and innovation system has seven functions (Bergek *et al.*, 2010).

- Knowledge development and diffusion.
- Influence on the direction of research and identification of opportunities.
- Entrepreneurial experimentation and management of risk and uncertainty.
- Market training.
- Resource mobilisation.
- Legitimation.
- Development of positive externalities.

The AKIS concept

The AKIS concept was based on the old AKS concept, which originated in the 1960s in scholarly work on agricultural advice and extension. That system was driven by an interventionist agricultural policy that sought to co-ordinate knowledge and innovation transfer in order to accelerate agricultural modernisation. In many countries, this was reflected in a strong integration of public research, education and extension bodies, often under the control of the Ministry of Agriculture.

An "I" was added in the 1970s to AKS: "agricultural knowledge and *information* systems" (AKIS). This addition was linked to the increased attention to information, and probably also in connection to the large scale introduction of computers. The term AKIS popped up in policy discourses at OECD and FAO. Later, and more discreetly, the "I" was redefined as "innovation", and thus AKIS became Agricultural Knowledge and *Innovation* systems. There were four principal reasons for this evolving definition:

- Research, extension and education have undergone a deep restructuring, transformed by the trend towards liberalisation (privatisation of service delivery, the multiplication of extension organisations, farmers contributing towards the cost of these services, competitive bidding for research and extension contracts, and tighter evaluation procedures).
- Policy agenda: increasing concern over the environmental impact of industrial agriculture, the quality of life of rural populations, rural employment, and the need to support the positive externalities linked to agricultural production.
- The linear model of innovation has progressively been replaced by a participatory or "side by side" network approach, in which innovation is "co-produced" through interactions between all stakeholders in the food chain (and especially for second order change, and the so-called "system innovation" which introduced, for example, multifunctional agriculture or organic farming).
- The growing disconnection between farmer knowledge and research and extension systems.

The formal definition of an AKIS is "a set of agricultural organisations and/or persons, and the links and interactions between them, engaged in the generation, transformation, transmission, storage, retrieval, integration, diffusion and utilisation of knowledge and information, with the purpose of working synergistically to support decision making, problem solving and innovation in agriculture" (Röling and Engel, 1991).

An AKIS should be able to propose and develop practical ideas to support innovation, knowledge transfer and information exchange. Innovation policy needs to reflect the manner in which innovation occurs today, often through diffuse networks of actors who are not necessarily focused on traditional research and development.

Learning and Innovation Networks are an example of such diffuse networks, created on purpose. Box 2.1 provides more information on learning networks in agriculture.

Box 2.1. Learning and innovation networks

Learning and Innovation Networks are thematically-focused learning networks composed of actors within and outside the formal, institutionalised, AKIS. Members can include farmers, extension workers, researchers, government representatives and other stakeholders (Rudman, 2010). The emphasis is on the process of generating learning and innovation through interactions between involved actors.

In European agricultural research, the term LINSA has been recently introduced. This is a Learning and Innovation Network for Sustainable Agriculture. The difference between AKIS and LINSAs is connected to how knowledge is conceptualised: traditional AKS sees knowledge as a "stock to be transferred," whereas LINSA emphasizes the processes needed to make knowledge useful and applicable to other actors. In other words: LINSA are one of the methods to add the "I" in traditional AKS to vitalize AKIS.

In the European Union's 7th Framework Programme, the SOLINSA project has been created and funded to develop concretely more effective and efficient support for LINSAs. It has three objectives:

- Offering tools and methods for practitioners involved in learning and innovation in agriculture
- Provide recommendations on policy instruments and financial arrangements that support learning and innovation for sustainable agriculture
- To put forward concepts that reflect on learning and innovation processes as drivers of transition to sustainable rural development

For more information on Solinsa, see *www.solinsa.net*.

Social innovation

The Systems of Innovation view underlines that innovation is also a social process between different actors. This is linked to the concept of social innovation. The concept of social innovation originates in critiques of traditional innovation theory. By calling for social innovation, new theories point to the need to take the social mechanisms of innovation into account (the social mechanisms of innovation).

A second dimension of the concept of social innovation is that innovations must take into account social responsibility. They should not only focus on the profit aspect, but also on the planet and the profit aspects of sustainability. As innovation is also disruptive, this can be a challenging demand.

There is a third dimension to social innovation: the fact that not only commercial activities need innovation, but also social and public activities. In the context of rural development, social innovation refers to the (social) objectives of innovation – that is those changes in the social fabric of rural societies, that are perceived as necessary and desirable in order to strengthening rural societies and addressing the sustainability challenge (social inclusion / equity: the innovation of society as well as the social responsibility of innovations).

First findings of the CWG

The CWG is still in the process of fact-finding and a report will not be available before early 2012. However, some first findings can be reported, although they are open to counter fact-finding and more precision in further work by the CWG.

The first major finding is on the usefulness of the AKIS concept. AKIS is originally a theoretical concept (based on observations) relevant to describe national or regional AKIS. These exist and members of the CWG have been able to describe their national or regional system in AKIS terms, and it is useful to reflect on their policies. However, it is clear that national or regional situations differ greatly in, for example, their institutional framework, their competitive position and their strategies for agriculture, as well in the history of the country or region. This implies that there is no *one size fits all* formula on what the ideal AKIS is. It is also clear that more scientific work is possible to support fact-finding and discussions on AKIS and AKIS-policy. For instance, could typologies of systems (in relation to strategies of regional food chains and policies) help to get some grip on the differences between 27 EU member states or 37 countries in the European Research Area?

AKIS are quite different between countries regions. This is especially true for the link between (applied) research and farmers via extension. Some examples illustrate this (Dockès *et al.*, 2011, based on Laurent, 2006):

- Mainly privatised systems for extension (e.g. the Netherlands, some states in Germany) where the funding mainly comes from direct payments from farmers, but are coupled with high state funding for research.
- Co-management between farmer organisations and the state (e.g. France, Finland, and some states in Germany), with public funding, and partial payments by farmers and farmer organisations.
- Semi-state management (e.g. Teagasc in Ireland which has a board with representatives from the state, industry and farmer organisations);
- Management by the state through regional organisations (e.g. Switzerland, Italy and Finland).
- Uncoordinated individual innovation nucleuses.

There are not only differences between countries, but also in time. A third major finding of the CWG is that some countries have restructured their AKIS considerably. For example, the Netherlands has privatised its state extension service, leading to competition, and has merged its applied research and agricultural university into the Wageningen University and Research Centre, which is regarded as a "third generation university" with innovation as part of its mission. Learning innovation networks are an important policy instrument to address systemic co-ordination issues. In France, the development of AKIS is characterised by clustering the so called *Pôle de compétitivité* – a regional clustering with special projects to support consortia. Denmark is a similar example, where applied research was merged into regional universities. The obligation of the Common Agricultural Policy of the Farm Advisory System (to make extension available on cross compliance) has lead in Hungary to the introduction of a Farm Advisory System, in addition to Farm Information Service (organised by the Chambers of agriculture) and the Network of Village Agronomists (and agri-business).

A fourth finding of the CWG is that AKIS components are governed by quite different incentives. Although communication and collaboration between the different components is seen as crucial, the components are driven by different incentives. Research is often evaluated in terms of publications, citations, and "excellence." Education funding is often based on student numbers. As suggested above, there is a wide variety of incentive mechanisms in extension: payments by farmers, vouchers, subsidised programs or input finance, to name a view. In a food chain, such an uncoordinated incentive scheme would be questionable, but it is not clear if this is also an issue in a Systems of Innovation that does not see innovation as a top down linear process. However, the need for multi- and trans-disciplinary approach is often mentioned to overcome systemic problems in current agriculture. In several cases, it is noted that competition impedes co-operation between actors.

Related to this issue is the fifth preliminary finding of the CWG: AKIS are governed by public policy but there is no consistency in AKIS policies. There are policies for education and for research, sometimes by different ministries. Some countries (e.g. Netherlands) view research and innovation programs as a policy instrument to reach certain public goals (e.g. with respect to the environment) and combine them with other types of regulation. The interaction with innovation in the private sector (like the food industry) is often weak and not clearly taken into account when designing policies. Questions can also be raised on the relation between agricultural innovation instruments and general innovation policy. Only exceptionally (a recent policy study in Flanders is an example) are discussions on coherency of policy tabled.

Monitoring of AKIS is fragmented, in terms of input, system, or output. At present, there is a major inconsistency between the high level of attention to “innovation” in the policy domain and the lack of data and research for evidence-based policy. Statistics and other data gathered focuses on R&D in the food industry, on patents (Community Innovation System), and the number of publications of the research system and their citations (like the Web of science). There are no monitoring reports for parliament or the public as is done in policy fields concerning, for example, environmental issues or income support. However, sometimes *ex post* policy analysis of certain innovation programmes is carried out and made public in at least some countries.

In conclusion, the initial findings suggest that further research and policy discussion on AKIS are useful.

Notes

1. Chief Science Officer Agrochains and Fisheries, Ministry of Economic Affairs, Agriculture and Innovation, The Hague, the Netherlands.
2. More information can be found on the website *ec.europa.eu/research/agriculture/scar* (or search EU SCAR), from which this information is taken.

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3. Australia's approach to rural research, development and extension

Allen Grant[1]

This section outlines how Australia's Agricultural Knowledge System (AKS) contributes to the productivity, sustainability and competitiveness of Australia's primary industries. The strong link between innovation and productivity growth and the role key members of the Australian AKS have in funding and conducting research and development, and delivering and adopting innovation are described. The challenges and opportunities facing the Australian AKS and the Australian Government's response are examined. Finally, how the National Primary Industries Research, Development and Extension Framework is assisting AKS members to better collaborate in order to improve the AKS's function and efficiency is described.

Background

Australian agriculture is very diverse, reflecting its unique climate and geography. Australia's agricultural production spans across tropical regions in the North and temperate regions in the South, encompassing both rain-fed and irrigated approaches, as well as broadacre and intensive. As a result, if Australia experiences crop failure or other extenuating circumstances in one region, there is usually alternate production of the same crop in another part of the country. This helps to achieve self-sufficiency across most commodity production. It should be noted, however, that when a tropical cyclone recently struck the far Northeast region of Australia and destroyed banana crops, there was no alternate sources of production.

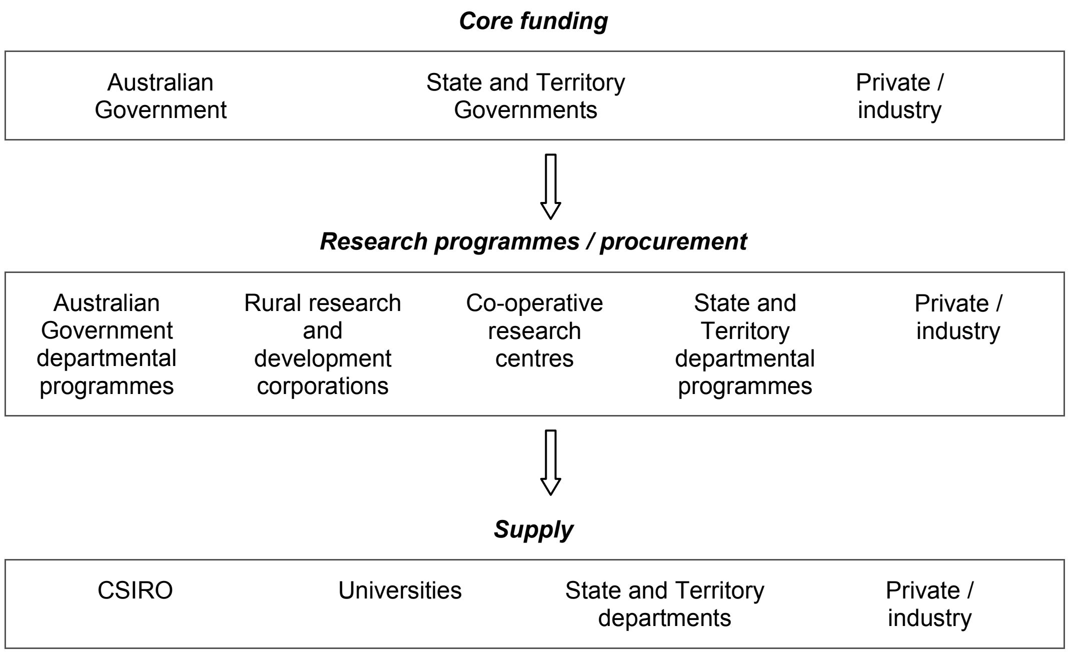
Australia is an export-oriented economy with a relatively small farming sector, comprised of about 134 000 farmers. Primary industries make a vital contribution to Australia's economic wealth and well being, mainly through agricultural exports. At any given time, agricultural exports may represent between 60% and 70% of total production. Between 2009 and 2010, agricultural production represented only 2.8% of our GDP. This is a relatively small number and one that is on the decline among developed countries. After accounting for broader food sectors and distribution, however, this figure rises to about 12%. Total production over this period reached AUD 36.7 billion, of which AUD 24.3 billion were exports. With such a focus on exports, exchange rates are very important. Australia’s exchange rate has appreciated considerably over the last decade from an Australian dollar worth around USD 0.50 to the current rate of around USD 1.07.

Australia AKS

There are several key contributors to Australia's Agricultural Knowledge System (AKS). Much of the core funding comes from the Australian government and state and territory governments. Australia's constitution calls for collaboration between state and territory governments. Governments they have historically played a major role in funding agricultural Research and Development (R&D). The balance of funding for R&D comes from the private sector.

Below this group of core funders are investors in R&D. This includes a series of government expenditure programs involving commonwealth, state and territory governments, the research and development corporations, and cooperative research centres. The 15 research and development organisations which form part of the RDC model collectively make up the largest component of Australia’s AKS. Cooperative research centres operate on a seven year funding cycle, whereby groups of semi-government and private sector organisations cooperate to invest funds for R&D in a particular area. The investment they contribute is matched by the commonwealth government. Research and procurement programmes are also funded through investments from private sector businesses, including through taxation incentives for R&D write offs. The supply side includes the Commonwealth Scientific and Industrial Research Organisation (CSIRO), universities and private sector actors, as well as state and territory departments which focus on delivery of regional and local R&D.

Figure 3.1. Key contributors to Australia's AKS



Source: Productivity Commission (Australia).

In Australia, the delivery of extension services has traditionally been managed by local or state governments. Over time, however, government investments in extension services have gradually diminished. This investment has been supplemented by the private sector, which has become much more involved in delivering a wide range of extension services. As a result, we must find a suitable balance between public and private investment in R&D extension services across all sectors.

Total rural R&D funding is around AUD 1.5 billion each year, including both public and private funds. This is a relatively small figure compared with the AUD 27 billion spent on total innovation across the whole economy, but it is still about 5% to 6% of total innovation expenditure — slightly more than agriculture's contribution to total GDP.

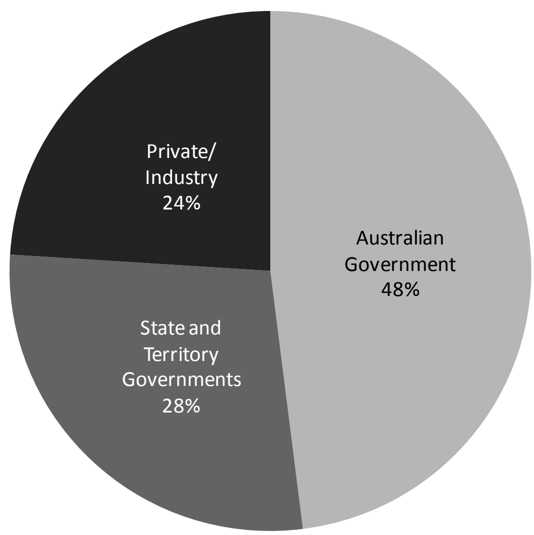
Measuring innovation expenditure presents some difficulties, particularly with regard to agricultural innovation. Estimates can vary according to whether one takes a top-down or bottom-up approach. Top-down estimates are based upon the amount of money funders contribute to the system, while bottom-up estimates are based upon the amount that actors contribute to actually undertaking R&D. Often these two approaches produce two different estimates. The reasons for this discrepancy remain unclear, but this is certainly a challenge we need to address.

The public sector accounts for about 76% of all investment in agricultural R&D. Of this public investment, nearly half comes from Australian government, with an additional 28% from state governments. The private sector provides about 25% of total investment, though this share is increasing as government investment declines over time. Private sector involvement is still low when compared with the United States, for example, where global R&D companies like Monsanto and Syngenta contribute substantial investments. This difference can be attributed, in part, to the fact that the Australian market is relatively small and depends upon significant investments from other countries. Because of the size and diversity of our agriculture sector however, we do not have the economies of scale to attract these investments. This is a major challenge for us, and one that underscores the need to be more internationally cooperative.

Some critics of Australia's system have argued that high levels of government investment are actually crowding out private sector investment. Much of this argument is based upon the high rates of return that accrue to the agriculture sector as a result of investment in R&D. According to economic theory, returns of 15% to 20% should attract more investors. As we have seen, however, this does not often happen in practice.

Figure 3.2. Estimated rural R&D funding sources

2008-09 total = AUD 1.497 billion



Source: Productivity Commission.

Research and development corporations model

Australia's R&D corporation model is unique to Australia and is a partnership between the Australian government and industry. Under this model, industry, and in particular individual farm businesses, agrees that it should contribute money to R&D for the long term benefits of that sector. Once it has achieved agreement from the majority of farmers (who will have to pay a levy), it asks the government to mandate, through legislation, that these levies should be paid by all relevant businesses in the sector. Such a mandate ensures that every producer makes a contribution to R&D consistent with their size and production levels, thereby avoiding some of the free-rider issues that a voluntary system may pose. Once private industry voluntarily agrees that the government should issue a mandate, it becomes a statutory responsibility for producers to pay their contribution.

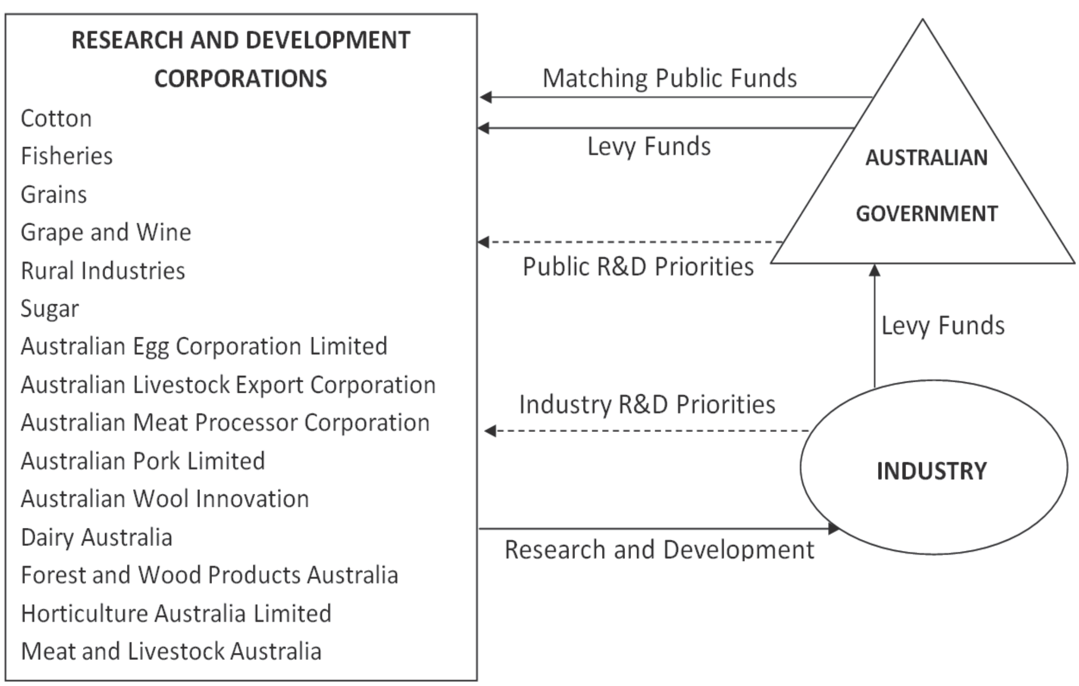
Once the mandate is issued, government and industry collaboratively determine priorities for R&D, based on the industry's strategic plans. When the government collects levy funds from producers, it matches those funds up to a cap, so as to avoid an unlimited drain on the public purse. The government then provides those monies (including levies collected from producers as well as matching government contributions) to the series of R&D corporations displayed in Figure 3.3.

There are 15 R&D corporations under this system, representing all of the major sectors of commodity production in Australia. One of the largest is Horticulture Australia Limited, which represents about 44 different horticulture production areas. As a result, more than 50 levies are collected from these different components.

This complex, yet effective model was created in 1989 and, since then, has remained largely unchanged. From 2008 to 2009, these R&D corporations spent a total of about AUD 470 million on R&D, of which around AUD 218 million was matched with public funds.

There is some debate surrounding this system. Some, for example, have questioned whether the government's matching funds should be spent only on so-called "public good outcomes," or whether this joint investment should be devoted to industry benefits. In order to address this issue, however, one must first define a public good investment. A private good investment will generate private sector profits, but if it also increases employment and enhances regional development or social cohesion, then it is likely to have some public good component, as well. The challenge is to get the balance just right – to ensure the correct incentives are in place to encourage the private sector to continue to invest in R&D while ensuring that key public good concerns are also addressed by relevant R&D.

Figure 3.3. Research and development corporations model

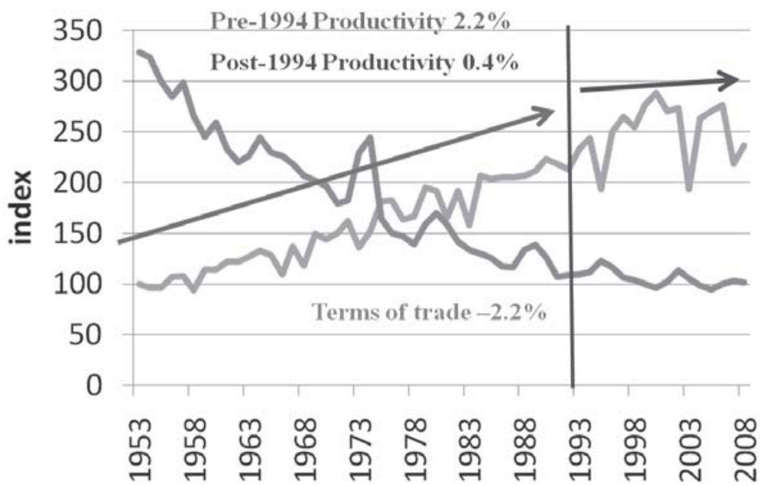


Challenges

Australia's AKS faces several challenges. For one, we must increase the rate of productivity growth across agriculture. The strong connection between R&D investment and productivity growth is well known in Australia and in other countries. Of course, there are also significant lags throughout this system, with the benefits of R&D being returned for as long as 25 years after the initial investment, according to Australian research.

As Figure 3.4 demonstrates, productivity growth in Australian agriculture (in particular the broad hectare farming and dairy sectors) was strong from the 1950s until 1994, especially when compared with productivity growth in other parts of the Australian economy. Over this period agricultural productivity grew at a rate of just over 2% per year, helping to offset a decline in the terms of trade faced by Australia's farmers. This productivity growth effectively allowed Australia's agricultural sector to compete in global markets despite declining terms of trade.

Figure 3.4. Productivity trends and terms of trade



Source: ABARES.

Since the late 1990s, however, agricultural productivity growth has slowed to about 0.4% per annum. Research suggests two main reasons for this decline: an extended ten-year drought that began in the 1990s; and a reduction in public sector investment in R&D. Today, it is imperative that we find new ways of addressing this slow down in productivity growth. General government budget constraints are likely to preclude investment of significantly more public funds in R&D. Given this it is imperative that we look for ways of using our existing resources more effectively.

We must strive to ensure that both R&D investment and the AKS in general function effectively and efficiently. As part of that process we are currently conducting significant reviews of Australia's AKS and, in particular, of the R&D corporations model. This review is being undertaken by the Productivity Commission, which is an independent body that takes a very structured and economic approach to addressing the costs and benefits of various forms of investment and assessing the effectiveness of such investment. Once this review is completed later in 2011, the government will use its outcomes to reform our AKS to a large extent.

In addition, we regularly review both national research priorities (across all sectors), and national rural R&D priorities. These reviews are conducted every five to ten years and tend to be fairly broad in scope, but each review may identify different priorities. Over the last ten years, for instance, climate change has become a higher priority for agriculture R&D expenditure.

We also recently established the Rural Research and Development Council which has conducted a holistic review of Australia’s rural innovation system, with the goal of developing a national strategic rural R&D investment plan.

National primary industries research, development and extension framework

The National Primary Industries Research, Development and Extension Framework is a key initiative, and one that represents the way forward. This framework aims to improve the operation and efficiency of the Australian AKS, both in the short-term and, more importantly, over the next 20 years. The framework was the product of a 2009 agreement among all governments in Australia, including state, territory and commonwealth levels. This partnership also includes the R&D corporations, research providers (CSIRO and universities), and the agriculture industry. Under this agreement, all of the major players in Australia's AKS have come together to review and develop the structure and institutional arrangements needed to improve the efficiency of national research for each agriculture sector, and to better address cross-sectoral R&D requirements.

To date we have developed 14 sectoral strategies, as displayed in Table 3.1. These strategies are mostly lead by the relevant R&D corporation and cover all major commodity areas in Australian agriculture.

Table 3.1. National primary industries research, development and extension framework

Sectoral strategies	Cross sectoral strategies
• Pork	• Animal welfare
• Wine	• Climate change
• Dairy	• Water use in agriculture
• Beef	• Biofuels and bioenergy
• New and emerging industries	• Plant biosecurity
• Horticulture	• Animal biosecurity
• Sheep meat	• Food and nutrition
• Sugarcane	
• Poultry	
• Fish and aquaculture	
• Forest and wood products	
• Grains	
• Cotton	
• Wool	

In addition, there are seven cross-sectoral strategies identified that deal with the procurement and delivery of R&D in areas common across individual sectors. These common issues include climate change, water use, and food and nutrition, among others. Dealing with the delivery of coordinated R&D to meet cross-sectoral requirements is complex and not easy. Finalizing these cross-sectoral strategies and ensuring the longer term commitment to implement and maintain the strategies from all the relevant players will pose a significant challenge in the near future.

The framework identifies the nature and extent of current R&D and extension resources currently available across the country. It identifies actions needed for them to be used more efficiently, effectively and collaboratively, both now and into the future. It aims to reduce duplication of effort and maximize collaboration across governments, industry and research investors. The framework identifies those who will lead national research efforts, those who will provide links to the development of research, and those who will support R&D through local extensions. In short it is a "lead, link and support" model.

An example of this is Australia's dairy industry. In Australia, each state has its own diary industry. In the past, each state conducted its own R&D to service their respective local industries. Because the needs and requirements of each dairy industry were largely consistent across all states, duplication tended to arise from this approach. Under the RD&E Framework we will identify who will lead the investment and delivery of R&D for the dairy industry on a national level. This initiative will likely be centralised in one institution and or a small number of institutions with increased collaboration. R&D will be delivered nationally to all sectors from the lead provider. In the case of the dairy industry, the state of Victoria in conjunction with the RDC Dairy Australia will take on the lead R&D responsibility and provide national and regional R&D to all dairy farmers across the country. For each sectoral and cross-sectoral strategy there is a detailed plan that identifies who will lead, link and support these strategies across the board.

At the moment, we are developing the 21 plans for each of these strategies, as part of a seven step process (Table 3.2). The first step involves an overview of each sector, identifying the scale, distribution, trends and threats. The second step calls for an analysis of current resources, including current investment in R&D and extension, as well as trends across public and private sectors. This is followed by the development of a future R&D and extension plan, establishing future strategic objectives and priorities for each sector. This plan also identifies whether current extension services are delivered from business, government, or a mix of both, while also looking forward to future R&D and extension requirements over the next 20 years. In step four, we conduct a capability analysis that examines whether we have the current capacity to meet the identified requirements over the next two decades. In most cases, the answer is no, due to various capacity and capability needs and gaps.

After these gaps are identified, we develop a detailed change plan setting out the steps and actions needed to establish and implement the new national R&D and extension strategy. This plan includes capability and management arrangements, as well as agreements for the sharing of information and intellectual property. The change plan provides a detailed analysis of how to change institutional arrangements if necessary, build better networks, and establish the consultation frameworks needed to meet future goals. It also provides strategies to ensure that funders, participants and users of R&D maintain collaborative relationships and provide framework support over a 20-year period. This aspect is especially important, since it is all too easy for these partnerships to disintegrate over time.

Steps one through five are relatively straightforward, but the real challenge lies in actually implementing this plan, and in sustaining the momentum of the new arrangements over a prolonged period. To help with this challenge an overarching set of rules to govern the system will be developed and then applied to each sectoral and cross-sectoral strategy. In the case of dairy industry R&D for example, we must develop a way to guarantee that the dairy industry in states like Western Australia will actually receive the relevant R&D on which they rely, even if it is developed and delivered from another part of the country. Any national (lead) R&D provider moreover, must be responsible for understanding both national and local needs for R&D and extension.

Table 3.2. Process for the development of sectoral RD&E plans

	Step	This means / includes
1	Sector overview	Description of scale, distribution, trends, opportunities and threats
2	Current resource analysis	Current investment in RD&E, public and private, amounts, trends, focus. Current RD&E (human and infrastructure) capability including location, focus, trends for both public and private sectors
3	Future RD&E Plan	Establish future strategic objectives and priorities for the sector
4	Capability analysis against plan	Compare information from current resource analysis and the requirements to address the future RD&E plan in order to identify future capability needs and gaps
5	Change Plan	Develop a detailed change plan to establish and implement the new national RD&E sector strategy, including agreements between parties for capability and management arrangements and information sharing, including intellectual property
6	Consultation and approvals	Describe and establish consultation arrangements with stakeholders (including governments, universities, RDCs, etc.)
7	Implementation arrangements	Timeframes and responsibilities, including monitoring, reporting and reviews

We are also exploring ways to reduce transaction costs between businesses within this framework. For example, we are looking to develop standard contracts for funding organisations to procure R&D, which would reduce transaction costs across the board. We are also looking to address intellectual property issues associated with R&D provision to provide more consistency and reduce transaction costs. Another project is determining consistent and appropriate methodologies for evaluating returns on investment from R&D that deal with economic, environmental and social returns.

Extension services have traditionally been delivered at the local level in Australia. If this is to continue, these services must be integrated with delivery of national R&D and associated regional development. This will require an analysis of the pros and cons of a national extension service versus better collaboration and integration of the current participants involved in extension.

Unfortunately, the RD&E Framework will never be able to guarantee that future governments will continue to invest in R&D at the same or higher levels than at present. In the event of future disinvestment, however, this model will hopefully help mitigate any negative effects by identifying those areas and initiatives that can be disinvested with minimal impact on the entire system. Through providing this intelligence, the model will help inform future investment decisions.

Opportunities for Australian AKS

Going forward, there are several opportunities for Australia's AKS. For one, we can continue to build stronger linkages between our own national R&D infrastructure, and the international community's infrastructure. Australia is developing a national broadband network that is currently being rolled out, and will be completed within the next two to three years. This will provide significant opportunities for producers to take advantage of

R&D, while providing additional levels of consultation and communication. It is important that this communication be open, and that it fosters stronger connections with the international community.

With the exception of the grain sector, Australia does not have a strong history of cooperative R&D with international organisations or researchers. We must acknowledge that we cannot produce all necessary R&D at home. We simply do not have the required capacity, finances, or skills, nor do we have the appropriate institutional establishments. In the future, then, we must look to work with other countries and overseas based organisations, in order to guarantee a more sustainable model.

Stronger international collaboration and engagement would offer significant benefits. It would allow us to understand our own markets better, while giving us access to new technology that could be adapted to Australian conditions. International engagement would also allow us to share our technical capabilities and knowledge with developing countries to help reduce poverty, improve natural disaster response, and strengthen global food security. Australia has already been instrumental in making some contributions to those key issues in recent years, and we are certainly prepared to make a stronger effort going forward.

Note

1. Executive Manager, Agricultural Productivity Division, DAFF, Australia.

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Productivity Commission research report *Public Support for Science and Innovation* March 2007 *www.pc.gov.au/projects/study/science/docs/finalreport*

Australian AKS Participants

Australian Centre for International Agricultural Research
www.aciar.gov.au

Australian Research Council
www.arc.gov.au

Cooperative Research Centres
www.crc.gov.au

National Primary Industries Research, Development and Extension Framework
www.daff.gov.au/agriculture-food/innovation/national-primary-industries

National Research Priorities
www.dest.gov.au/NR/rdonlyres/AF4621AA-9F10-4752-A26F-580EDFC644F2/2846/goals.pdf

Research and Development Corporations

www.daff.gov.au/agriculture-food/innovation/research_and_development_corporations_and_companies
www.ruralrdc.com.au

Primary Industries Ministerial Council
www.mincos.gov.au

Rural Research and Development Council
www.daff.gov.au/agriculture-food/innovation/council

Rural Research and Development Priorities
www.daff.gov.au/_media/documents/ag-food/innovation2/Priorities_Booklet_FINAL.pdf

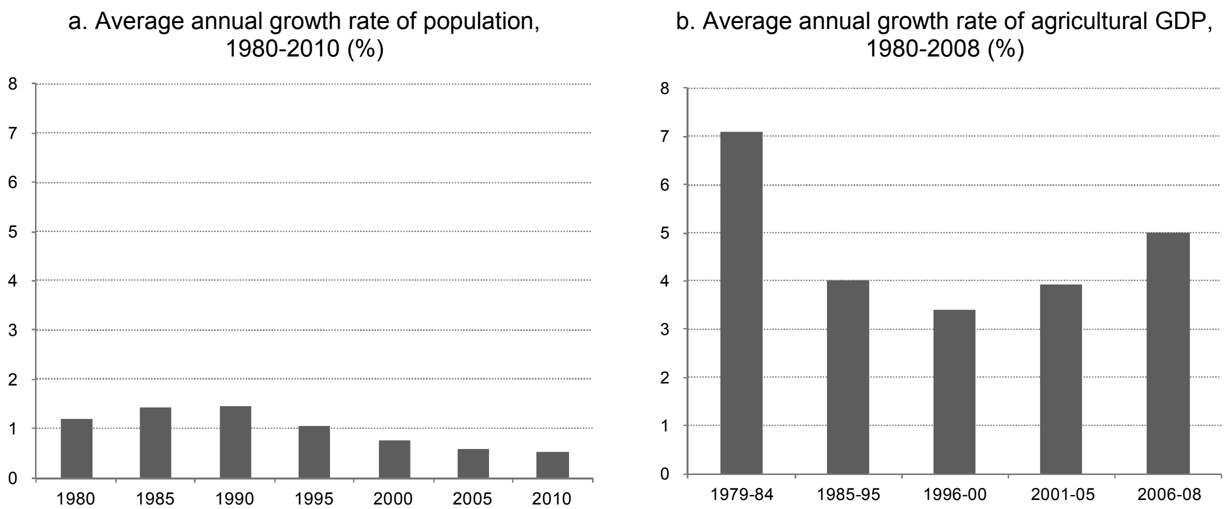
4. China's agricultural innovation system: Issues and reform

Ruifa Hu[1]

Agricultural research has been an engine of agricultural growth in China over the past 30 years. With rising food demand, China's leaders believe agricultural technology is a major solution to improving the nation's food security. They have developed a national agricultural Research and Development (R&D) system and have tried to reform this system so that the technologies generated can be more responsive to farmer demands. Since 1985, the government has invested significantly in R&D, particularly in recent years; government R&D investment increased by more than 15% during 2000-09. However, China's agricultural research and extension face significant challenges as a public-dominated system that has its pros and cons. The leaders are well aware of the weaknesses of this system and have recently sought to encourage the private sector to join public efforts in the agricultural R&D system. If this is to happen, it is expected that a new era in China's agricultural R&D will develop.

In the past 30 years, China's GDP has grown on average about four times faster than its population (Figure 4.1). Because of this, poverty rates have been rapidly decreasing (Figure 4.2). In fact, the decline of poverty within China alone accounts for most of the decline observed across the entire world.

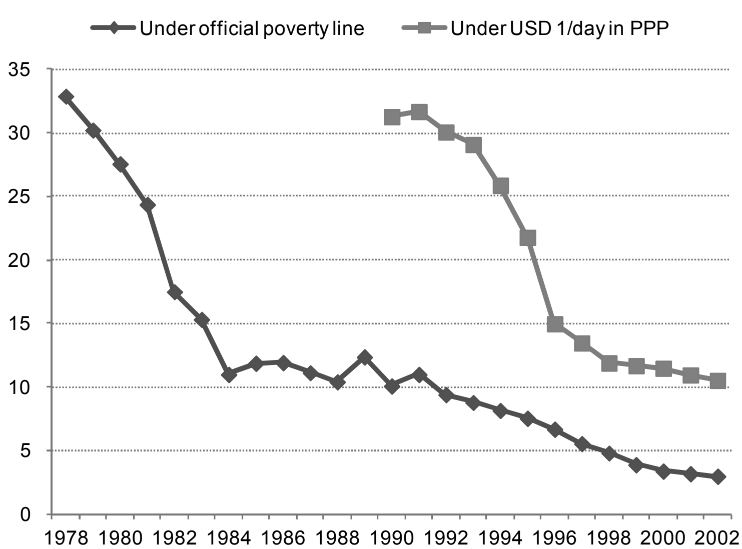
Figure 4.1. Average annual growth rate of population and agricultural GDP in China



Source: Author's calculations based on data from ZGTJNJ (2010).

China's total factor productivity (TFP) has increased as well (Jin *et al.*, 2002; 2010), and technology has played a major role in fuelling this growth since the mid-1980s. Output, meanwhile, has risen, while input has fallen (Figure 4.3.a). TFP is also growing at a faster rate each year (Figure 4.3.b). Much of this is due to technical change, which, in turn, has raised China's agricultural production frontier (Jin *et al.*, 2002; 2010). This means that China is already operating efficiently at the frontier.

Figure 4.2. Rural poverty incidence in China, 1978-2007
(% of population)

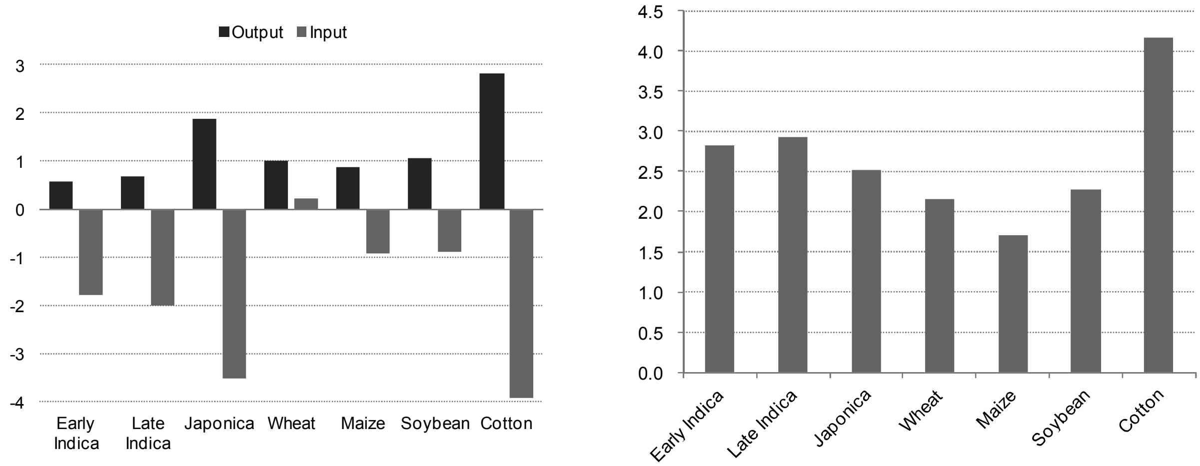


Source: Huang *et al.* (2010).

Figure 4.3. Average annual growth rate of output, input and TFP for main crops in China, 1995-2004

a. Average annual growth rate of output and input, 1995-2004 (%)

b. Average annual growth rate of TFP, 1995-2004 (%)



Source: Jin *et al.* (2010).

A number of studies have shown that technology has been a major engine of food and agricultural growth in China since the mid-1980s (Huang and Rozelle, 1996; Fan and Pardey, 1992; Fan, 2000; Huang *et al.,* 2000; 2003), as well as demonstrating the importance of China's public agricultural R&D system in the increase in crop productivity (see Carter, 1995 for an extensive review of the evidence). The system could play a more important role to enhance food security, reduce poverty, and to boost both competitiveness and farmer income, while preserving the environment (Huang *et al.*, 1995, 2000).

From a policy perspective, this section discusses three questions:

- What is the main reason that R&D has contributed significantly to agricultural growth?
- What can we learn from Chinas' experiences and lessons?
- What are the challenges that China should consider today, while implementing agricultural R&D reform?

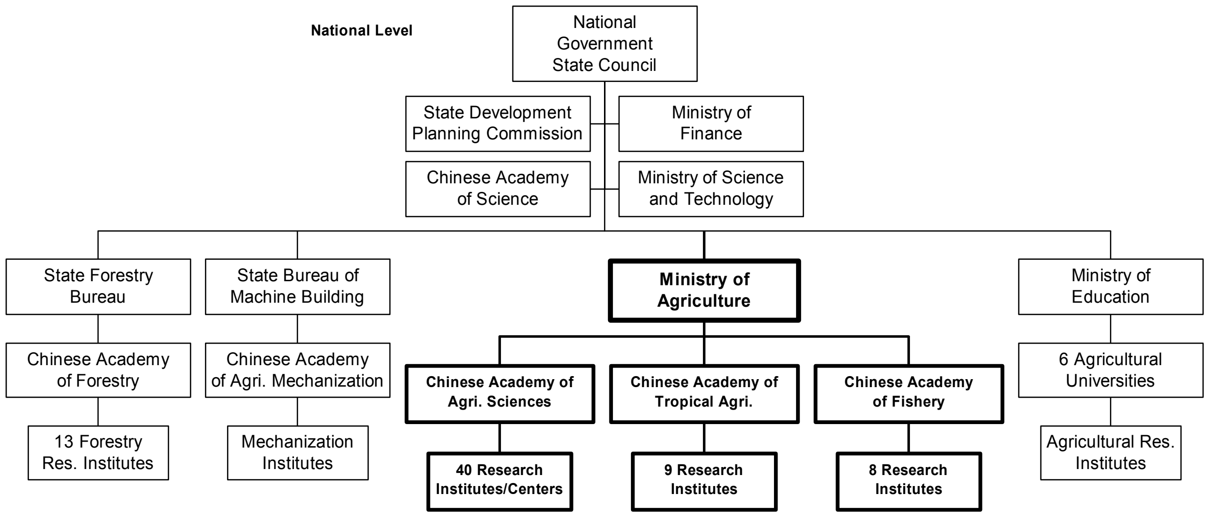
To examine these questions, we will first outline China's R&D system, before providing an analysis of the challenges and reforms it is confronted with, followed by concluding remarks.

China's R&D system

China's agricultural R&D system at the national level (Figure 4.4) is a complex system. There are four ministries that manage the research system, and each ministry includes a research academy. Research centres account for 10% of total research staff and 15% of the total budget (Huang *et al.*, 2003).

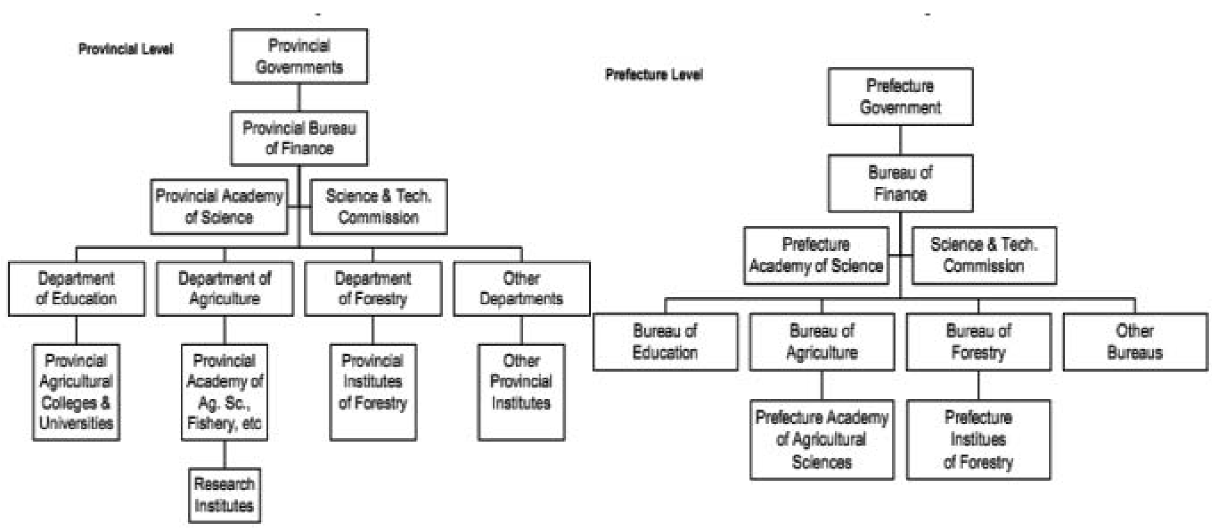
The provincial and prefecture system is similar to the national system (Figure 4.5). The provincial research centres account for 41% of all research staff and 51% of total budget. At the prefecture level within each province, research centres account for 32% of research staff and 34% of total budget.

Figure 4.4. China's agricultural R&D system: Organisation chart for agricultural research (national level)



Source: Huang *et al.* (2003).

Figure 4.5. China's agricultural R&D system: Organisation chart for agricultural research (provincial and prefecture level)

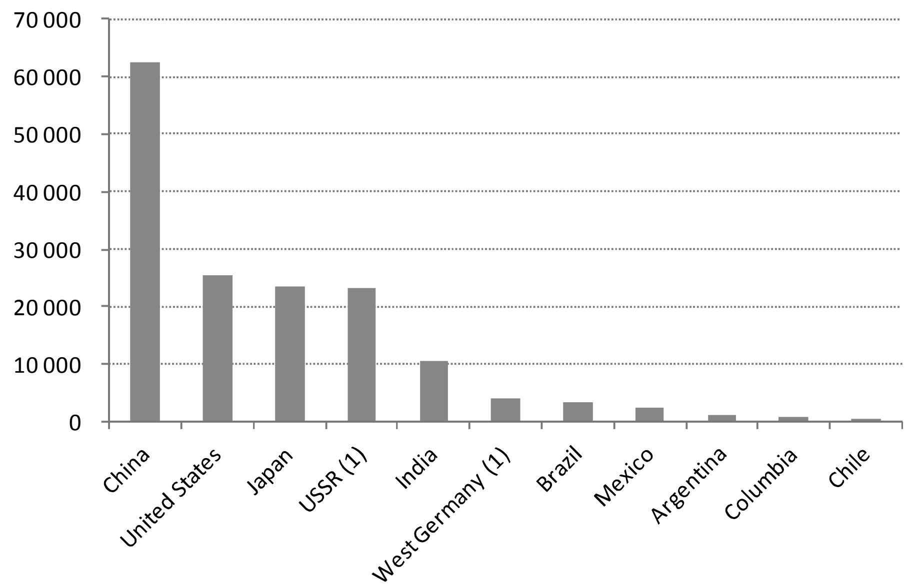


Source: Huang *et al.* (2003).

China's public agricultural R&D system focuses not only on basic research, but on development research, as well (Huang *et al.*, 2000; 2003). The central government has established agricultural research institutes that cover most of the agricultural products within the nation. Local governments have established agricultural research institutes that covered nearly all products in their own regions, as well. There are 1 237 agricultural research institutes and 88 agricultural universities or technological academies scattered across every province or prefecture. Research fields, meanwhile, cover nearly all agricultural products within China. Since 2008, the Ministry of Agriculture has specially invested in 50 innovation product industries.

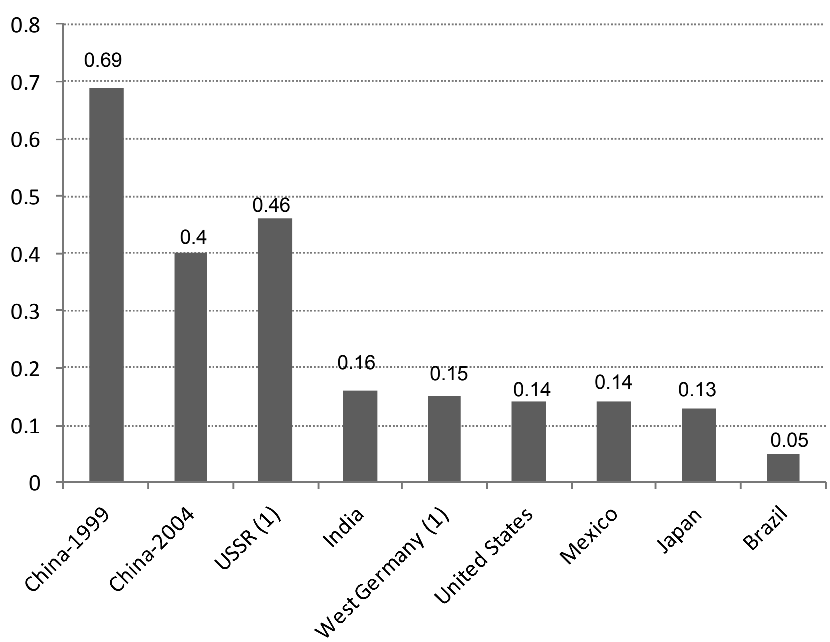
China boasts the largest public agricultural R&D system in the world. This system includes more agricultural R&D staff than any other (Figure 4.6). The Chinese system also has more researchers per USD 1 million of agricultural GDP than any other system (Figure 4.7). In fact, we found that our research system is overstaffed (Huang *et al.*, 2003).

Figure 4.6. Number of agricultural R&D staff (active researchers), 2004



1. Figures are for the late 1980s (see Alston, 1995).
Source: Huang *et al.* (2003).

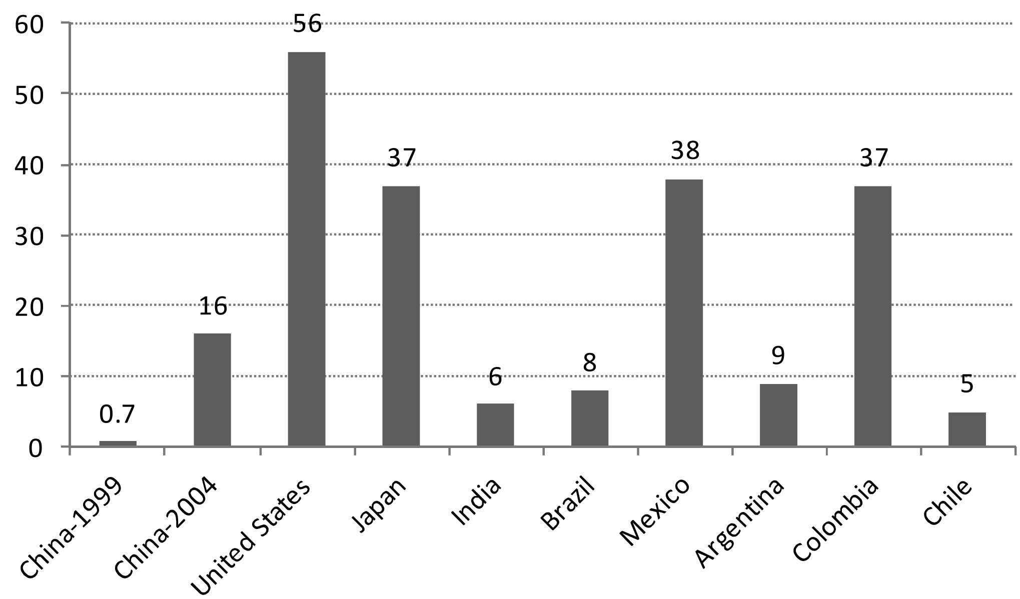
Figure 4.7. Number of researchers per USD 1 million of agricultural GDP, 2004



1. Figures are for the late 1980s (see Alston, 1995).
Source: Huang *et al.* (2003).

China's agricultural R&D system is public-dominated, but it is changing very rapidly (Hu *et al.*, 2009). In the late 1990s, the private sector's share of agriculture within China was very small compared with other countries, at less than 1%. By 2006, however, that figure increased to 16% (Figure 4.8).

Figure 4.8. Private sector's share of agricultural research staff, early 1990s (%)

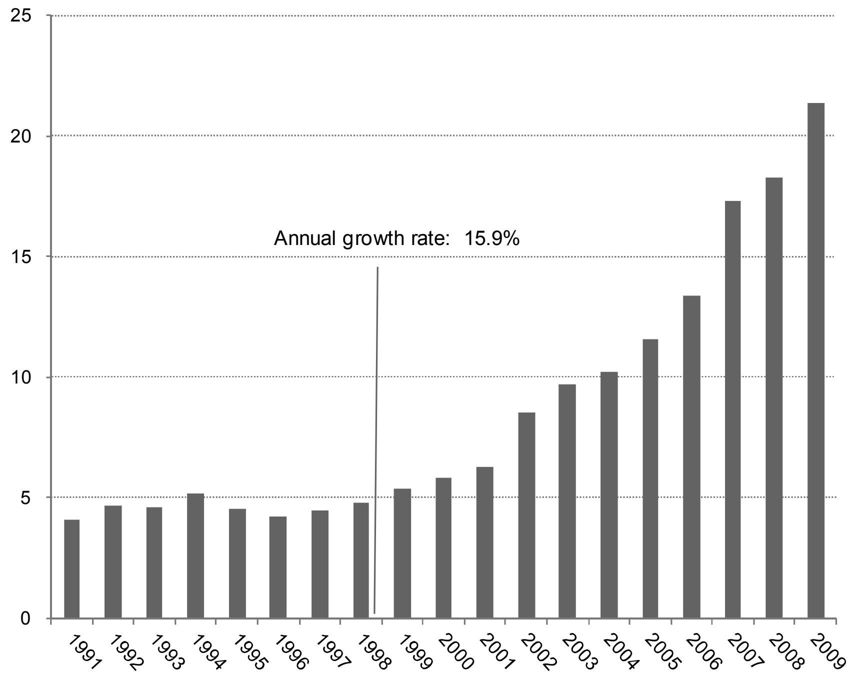


Source: Alston and Pardey (1998); Huang *et al*. (2003); Hu *et al*. (2009).

Figure 4.9 shows that government fiscal investment in agricultural research has increased rapidly, with an annual growth rate of nearly 15.9%, from 2000 to 2009. Even though this investment may increase quickly, the public agricultural R&D investment intensity (agricultural R&D expenditures as a percentage of agricultural GDP) was only 0.61 in 2009 (Figure 4.10), much lower than in other industrialised countries (Hu *et al.*, 2007). Since 2000, the increase in research investment has been higher in China than in any other country in the world (Hu *et al.*, 2007).

China also has the largest agricultural extension system in the world, with more than one million staff members in 2000 (Figure 4.11). Though this number has since declined, China's system remains the largest in the world, with agricultural extension systems located in even the most remote townships across China (Figure 4.12). This system ensures that new innovations can be adopted in time. However, it is overstaffed.

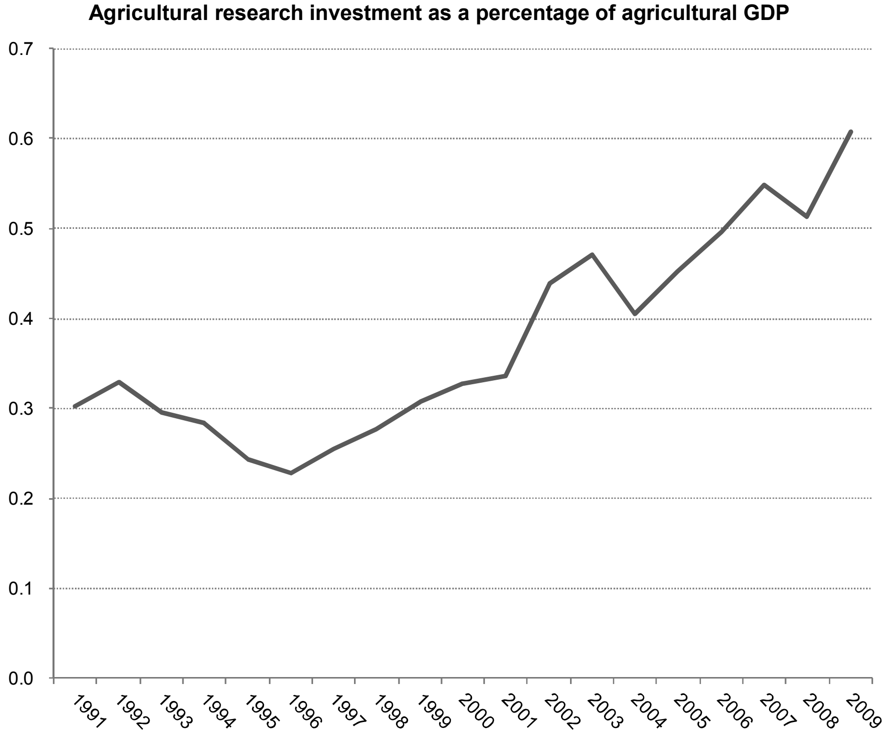
Figure 4.9 Government fiscal investment in agricultural research (billion CNY in 2005 prices)



Source: Hu *et al.* (2007), updated after 2006 using the same method.

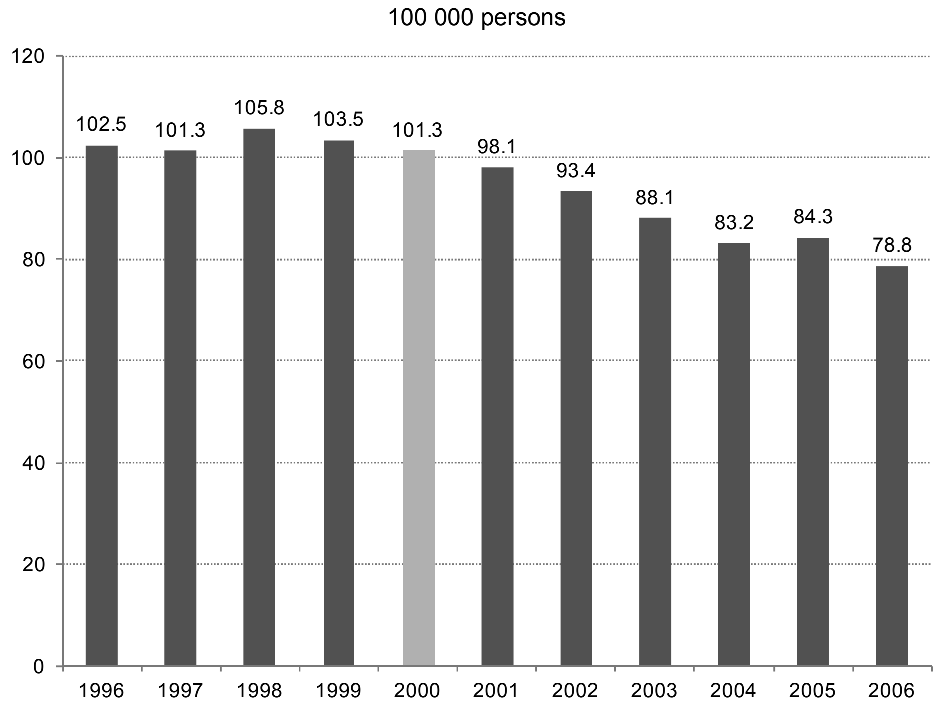
Figure 4.10. Agricultural research investment intensity in China

Agricultural research investment as a percentage of agricultural GDP



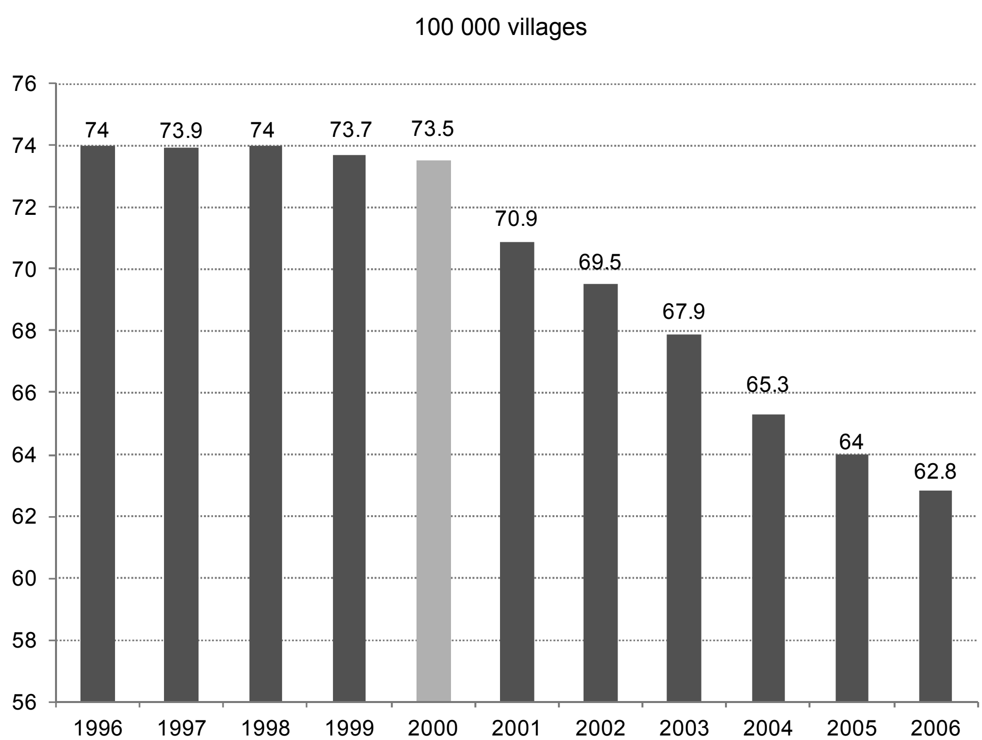
Source: Hu *et al.* (2007), updated after 2006 using the same method.

Figure 4.11. Staff under government agricultural extension system in China



Source: Chinese Ministry of Agriculture.

Figure 4.12. Agricultural administrative villages



Source: ZGTJNJ (2007).

Challenges and reforms

This system has been confronted with a number of challenges in recent years. For one, it lacked private sector involvement. Without greater private sector engagement, research programmes may not address the most relevant and immediate problems faced by farmers. This can also weaken links between the generation and dissemination of technologies, and between supply and farmers' real demand for useful technologies.

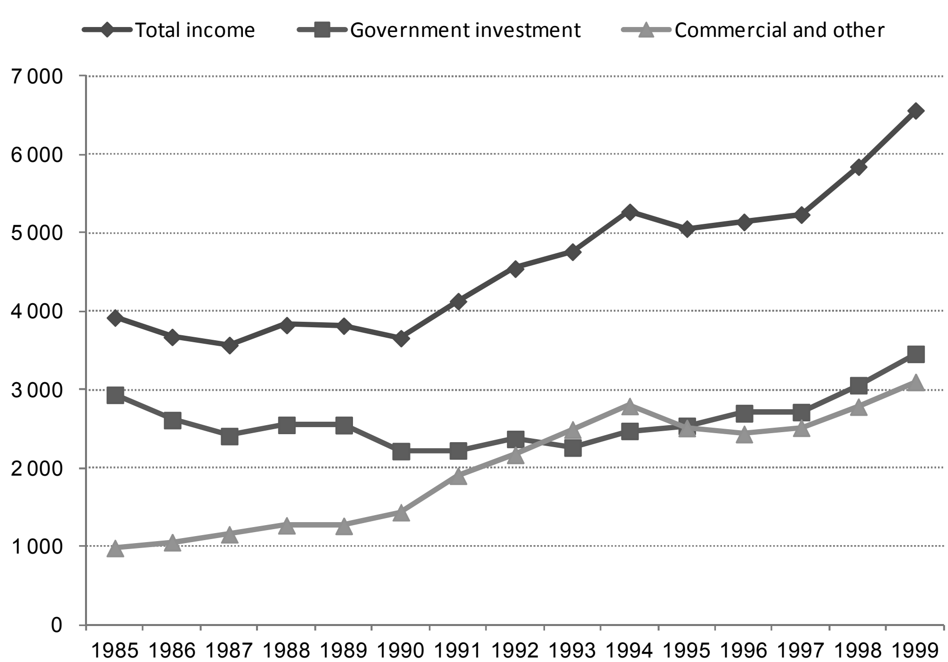
Decentralisation has been another challenge due to weak co-ordination among central and local institutions. Duplication of research efforts can often waste scarce research resources. The system was also overstaffed and short on quality scientists, due in large part to low salaries and low incentives. In short, the system lacked human capacity.

In response to these challenges, the Chinese government conducted two rounds of reforms. The first took place between 1985 and 1998 and focused on the gradual commercialisation of research and on the transition to a new research grant system that was based not on formula-based allocation, but on competitive grants. After the first round of reforms, total investment in agricultural research increased sharply. Government investment, however, barely increased at all (Figure 4.13).

This spurred the government to implement a second round of radical reforms, with the goal of developing a market-oriented, effective, creative and modernised agricultural research system. In terms of strategies, this initiative focused on recruiting better scientists and radically commercialising research. The reforms also called for more investment and improved efficiency through competitive grants. On the managerial level, we launched an incentive-based system reform and a more market-oriented reform.

Figure 4.13. Changing sources of agricultural research investment

Million CNY in 1998 prices



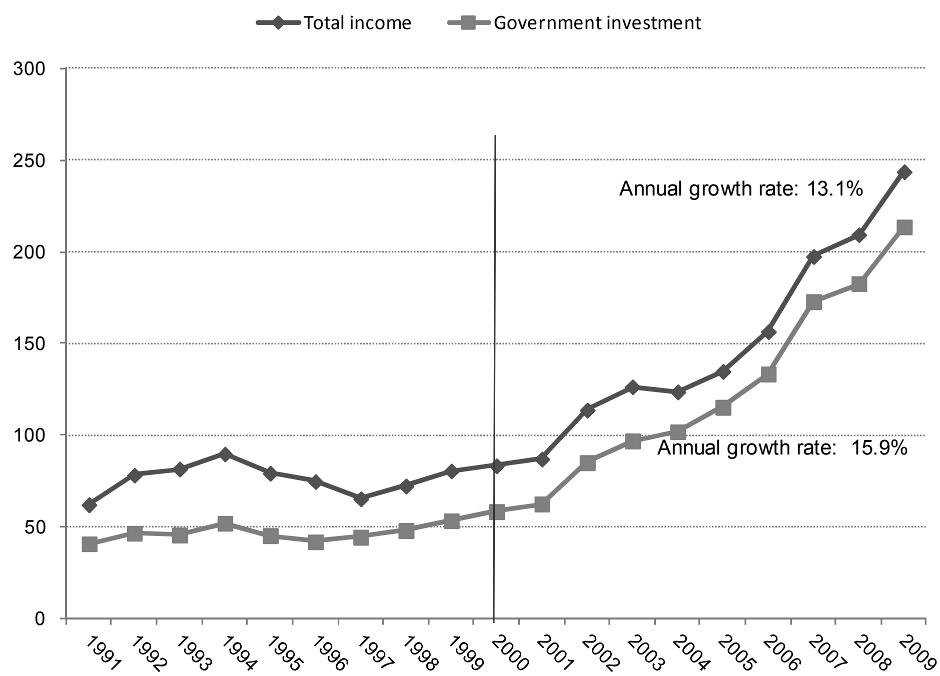
Source: Huang *et al.* (2000).

After the second round of reforms, government R&D investment increased by 15% annually from 2000 to 2005 (Figure 4.14). R&D expenditures are certainly rising, but most of this increase can be attributed to competitive grants. This is a new challenge that China will face.

Private sector R&D investment has grown faster than public investment (Figure 4.15). The question, however, is whether government investment noticeably contributes to the increase in private sector investment. We found that if the public sector invests in R&D for the foundation and application of research, then private sector investment will increase (Hu *et al.*, 2011). If, however, this government spending goes toward development research, private sector investment will decrease. In short, public-dominated R&D investment restricts private investment.

Figure 4.14. Agricultural research expenditure

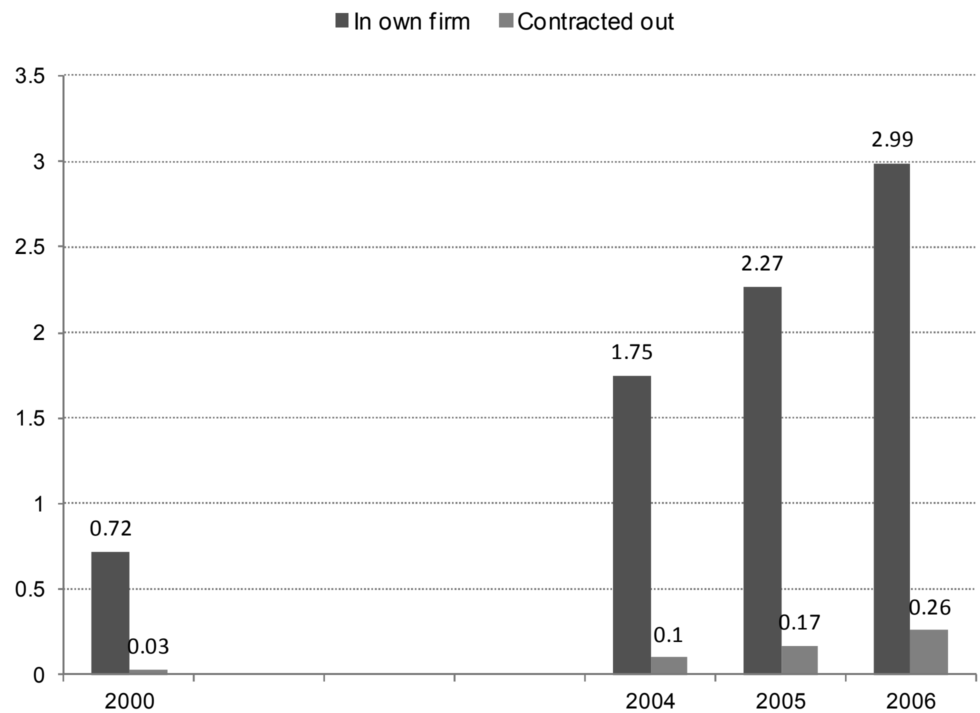
Million CNY in 2009 prices



Source: Hu et al. (2007), updated since 2006 using the same method.

Figure 4.15. Private agricultural R&D investment in China

Billion CNY in 2006 prices



Source: Hu *et al.* (2009).

Conclusion

Agricultural research has been an engine of growth in China. With demand for food on the rise, China's leaders believe agricultural technology could provide a solution to the nation's food security concerns. To this extent, they have developed a national agricultural R&D system that has since been reformed, in order to ensure that technologies generated can be more responsive to farmers' demands.

China has also invested heavily in R&D in recent years. China's agricultural research and extensions, however, are facing great challenges. As we have seen, a public-dominated system has its pros and cons. Our leaders are well aware of its cons, and have recently tried to mitigate them by encouraging the private sector to join the public sector in agricultural R&D systems. If this happens, we expect to usher in a new era of agricultural R&D across China.

Note

1. Professor at the School of Management and Economics, Beijing Institute of Technology, China.

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5. Agricultural R&D in Africa: Investment, human capacity and policy constraints

Gert-Jan Stads and Nienke Beintema[1]

In the face of volatile and rising food prices, rapid population growth, and climate change, governments are increasingly recognising the value of greater investment in agricultural research and development (R&D) as an essential element to increase agricultural productivity in Sub-Saharan Africa. Based on data collected from 370 R&D agencies in 32 countries, the Agricultural Science and Technology Indicators (AST) initiative found that after a decade of stagnation during the 1990s, investments and human resource capacity in public agricultural R&D in Sub-Saharan Africa grew by more than 20% during 2001–08. Most of this growth, however, occurred in only a handful of countries and was largely the result of increased government commitments to boost low salary levels and to rehabilitate infrastructure, rather than actual research programmes. Many other countries — particularly those in francophone West Africa — reported stagnating or falling investment and capacity levels and these countries continue to face fundamental challenges, including rapidly aging pools of scientists, a high dependency on donor and development bank funding, and very large fluctuations in funding from one year to the next.

Notwithstanding the challenges facing many countries, renewed commitment to agriculture by governments and donors indicates improved prospects for agricultural R&D for a number of African countries. But this political support must be translated into a set of specific directives by governments, donors, and other stakeholders if the many challenges facing agricultural R&D systems are to be addressed. Among the areas to be addressed are: 1) counteracting decades of underinvestment in agricultural R&D; 2) halting excessive volatility in yearly investment levels; 3) addressing existing and imminent challenges in human resource capacity; and 4) maximising regional and sub-regional co-operation in agricultural R&D.

Rationale and modalities for monitoring agricultural R&D resource allocations

Extensive empirical evidence demonstrates that agricultural research and development (R&D) investments have greatly contributed to economic growth, agricultural development, and poverty reduction in developing countries over the past five decades (World Bank, 2007; IAASTD, 2008). Given important challenges, such as rapid population growth, adaptation to climate change, and the volatility of prices in global markets, policymakers are increasingly recognizing the value of greater investment in agricultural R&D as an essential element in increasing agricultural productivity. In order to measure, monitor, and benchmark the inputs, outputs, and performance of agricultural science and technology (S&T) systems at the national and regional levels and to assess progress over time, quantitative data are essential. S&T indicators are an indispensable tool when assessing the contribution of agricultural S&T to agricultural growth and, more generally, to economic growth. They assist research managers and policymakers in formulating policy and making decisions about strategic planning, priority setting, monitoring, and evaluation.

The Agricultural Science and Technology Indicators (ASTI) initiative is one of the few sources of information on agricultural S&T statistics for low- and middle-income countries. Facilitated by the International Food Policy Research Institute (IFPRI), ASTI has been compiling, analysing, and publicizing primary data on institutional developments, investments, and capacity trends in agricultural R&D in low- and middle-income countries since 2001, building on prior projects undertaken by IFPRI and the former International Service for National Agricultural Research (ISNAR). ASTI has published a large number of country briefs and country notes, regional synthesis reports, and datasets that have been widely and frequently cited in national and international agricultural research policy documents. ASTI outputs provide both data trends — the progress of human and financial capacity agricultural research over time — and data comparisons — the performance of a country or a region relative to another. Data collection, analysis, and dissemination are conducted through a network of national, regional, and international agricultural R&D agencies.

ASTI datasets are collected and processed using internationally accepted definitions and statistical procedures for compiling R&D statistics developed by the Organisation for Economic Co-operation and Development (OECD) and United Nations Educational, Scientific and Cultural Organisation (UNESCO). This is important to ensure the comparability of ASTI's datasets with others.[2]

Global trends in agricultural R&D spending and capacity

Over the past decade, ASTI has carried out surveys in more than 60 developing countries in Sub-Saharan Africa, Latin America and the Caribbean, the Middle East and North Africa, and Asia-Pacific regions in close collaboration with national partners. Regional totals have been scaled up to account for missing countries. In efforts to achieve global coverage, ASTI links its R&D indicator datasets to those of the OECD; Eurostat; and country-specific datasets, such as ERS-USDA (2010) for the United States, Chen and Zhang (2010) for China, and Mullen (2007), for Australia. Given the irregular nature of data collection and the time lags involved in accumulating, compiling, analysing, and refining it (meaning filling gaps, addressing anomalies, and interpolating omissions), ASTI's most recent datasets for Sub-Saharan Africa are dated 2008, for Asia 2002/03,[3] and for Latin America 2006; country coverage for West Asia/North Africa, on the other hand, is highly limited. Given these realities, the most recent year for which we have a complete global overview of public agricultural R&D investments is 2000.

In 2000, total global public agricultural R&D spending was estimated at USD 24.9 billion in 2005 purchasing power parity (PPP) USD (see Box 5.1 for an explanation of PPPs). Of this amount, USD 13.5 billion was spent in the 40 high-income countries (54%) and USD 11.4 billion was spent in the 131 low- and middle-income countries (46%) (Table 5.1).

Table 5.1. Public agricultural R&D spending by region, 2000

Country category	Spending (million 2005 PPP USD)	Shares (%)
Low- and middle income countries		
Sub-Saharan Africa (45)	1 315	5
East Asia and Pacific (20)	3 099	12
East Asia and Pacific, minus China (19)	1 192	5
South Asia (6)	1 678	7
South Asia, minus India (5)	377	2
Latin America and the Caribbean (25)	2 755	11
Middle East and North Africa (12)	1 412	6
Eastern Europe and former Soviet Union (23)	1 177	5
Subtotal (131)	**11 435**	**46**
High income (40)	13 456	54
Total (171)	**24 891**	**100**

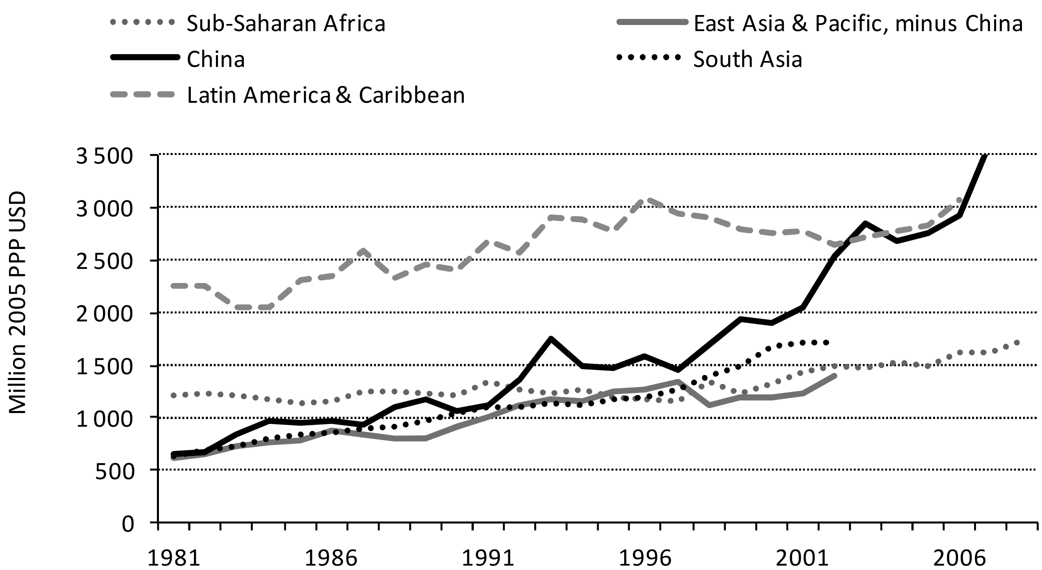
Note: The 2000 total previously reported by Pardey *et al.* (2006) underwent a revision in response to a major World Bank adjustment of PPP values, an update in ASTI's country classifications, and the incorporation of newly released estimates for Latin America and the Caribbean and a few other countries (see Beintema and Stads, 2008a).

Source: Beintema and Stads (2010); China from Chen and Zhang (2010); Sub-Saharan Africa from Beintema and Stads (2011).

Data on private sector investments in agricultural R&D are limited. In 2000 (the only year for which global estimates are available), the private sector spent an estimated USD 16 billion 2005 PPP USD; 41% of the global total (public and private). Almost all of these private sector investments were made by private companies performing agricultural R&D in high income countries. The role of private sector investment in the developing world remains small (Beintema and Stads, 2008b).

Although post-2000 data on global public investment trends are unavailable, more recent data collected by ASTI were published for Asia-Pacific (to 2002/03; China to 2007), Latin America (to 2006), and Sub-Saharan Africa (to 2008) (Figure 5.1). Agricultural R&D investments in China, India, and Africa have steadily increased since 2000. Latin America is characterised by a high degree of cross-country variation. Agricultural research spending in countries like Argentina, Costa Rica, and Uruguay rose markedly during 2000–06, whereas expenditures in countries like Chile, El Salvador, Guatemala, Honduras, and Paraguay contracted (Stads and Beintema, 2009). Brazil, the region's largest country, also experienced substantial boost in its public agricultural R&D spending in 2008–09 due to the Brazilian federal government's renewed commitment to agricultural R&D (Beintema, Avila and Fachini, 2010).

Figure 5.1. Public agricultural R&D spending by region, 1981–2008



Source: Table 5.1.

Box 5.1. Measuring agricultural R&D resources

Purchasing power parities (PPPs) as the preferred measure of R&D investments

Comparing R&D data is a highly complex process due to important differences in price levels across countries. The largest components of a country's agricultural R&D expenditures are staff salaries and local operating costs, rather than capital investments that are traded internationally. For example, the wages of a field labourer or lab assistant at a research facility are much lower in Kenya than in any European country; locally made office furniture in Senegal is considerably cheaper than a similar set of furniture bought in the United States.

Standard market exchange rates are the logical choice for conversions when measuring financial flows across countries. However, they are far from perfect currency converters for comparing economic data. At present, the preferred conversion method for calculating the relative size of economies or other economic data, such as agricultural R&D spending, is the purchasing power parity index. PPPs measure the relative purchasing power of currencies across countries by eliminating national differences in pricing levels for a wide range of goods and services. They are also used to convert current GDP prices in individual countries to a common currency. In addition, PPPs are relatively stable over time, whereas exchange rates fluctuate considerably (for example, the fluctuations in the USD-EUR rates of recent years).

The concept of full-time equivalent (FTE) researchers

ASTI bases its calculations of human resource and financial data on full-time equivalent staffing, or FTEs, which take into account the proportion of time researchers spend on R&D activities. University staff members, for example, spend the bulk of their time on non research-related activities, such as teaching, administration, and student supervision, which need to be excluded from research-related resource calculations. As a result, four faculty members estimated to spend 25% of their time on research would individually represent 0.25 FTEs and collectively be counted as 1 FTE.

Source: Beintema and Stads (2008a, 2011) and ASTI's website (*www.asti.cgiar.org/methodology*).

In addition to the investment trends, ASTI also collects information on the number of full-time equivalent (FTE) researchers employed in agricultural research in developing countries (see Box 5.1 for an explanation of FTEs). Capacity trends in many countries have been less erratic than investment trends. Overall most low- and middle-income countries in Sub-Saharan Africa, Latin America, and Asia–Pacific have made considerable progress in building their research staff capacity, both in terms of total researcher numbers and qualification levels. The participation of female scientists has also increased in a large number of countries.

The government sector is still the main performer of public agricultural R&D, both in terms of execution and funding. The government sector accounted for 61, 62, and 73% of total FTE researchers in Latin America (based on 2006 data), Asia (excluding China, based on 2002/03 data), and Sub-Saharan Africa (based on 2008 data), respectively. Despite the prominent role of the government sector, the higher education sector has gained ground in a number of countries, although the individual capacity at many higher education agencies remains very small. The non-profit sector (mostly NGOs or producer organisations) plays a limited role in agricultural R&D in Asia and Sub-Saharan Africa, but is relatively important in certain Latin American countries. Colombia, for example, has large coffee, palm oil, sugarcane, and rice producer organisations involved in agricultural research (Stads and Romano, 2008).

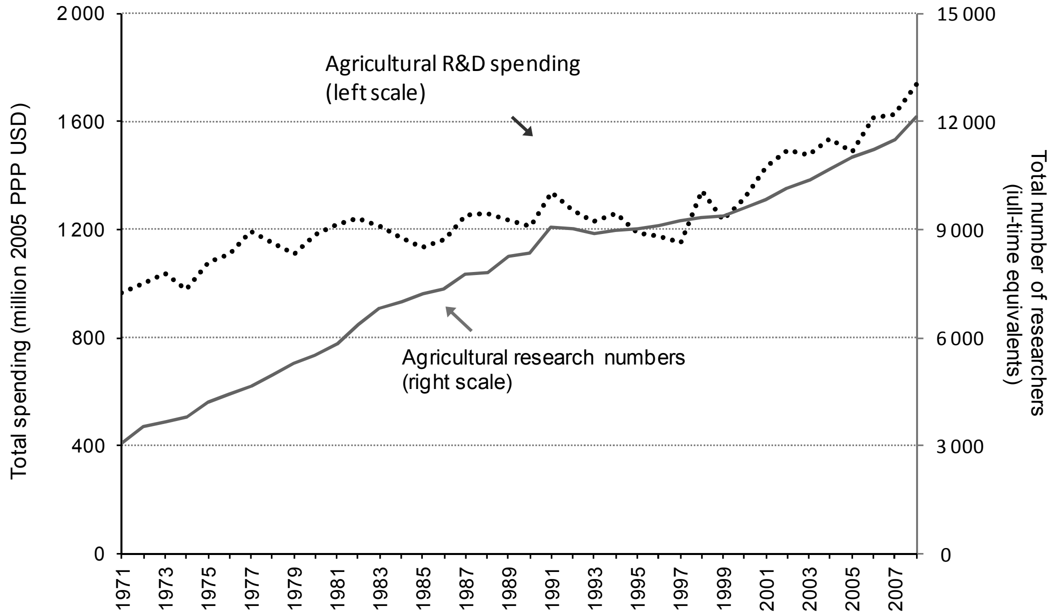
Investment and capacity trends in public agricultural R&D in Sub-Saharan Africa

In the 1990s, greater instability was evident in agricultural R&D in Sub-Saharan Africa compared with other world regions, mainly due to political unrest, social and economic hardship, and institutional vulnerability. Spending levels fluctuated in many countries, and overall growth slowed over time. This trend appears to have reversed, at least in the aggregate for the 2001–08 period. In 2008, public agricultural R&D investments for Sub-Saharan Africa as a whole — based on data for the 32 ASTI countries and estimates for 14 other, often small countries — totalled USD 1.7 billion in inflation-adjusted PPP USD — or USD 0.8 billion in 2005 constant USD (Figure 5.2). This was almost 20% higher than the levels recorded in 2001 and marks a considerable shift away from the slow 1.0% annual growth in agricultural R&D investments recorded in the 1990s (Beintema and Stads, 2011).

Growth in agricultural R&D human capacity was strong in the 1970s and 1980s, at 5.4% and 3.8% per year, respectively, but during the 1990s it slowed to a mere 1.3% per year. Since the turn of the millennium, growth in researcher numbers has once again accelerated. In some countries, renewed growth was due to the cessation of long-term recruitment bans, whereas in other countries it stemmed from increased involvement in agricultural research by the higher education sector. In 2008, Sub-Saharan Africa employed 12 120 FTE researchers, compared with 9 824 FTEs in 2001.

Figure 5.2. Trends in total public agricultural R&D spending and staffing in Sub-Saharan Africa

1971-2008

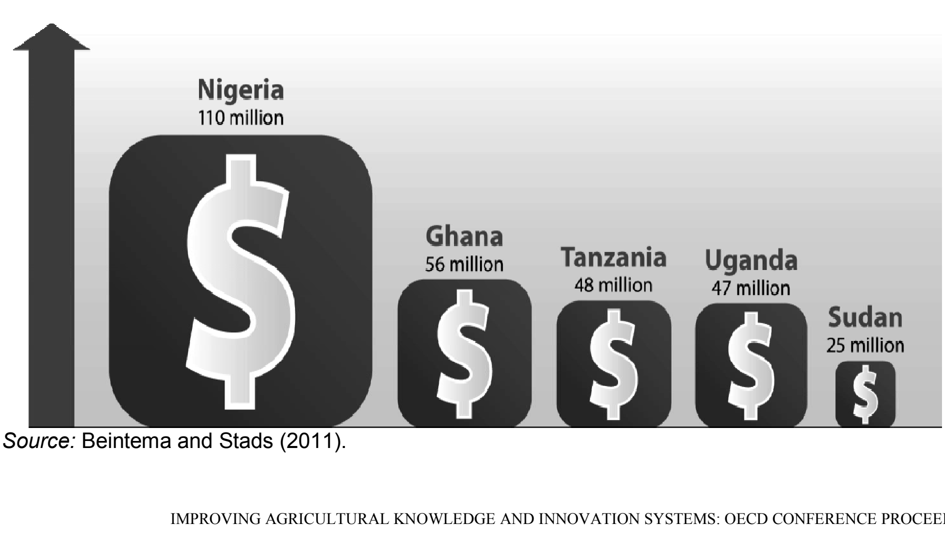


Note: Data on research spending and capacity for the 14 non-ASTI countries (accounting for 10% of total agricultural output in SSA) were estimated based on their share of agricultural output.

Source: Beintema and Stads (2011).

Country-level data reveal that the region-wide spending and capacity increases of roughly 20% during 2001–08 were largely driven by only a handful of countries. More than one-third of the growth in public agricultural R&D spending during this period is attributable to a USD 110 million increase in spending in Nigeria. Ghana, Sudan, Tanzania, and Uganda also experienced relatively high increases in total spending of between USD 25 million and USD 56 million each (in 2005 PPP USD) (Figure 5.3). Growth in these countries stemmed from increased national government contributions to agriculture in general and to agricultural R&D in particular. In contrast, Ethiopia and South Africa experienced notable declines.

Figure 5.3. Main drivers of growth in agricultural R&D spending in Sub-Saharan Africa, 2001–08

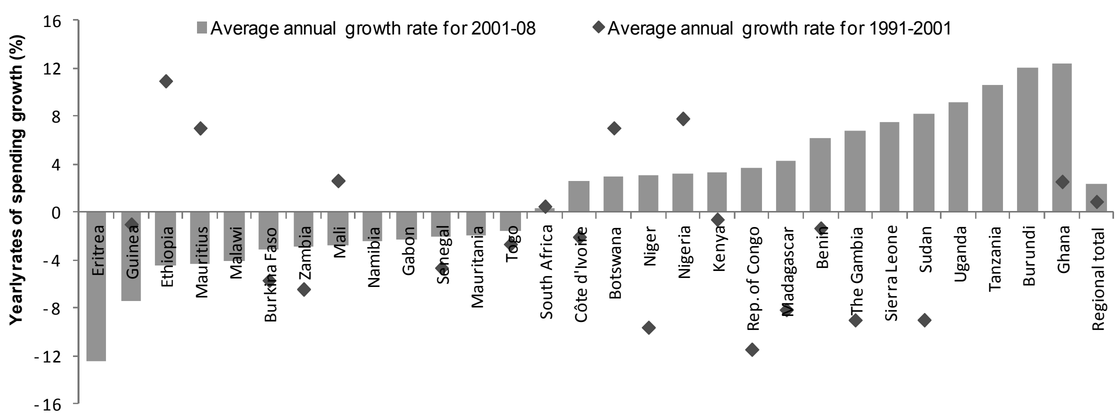


Source: Beintema and Stads (2011).

Though increases and decreases in the absolute levels of agricultural R&D spending and capacity of the region's larger countries overshadow those of many of the smaller countries, a closer look at relative shifts in investment and capacity levels over time reveals some interesting cross-country differences and challenges. During 2001–08, 13 of 29 countries experienced negative annual growth in public agricultural R&D expenditures, ranging from – 1.6 to –12.4% per year (Figure 5.4), which is sizeable given that spending in Sub-Saharan Africa as a whole actually increased throughout this period. Of these 13 countries, seven are francophone countries located in West and Central Africa. Falling investment levels in agricultural R&D in these countries resulted mainly from the completion of large donor-funded projects, often financed through World Bank loans. Comparing the 2001–08 growth rates with those of the 1990s clearly illustrates the volatility of agricultural spending levels for many of the region's countries. Eritrea and Ethiopia, for example, experienced negative growth during 2001–08 following a decade of particularly high positive growth, which is indicative of high dependency on donor funding.

Figure 5.4. Compound annual agricultural R&D spending growth rates in Sub-Saharan Africa,

2001–08 compared with 1991–2001

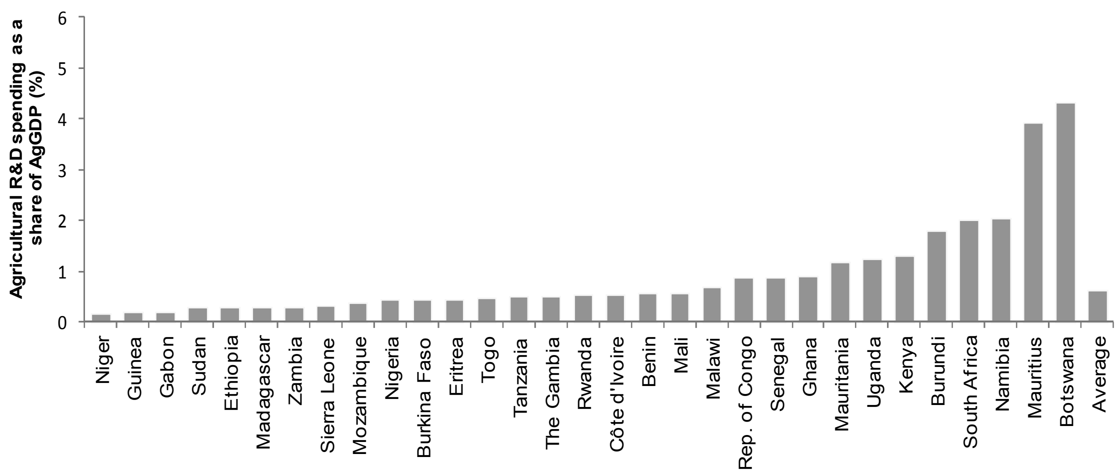


Note: The figure excludes Mozambique, Rwanda, Sierra Leone, and Zimbabwe because time-series data did not date back to 2001. Compound growth rates are calculated using the least-squares regression method.

Source: Beintema and Stads (2011).

Analysing absolute levels of research expenditures explains only so much. Another way of comparing the commitment to public agricultural research investments across countries is to measure total public agricultural R&D spending as percentage of agricultural output (AgGDP). This relative measure indicates the intensity of investment in agricultural research, not just the absolute level of spending. In 2008, Sub-Saharan Africa invested USD 0.61 for every USD 100 of agricultural output on average (Figure 5.5), which was below the African Union's New Partnership for Africa's Development (NEPAD) target of at least 1% of GDP. Only 8 of the 31 sample countries for which data were available met this 1% target: Botswana, Mauritius, Namibia, South Africa, Burundi, Kenya, Uganda, and Mauritania. Some of Sub-Saharan Africa's smallest countries have such low and declining levels of investment and human resource capacity that the effectiveness of their national agricultural R&D could be questioned. This also highlights the need for regional initiatives to address the unique needs of small countries and to take advantage of collaborative synergies.

Figure 5.5. Intensity ratio (spending/AgGDP) in Sub-Saharan Africa, 2008

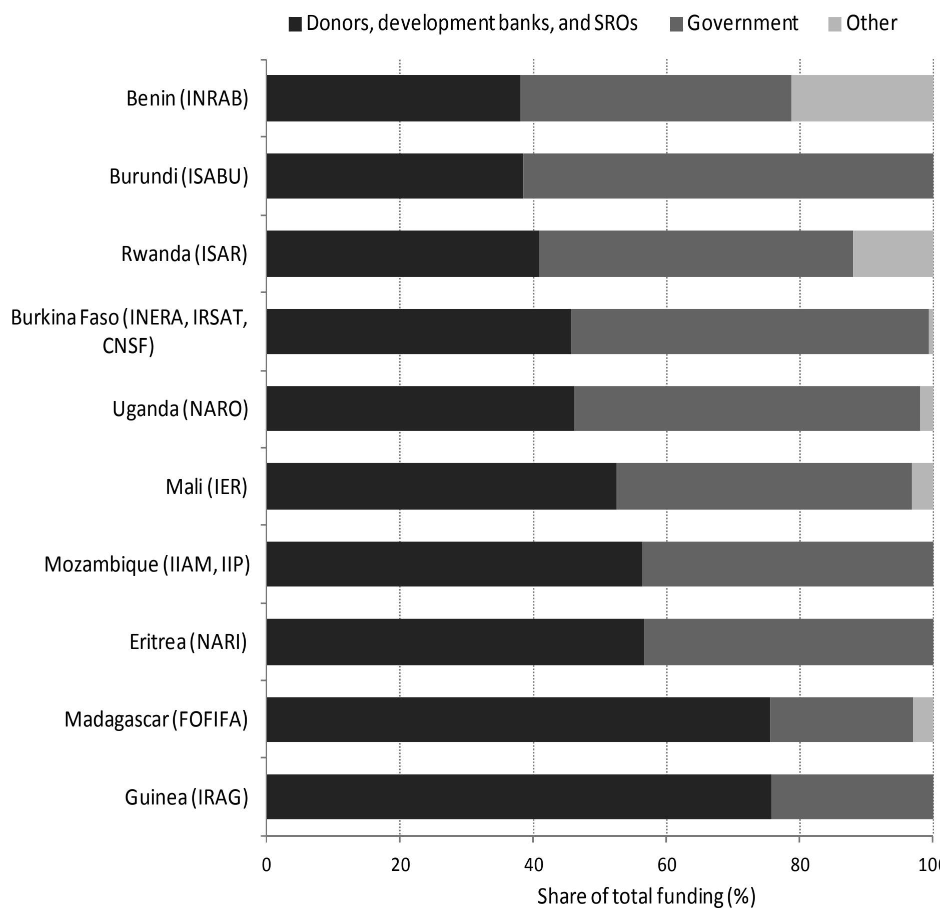


Source: Beintema and Stads (2011).

Funding for African agricultural R&D is derived from a variety of sources, including national governments; donors, development banks, and (sub-)regional organisations; producer organisations; the private sector; and internally generated resources. Growth in spending in Ghana, Nigeria, Sudan, Tanzania, and Uganda — the main drivers of regional growth in agricultural R&D spending — was largely the result of significant injections of government funding. In contrast, many other countries continue to be extremely dependent on unstable inflows of donor funding and development banks loans (Figure 5.6), and in many instances the completion of large donor-funded projects has precipitated severe financial crises, seriously undermining any progress made. Donor funding is typically short-term and ad hoc, calling into question the long-term effectiveness and efficiency of this type of funding. In addition, research by nature involves inherent time lags between investment in R&D and the attainment of returns to those investments in the form of tangible benefits. The completion of large World Bank-financed projects in Niger and Burkina Faso, for example, has had a large impact on overall agricultural R&D investment levels in these countries. The situation in Niger remains particularly precarious, as annual government contributions to INRAN,[4] the country's principal agricultural R&D agency, no longer cover the institute's payroll expenses (Figure 5.7). Volatility in countries like Gabon and Nigeria can largely be explained by fluctuations in government allocations from one year to the next. In Gabon, for instance, the government budgets assigned to research institutes are frequently adjusted downwards during the budgetary year in response to fluctuations in the country's oil revenues.

In 2008, 30% of agricultural researchers in Sub-Saharan Africa were qualified to the PhD level, 43% to the MSc level, and 27% to the BSc level (Figure 5.8). Researcher qualifications varied considerably across countries and by gender. More than half of FTE researchers in Burkina Faso, Côte d'Ivoire, and Senegal and more than 40% of those employed in Benin, the Republic of Congo, and South Africa were trained to the PhD level. It is striking that many West and Central African countries have maintained relatively large pools of well-qualified researchers despite recent losses in human and financial resource capacity. These high shares stem in large part from training programmes conducted during the 1990s (and earlier), funded through bilateral donors or World Bank-financed projects.

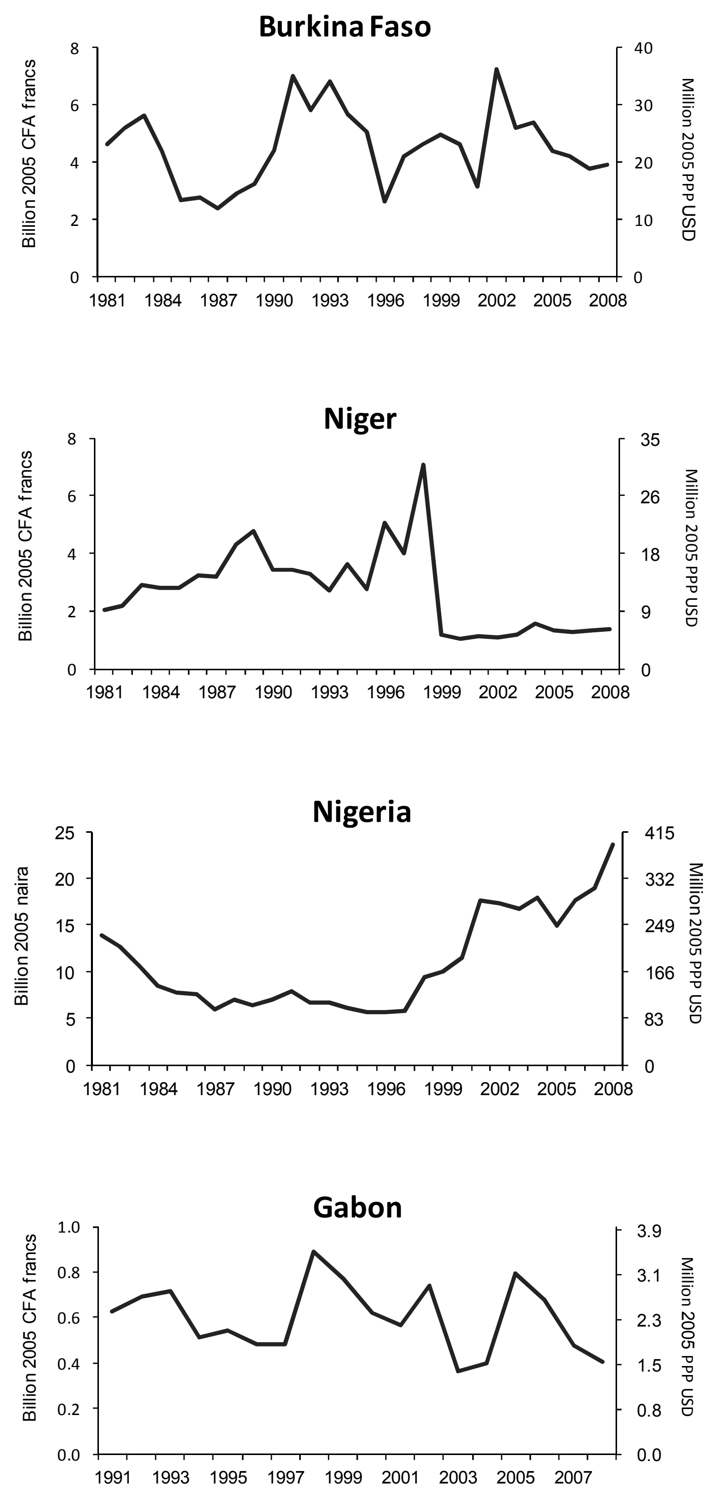
Figure 5.6. Relative shares of funding sources for the main agricultural R&D agencies in selected donor-dependent African countries, 2008



Note: SROs indicates sub-regional organisations. Other includes various funding sources such as contributions through export or production levies, sales of goods and services and contractual research performed for public and private agencies. For full institute names of acronyms, please see the various country notes available at *www.asti.cgiar/publications/ssa* .

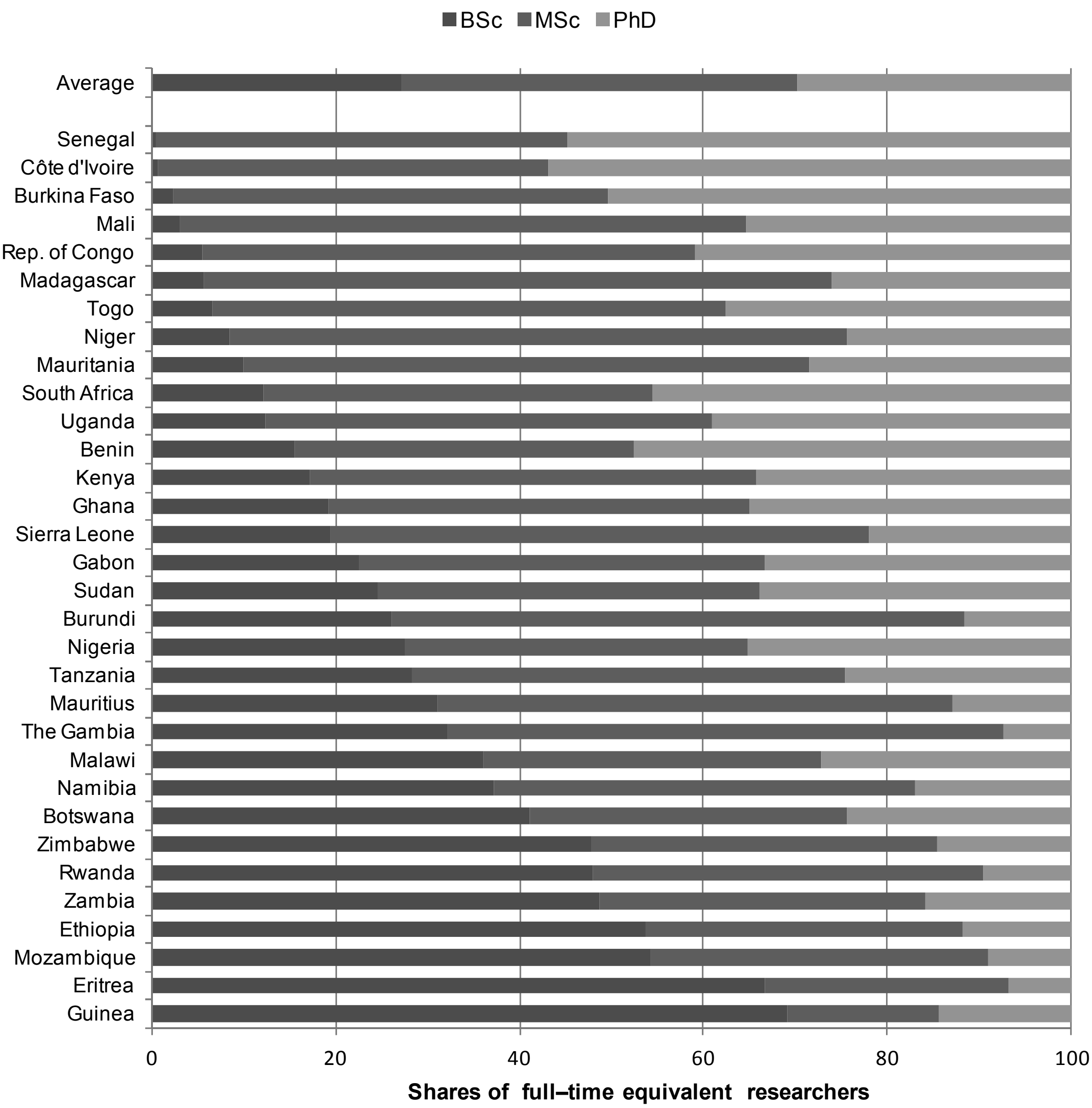
Source: Beintema and Stads (2011).

Figure 5.7. Volatility in annual funding levels, selected African countries, 1981–2008



Source: Compiled by the authors from country-level ASTI survey data.

Figure 5.8. Distribution of agricultural researchers in Sub-Saharan Africa, by country and degree qualification, 2008



Note: Figure excludes support staff (technicians, research assistants, laboratory assistants) who have BSc, MSc, and occasionally PhD qualifications, but who are not classified as researchers.

Source: Beintema and Stads (2011).

A major concern in many countries, particularly in West and Central Africa, is a rapidly aging pool of scientists, many of whom will approach retirement within the next decade. In Cameroon and the Republic of Congo, for instance, agricultural researchers at the main agencies are well over 50 years old on average. Attracting and retaining R&D staff is a serious problem in many countries. The total number of PhD-qualified scientists at the *Institut sénégalais de recherches agricoles* (ISRA), the main agricultural R&D institute in Senegal, fell from 70 in 2003 to 54 in 2008. Some of these scientists left ISRA to take advantage of opportunities in the higher education and private sectors, where salaries are reported to be up to three times higher than in the public sector; many of the more senior researchers also retired. The overall limited research capacity in small countries, alongside low numbers of well-qualified staff, poses significant constraints on their ability to conduct high-quality research and extract external funding. The National Agricultural Research Institute in The Gambia is a case in point. During 2003–09, the number of PhD-qualified researchers decreased from 7 to 2 as a result of retirement, departure, or death. Many of the institute's remaining staff members lack advanced training or experience.

Another concern in some countries is the deterioration of average degree levels. In 2008, half of Zambia's public agricultural researchers were trained to the MSc and PhD levels—a significant shift from 2001, when 70% of researchers held postgraduate degrees. Similarly, the overall share of postgraduate (MSc and PhD) researchers in Nigeria fell from 79 to 72% during 2001–08, and in Botswana the share fell from 66 to 59%. The increasing share of BSc holders in agricultural R&D in these countries results from recruitment freezes followed by rapid hiring spurts, a lack of training opportunities, and fewer senior staff to tutor youngsters.

Private-sector investments in African agricultural R&D: The case of Senegal

There is substantial empirical evidence suggesting that private innovation — introducing new technologies from in-country R&D or transferring technologies from foreign public or private sources — has contributed to growth, development, and poverty reduction in many developing countries. Technologies developed by private companies in industrialised countries, including new plant varieties, fertilizers, pesticides, machinery, vaccines, poultry breeds, and livestock breeds, have contributed significantly to agricultural productivity gains in parts of Asia, Africa, and Latin America. The most dramatic recent example of benefits from private research is the spread of Bt cotton and Bt maize which has benefited millions of small farmers in Asia and Africa with higher incomes and less exposure to dangerous pesticides. More recently, technologies developed by private companies in developing countries such as India, China, Brazil, and South Africa have also begun to make similar contributions in other regions of the developing world.

Unfortunately, few studies have actually analysed the determinants of private agricultural innovation (from in-country R&D and/or technology borrowing) with sufficient data or sufficiently rigorous models to give policymakers guidance on the contribution that private innovation can make to agriculture objectives, and which policies are most effective in influencing private innovation. Even fewer studies have looked at how policies and donors could induce the private sector to focus more of its efforts on the problems of the poor. Many donors, government scientists, and policymakers acknowledge that the private sector can be a possible contributor to poverty reduction; what is lacking is the knowledge of the specific strategic policy actions that could be inducing private investment in agricultural R&D both in and for developing countries.

ASTI, Rutgers University, and a number of in-country consultants partnered to address this gap in information by collecting, analysing, and disseminating accurate data and information on private agricultural R&D and innovation in a number of Sub-Saharan African and South Asian countries.[5] Though it had various limitations, it gives a comprehensive overview of the private sector's role in generating and/or introducing new and improved agricultural technologies, as well as the policy options to consider facilitating and enhancing private technology generation.

As in most developing countries worldwide, the private sector in Senegal is relatively underrepresented in the conduct of agricultural R&D. In 2008, private companies represented just 14% of the country's total agricultural R&D spending, with the public sector (mainly ISRA, ITA,[6] and the universities) carrying out the vast majority. Since the turn of the millennium, the private sector's role has only marginally increased. The reasons for this limited private involvement in agricultural R&D in Senegal are manifold. Many private companies operate with limited competition, discouraging future R&D investment. Furthermore, most companies lack long-term vision when it comes to the benefits of research, and many believe that new technologies will eventually spillover from the public sector or from abroad, eliminating their need to invest their resources. A more enabling environment for private R&D needs to be created to change this perspective. A large number of companies mentioned that government policies and regulations (and their poor implementation) hamper large-scale private R&D and innovation. Among those cited were the lengthy administrative procedures required to import agricultural inputs; the stringent regulations involved in registering and releasing new products; the lack of enforcement of laws to eliminate unfair foreign competition that disadvantages Senegalese companies; the widespread piracy of private innovations, and the lack of tax incentives to reward companies who invest in innovation.

Nonetheless, the Senegalese government has taken various measures in recent years to stimulate private participation in agricultural R&D and innovation. Regional seed, fertiliser, pesticide, and livestock regulations have been harmonised to reduce trade barriers in the sub-region. Additional national initiatives, such as the establishment of a competitive fund to stimulate private-sector involvement in R&D and the launch of the ambitious government plan to boost food production, have provided tremendous opportunities to the private sector and have enhanced public–private partnerships in agricultural R&D and innovation. Though the Senegalese government identified food self-sufficiency as one of its top priorities, it is widely criticised for lacking a clear sense of direction in the area of agricultural innovation. Four different government agencies are currently charged with setting the country's agricultural innovation agenda, and they often have overlapping and even conflicting mandates.

Despite the limited overall involvement of the private sector in agricultural R&D and innovation in Senegal, the private sector plays an important innovative role in key export areas. While the government sector dominates Senegal's agricultural R&D system when it comes to food crops (rice and maize), private-sector companies are major innovators in the cotton and horticultural subsectors, which provide Senegal with its principal export crops. In fact, these companies play a more crucial role than the public agencies in the release of new varieties and in providing timely, high-quality solutions to crop diseases (Table 5.2). In addition, innovations in food processing, storage, and packaging have enabled many Senegalese horticultural and fisheries products to meet strict European quality and hygiene standards, boosting Senegal's exports in these areas. In addition, an increasing number of private innovations are being patented, both locally and abroad.

Table 5.2. Cultivars registered by the public and private sector for selected crops

2005–09

	Number of cultivars registered	
Crop	**Public sector**	**Private sector**
Maize	8	2
Rice (irrigated and rain fed)	16	–
Sugarcane	–	1
Cotton	–	2
Sunflowers	–	3
Groundnuts	6	–
Green beans	–	1
Tomatoes	–	2
Sesame	6	–
Eggplant	–	1
Carrots	–	1
Okra	–	1
Lettuce	–	1
Onions	–	2
Total	**36**	**17**

Source: Stads and Sène (2011).

Policy directions to address current challenges in African agricultural R&D

Despite an overall increase in agricultural R&D investment and capacity levels since the turn of the millennium, African agricultural R&D is still dominated by underfunded public agencies staffed by undertrained researchers. This is clearly not the way forward if Africa is to enhance smallholder production, cut (rural) poverty and compete with top-quality agricultural products in a global market. Building on the strategic recommendations of various highly influential reports and meetings, and taking into account the various investment and capacity challenges outlined in the current paper, the following areas with strong implications for policy must be addressed by governments, donors, and other stakeholders:

- National governments must provide higher and more stable levels of funding to public agricultural R&D. Governments will need to identify long-term national R&D priorities and design relevant programmes while donor funding needs to be better aligned with these priorities. In addition, governments must create a more enabling environment to stimulate private investment in agricultural R&D.

- Existing and imminent challenges in human resource capacity need to be urgently addressed. Governments and donors must expand their investments in agricultural higher education to allow universities to increase the number and size of their MSc and PhD programmes. Moreover, many countries with serious capacity gaps will have to increase the civil servant retirement age or institute flexible working arrangements to ensure that retired researchers can contribute to much-needed training and mentorship initiatives.

- Agricultural R&D must be maximised at the (sub-)regional level. Creative efforts to build and enhance strong sub-regional linkages need to be further strengthened in order to maximise synergistic opportunities across countries. The maturation of regional and sub-regional organisations presents new opportunities for addressing funding stability as well as the problems faced by small countries that lack the required critical mass to produce high-quality research outputs.

Notes

1. Agricultural Science & Technology Indicators (ASTI) initiative at the Rome office of the International Food Policy Research Institute (IFPRI). This note is a compilation of data results and analysis from various ASTI publications

2. See the ASTI website (*www.asti.cgir.org*) for more information on ASTI's methodology and data collection procedures

3. ASTI is currently updating its datasets for South Asian and a some key Southeast Asian countries to the year 2009/10

4. *Institut National de la Recherche Agronomique du Niger* (National Institute for Agricultural Research of Niger).

5. The current study was the first of its kind to assess the role of the private sector in agricultural R&D and innovation in Sub-Saharan Africa and South Asia Major firm-level surveys were conducted in Bangladesh, India, Kenya, Pakistan, Senegal, South Africa, Tanzania, and Zambia during 2009-10. The overall objectives of the survey were: 1) to provide accurate data on private agricultural R&D and innovation which will allow for better analysis of the role of private sector research and innovation; 2) to identify key policies and government investments that can encourage private firms to introduce agricultural technologies from in-country R&D and/or through technology transfers that can help reduce poverty and hunger; and 3) to assess the impact of private research and innovation on poverty reduction, hunger, health, and environment. The findings of the study will be presented in a number of synthesis and country reports.

6. *Institut de technologie alimentaire* (Food Technology Institute).

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6. Responses to new agricultural challenges

Leticia Deschamps Solórzano[1]

The changing natural and economic global environment offers the agri-food sector challenges and opportunities. Innovation leading to increased productivity and sustainability will be required to help the sector meet expectations in a context of higher and more variable prices, stronger demand and resource constraints. Agricultural Knowledge and Innovation Systems are diverse and evolving from a linear approach to a more collaborative approach between countries and members of the Agricultural Knowledge and Information System (AKIS): public and private sector, higher education, research centres, producers, extension services and institutions specialised in technology transfer. In this context, networking is gaining in importance. The INNOVAGRO network has been created to foster international collaboration and communication cross border and continent to help the agri-food sector meet emerging challenges and size opportunities.

Introduction

The agri-food sector has become greatly dependent on technology advancements to achieve sustained growth in productivity. Nevertheless, both research and technology transfer systems in the agri-food sector present the challenge of migrating towards innovation oriented systems that demand cooperation among a plethora of different actors: producers, federal, state and municipal governments, as well as research and educational institutions and the private sector (industry, commerce, etc.). This co-operation is essential in order to identify and satisfy the demands posed by producers, as well as to respond to problems like poverty, competitiveness and dwindling natural resources.

In this section, the relationship between the aforementioned emerging challenges is examined, and several topics related to the question "How well do Agricultural Knowledge Systems respond to new challenges?" are addressed. This section is divided into three main parts.

First, the global changes and challenges will be addressed and highlighted. Secondly, different approaches to knowledge systems will be analysed, with an emphasis on Innovation Systems because both research and technology shift gradually towards pure innovation practices or innovation in itself. In other words, this section places a particular interest on the factors which determine the proper application of knowledge. Finally, an Innovation Management Network for the Agri-food Sector will be discussed as an example of the new trends in innovation management systems.

Changes and challenges

Changes

The world is facing an ever-increasing internationalisation and globalisation process. This process brings several opportunities for development, but also implies numerous different changes for the agri-food sector. In this context, the market is considered the primary incentive for change. This is because economic markets increasingly drive agricultural development and Agricultural Knowledge Systems (AKS) are finding it difficult to contribute to this development process due to the fast pace of the market and the difficulties involved in generating, diffusing and appropriating innovations.

Secondly, another important change is the global impact of climate change on food production and the need to mitigate and/or adapt to this change. Undoubtedly, climate change has been pressing countries to invest in technology and improved seeds that can withstand droughts and floods, as well as to develop new, more nutritious breeds and varieties that are resistant to disease and increase yields. All these events drive innovation, and Agriculture Knowledge Systems must be able to effectively study and analyse these phenomena.

However, the effects of climate change can reduce the availability of resources. This reduction in availability, together with increased climate variability have put agriculture at a crossroads and have driven it to find new, environmentally friendly forms of production in order to adapt to climate change as optimally as possible.

Thirdly, demographic explosions and changes in dietary habits result in significant increase in food demand. Furthermore, sustained economic growth in countries such as

China and India, as well as rising food prices led to an increase in concerns about global food security. This is coupled with a slowdown in the growth rate of agricultural productivity.

Additionally, just as population and economic growth drive innovation and change, knowledge, information and technology are increasingly generated, diffused and applied through the private sector. This generates a changing environment in which innovation in the agri-food sector must be analysed and managed.

Another change to be considered is the growth, development, availability and diffusion of information and communication technologies such as the internet and the advent of forums provided by social networks and online collaboration tools. These tools have transformed the way to access new knowledge and take advantage of knowledge development. An innovation management system must certainly be able to absorb and take advantage of these emerging tools.

Finally, there is a need to stress the changes in agri-food sector's learning structure. In this structure, technical change and knowledge have become interactive processes, involving different types of actors such as researchers, producers, and extension services.

Challenges

Some of the changes mentioned in the previous section in turn develop, either directly or indirectly, into new challenges. One of the most salient challenges is the increase in poverty. Even though this is a structural challenge, it concerns agricultural knowledge systems because of the increasing divide in the generation of innovation and the transfer of knowledge and technology between rich and poor countries.[2] As this gap widens, it becomes ever more difficult to attain implementation of new technological and organisational innovations in poor countries, which in turn contributes to further widening of the gap, both in terms of productivity and knowledge.

Similarly, climate change requires adaptation and/or mitigation strategies in order to deal with the monumental scope of its potential consequences. It is essential that the agri-food sector be able to respond, and react promptly and accordingly in order to deal with the dilemma of limited resources and increasing climate variability in order to guarantee a sufficient food supply for the world's population.

Likewise, food security requires that the agri-food sector (and with it all the innovation systems that work to foster its development) respond to the current rise in global food prices, as well as the limited food supply. In order to obtain better results from the agri-food sector a deeper commitment to long-term investments and to work cooperatively (as a network as well as other forms of cooperation) is required from innovation systems (Pardey and Alston, 2010).

In general, the agri-food sector has experienced a slowdown in productivity growth. There is also a trend towards "a slowdown in spending growth and a diversion of funds away from farm productivity enhancement" (Pardley and Alston, 2010; Stads, 2011) which leads to uncertainty and further changes. In addition, there is an obvious deceleration in investment for research, development and innovation, and there has been a decline in investments levels in some countries (Beintema, N. M. and G. Stads (2008); Pardley and Alston, 2010).

Additionally, there is a trend concerning lower investments in the form of decelerated research that impacts innovation in the agri-food sector. This contrasts with what was observed throughout the 20th century (Alston, 2011). The trend has significant consequences for food security through diminished productivity and overall competitiveness (Beintema and Stads, 2010).

As mentioned earlier, the knowledge gap between developed and developing countries has widened, which exacerbates several challenges that should be kept in mind. There has been a shift towards new investment priorities, in the form of diminishing investments for productivity enhancement and increased focus on problem solving for climate change, food security and quality issues. Similarly, investments on other uses for food crops, such as medicinal, industrial and energy production, as well as cash crops, have taken priority, complicating the existing challenges for the agri-food sector even more (Pardley and Alston, 2010). Understaffed innovation and research centres with limited growth in the quality and quantity of researchers in some areas pose further challenges to the sector (Alston, 2011).

These obstacles coalesce into a monumental global challenge that consists of managing limited resources, diminishing productivity, and increasing climate variability while guarantying food for the world's population in a sustainable manner.

Stronger international cooperation is needed in order to face these challenges. Co-operation in turn presents a challenge for countries to strengthen their international bonds, and these countries should participate in networks that foster co-operation, collaboration, learning and communication. These networks maximise resources and will focus on developing research, technology transfers and innovation management.

Different approaches to knowledge and innovation systems[3]

This section will focus on Innovation Systems; specifically, it will focus on those innovations based on creation and diffusion of knowledge and which recognize innovation as an interactive process. Historically, several different approaches have been defined as Knowledge and Innovation Systems; for the purposes of this section an innovation system will be defined as *the set of actors or players, interactions and policies that contribute to the creation, dissemination, development and adoption of technologies and innovations that can improve or strengthen productivity, competitiveness, sustainability and equity in the agri-food sector*[4].

Innovation in the agri-food sector has been usually approached from different theoretical points of view which strive to understand how this process takes place. Innovation can occur through the implementation of an idea, or from new technologies that have their source in either the innovative strength of the company or in research.

Innovation is the introduction of a new (or significantly enhanced) product, process, commercialisation method or organisational method within the internal practices of a business, work, place, organisation or external relationships (OECD, 2005). Innovation necessarily involves a certain degree of novelty. It is also important to mention that although research and development are a part of innovation, not all innovations include them; there is growing recognition that innovation encompasses a wide range of activities in addition to research and development (R&D), such as organisational changes, training, testing, marketing and design. It is essential to recognize the importance of innovation transfers and their non-linearity and multi-direction. Although the Oslo Manual mostly focuses on innovation related to practices, real world experience has shown that innovation should also be considered at the knowledge management level that leads to increased competitiveness in actors.

Innovation is not the product of a linear systems, it is rather a complex and collective phenomenon that manifests itself in an interactive process that links actors who act according to market driven incentives, as well as companies and other institutions. These may act according to strategies and rules that are not market driven, such as institutions, research centres and universities. This innovation process led to the development of the national innovations systems because the old linear model of technology transfer is outdated. The old linear model of technology transfer should be replaced with an interactive model of networking systems which integrate knowledge, production, adaptation, advice and education (World Bank, 2006).

Innovation implies mainly changes in practices that lead to a significant improvement in the competitiveness of actors, judged according to the objectives pursued when these innovations are implemented.

As previously mentioned, Innovation Systems can be defined as the set of actors, interactions and policies for the creation and dissemination of technologies and innovations that improve productivity, competitiveness, sustainability and equity in the agri-food sector (IICA, 2011; Dockes, Tisenkopfs, Bock, 2011).

Knowledge and Innovation Systems can be varied and diverse. They include: National Research Systems (NARS), Agriculture Knowledge Systems (AKS), Agriculture, Knowledge Innovation Systems (AKIS), Agriculture Innovation Systems (AIS) and National Agricultural Innovation Systems (NAIS). Each of these has a different orientation: they could focus on the generation and transfer of technology or on dissemination of knowledge and technology, or on institutional innovation and technological innovation. Table 6.1 summarises the main characteristics of each type of system, while Box 6.1 describes the Mexican agricultural innovation system.

Agricultural Innovation Systems are Innovation Systems at the national or regional levels. In general, the author comments the different approaches to knowledge and innovations systems, with special emphasis on National Agricultural Innovation Systems.

National Agricultural Research Systems (NARS)

A NARS is composed by a set of organisations, whose main purpose is agricultural research and development within a country. NARS are linear systems that have been in use for almost 40 years. The general idea consists of, firstly, undertaking agricultural research, followed by the adoption of technology through technology transfers, finally leading to increase productivity. The capacity for research comes from the country's underlying research infrastructure.

National Agricultural Research Systems place heavy emphasis on the development of the research system. As a consequence, they generally lack adoption and transfer of technology.

Agricultural Knowledge Systems (AKS)

"An agricultural knowledge system is a collection of actors such as researchers, advisors and educators, who work primarily in agricultural knowledge institutes. The emphasis is in these actors and the roll of formal knowledge production in national agricultural research systems. This knowledge is then transferred to the agricultural sector through agricultural extension services and education" (Rudman, 2010; Dockés, Tisenkopfs and Bock, 2011).

AKS and their concept originated in the 1960s (Leeuwis and Van den Ban, 2004). They were created as a result of new agricultural policies that have two main goals: firstly AKS intend to co-ordinate innovation through knowledge transfer. Secondly, working with the ministries of agriculture they attempt to implement a structure of public research, education and extension services at a national level. The main goal was to accelerate agricultural modernisation, especially in third world countries.

Agricultural Knowledge Innovation Systems (AKIS)

The main idea behind AKIS (originally Agricultural Knowledge and Information Systems) was introduced in the 1970s by the OECD and FAO. In this approach, "a set of agricultural organisations and persons and the links and the interactions between them engaged in the generation, transformation, transmission, storage, retrieval, integration, diffusion and utilisation of knowledge and information, with the purpose of working synergistically to support decision making, problem solving and innovation in agriculture" (Rolling and Engel, 1991). Originally the concept of AKIS referred to Information Systems; however, more recently it has changed referring mostly to Innovations Systems because it chiefly denotes "the influence and complexity of innovation and knowledge systems in rural spheres" (Dockes, Tisenkopfs and Bock, 2011). This concept expands on the notion of Agricultural Knowledge Systems because it includes actors that are outside to the education and research sectors. In addition, AKIS relate strongly to the concept of innovation with emphasis on the transfer and creation of knowledge through innovation.

Agricultural Innovation Systems (AIS)

The AIS concept was developed to improve the understanding of how agricultural systems can make better use of new knowledge and economic changes. AIS also involve alternative interventions that go beyond research investments. It recognizes different actors, disciplines and sectors involved in innovation, specially the private sector; this is because promoting innovations in agriculture requires coordinated support to agricultural research, extension and education, fostering innovation partnerships and linkages along and beyond agricultural value chains, and creating an enabling environment for agricultural development. It is also essential for the AIS to strengthen interactions between actors as well as creating an environment that enables innovation implementation.

Box 6.1. The Mexican agricultural innovation system

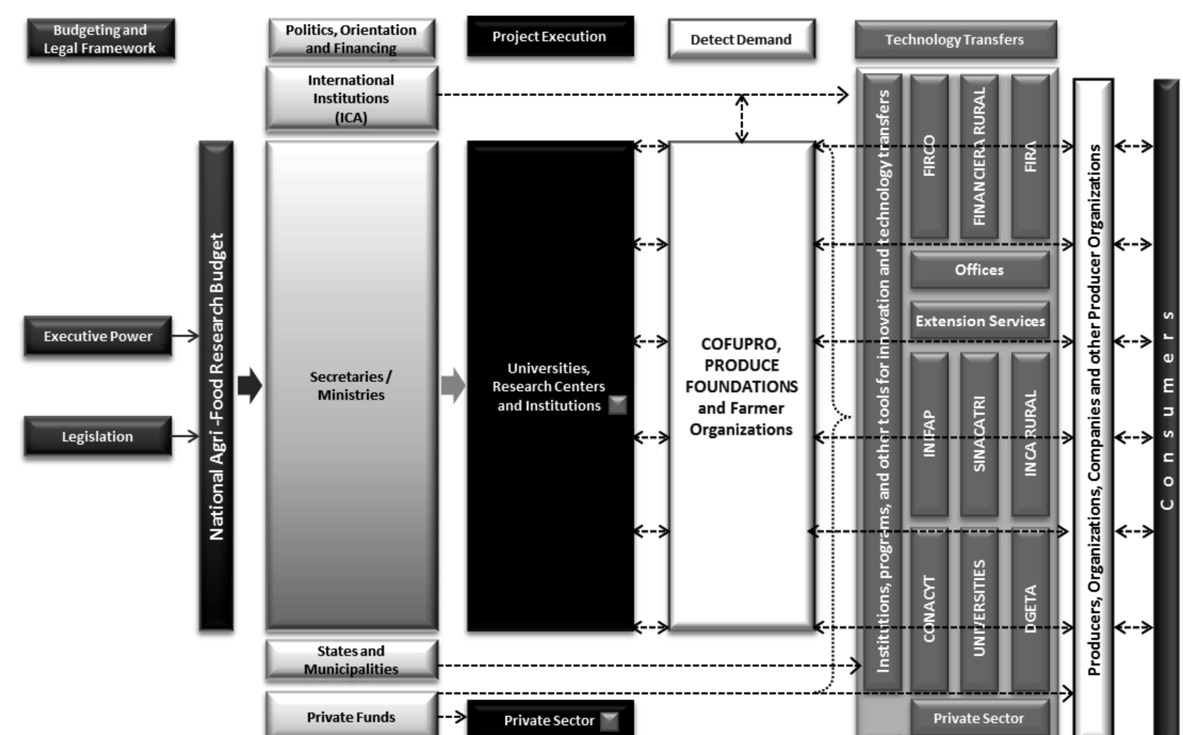
Research and Technology Transfer Systems in the agri-food sector are gradually experiencing a transition towards innovation systems based on an interactive process. The results depend on the relationships between different companies, organisations and sectors, As well as institutional behaviors in order to respond to producer's demands and provide a solution to problems such as poverty, low competitiveness and threatened sustainability.

This approach is based on a national innovation system, understood as an interactive creation model in which several different actors participate, along with institutions that are related to production and technological development. Under this system, knowledge and its uses are aimed towards collaborative projects within a research and technology transfer framework. Thus this is a network of players within a normative environment that regulates their operations. In this innovation system, attention is shifted towards innovation in itself; that is, towards the factors that determine the most effective use of knowledge in a context of research and therefore how it generates knowledge.

In Mexico, there is a network of actors who all have several different functions. The system is characterised by a high degree of institutional diversity, as well as by the presence of the public sector, academia, and companies and producers. The government actively participates by defining policies and financing, as well as by validating and participating in technology transfers.

The figure below represents Mexico's national innovation system. The purpose of the system is to integrate generation, dissemination and knowledge management, with research validation, promotion of technology transfers and the encouragement of innovation.

National Agri-Food Innovation System in Mexico



Source: Author's Own Work

Mexico's National Innovation System operates in many different levels, including but not limited to academia and the public and private sectors. Concerning innovation management there are several institutions that function as intermediaries within the system. These intermediaries will be referred to as innovation brokers. Courtney and Winch define an innovation broker as "an organisation, which is focused neither on the generation nor the implementation of innovation but rather on enabling other institutions to innovate." In other words, innovation brokers are institutions within an innovation system, which catalyzed innovation from other actors in the system but without producing innovation themselves. Innovation brokers have an important role; they introduce dynamics into the process by connecting actors, overcoming gaps in the system, optimizing interactions and enhancing productivity and innovation in small-scale farmers and producers. Innovation brokers are facilitators and do not contribute to innovation or technology; they only extend cooperation and articulate needs and the composition of the network. (Klerks, Hall and Leeuwis, 2009)

As seen in the figure COFUPRO which stands for the National Coordinator for Produce Foundations, plays and intermediary role in the management of the network of the Mexican Innovation System. COFUPRO is a non-governmental organisation, which co-ordinates 32 unique institutions (one per state) working together with public and private institutions, both nationally and internationally. COFUPRO was created as a response to common needs and individual limitations regarding in support of technological innovations. It has play an important role in positioning technology and innovation in the agri-food sector, and as a strategic element to attain competitiveness. COFUPRO is one of the institutions in the country committed to the national agri-food innovation and research agenda. It has also enabled a national technological innovation network. It is a clear example of an innovation broker.

Table 6.1. Defining features in relation with the agricultural innovation systems

Defining feature	NARS	AKS	AKIS	AIS	NAIS
Actors	Research organisations, agricultural universities, extension service and farmers	Researchers, advisors and educators of Agriculture Knowledge Institutions, under the control of the Ministry of Agriculture	Farmer, research, extension and education	Wide spectrum of actors	Economic actors that generate and use knowledge
Outcome	Technology invention and technology transfer	Technology embedded in products	Technology adoption and innovation	Different types of innovation	Different types of innovation
Approach	Using science to create new technologies	Diffuse knowledge and develop new skills	Accessing agricultural knowledge	New uses of knowledge for social and economic change	Using and managing innovation at the national level
Mechanism for innovation	Technology transfers	Knowledge transfer through agricultural extension and education	Knowledge and information exchanges	Interaction an innovation among stakeholders	Interaction among the users
Role of policy	Resource allocation, priority setting	Diffuse knowledge to increase productivity	Linking research, extension and education	Enabling innovation	Foster co-operation between actors and enable a framework for innovation
Nature of capacity strengthening	Strengthening infrastructure and human resources	Teaching farmers new skills	Strengthening communication between actors in rural areas	Strengthening interactions between actors, institutional development and change to support innovation; creating and enabling environment	Strengthening interactions between all economic actors at a national level
Resources	Infrastructure and human resources	Infrastructure and human resources	The media	Interaction platforms	Knowledge-based interaction platforms
Degree of market integration	Nil	Low	Low	High	High

National Agricultural Innovation Systems (NAIS)

A NAIS within a country is defined as a set of actors (i.e. farm organisations; input supply, processing and marketing enterprises; research and education institutions; credit institutions, extension and information units, private consultancy firms, international development agencies, and governments) that contribute to the development, diffusion, and use of new agricultural technologies and institutional innovations that influence, directly and/or indirectly, the process of agriculture knowledge, learning and change at the national level.

In this approach, innovation is used and managed at the national level. It encompasses a wider set of relationships in which economic actors generate and use knowledge. They foster interaction between research and related economic activity; promote attitudes and practices that accompany it, and generate the creation of an enabling environment that encourages interaction and helps to put knowledge into socially and economically productive use. Finally, relationships between actors and sectors embed innovation capacities.

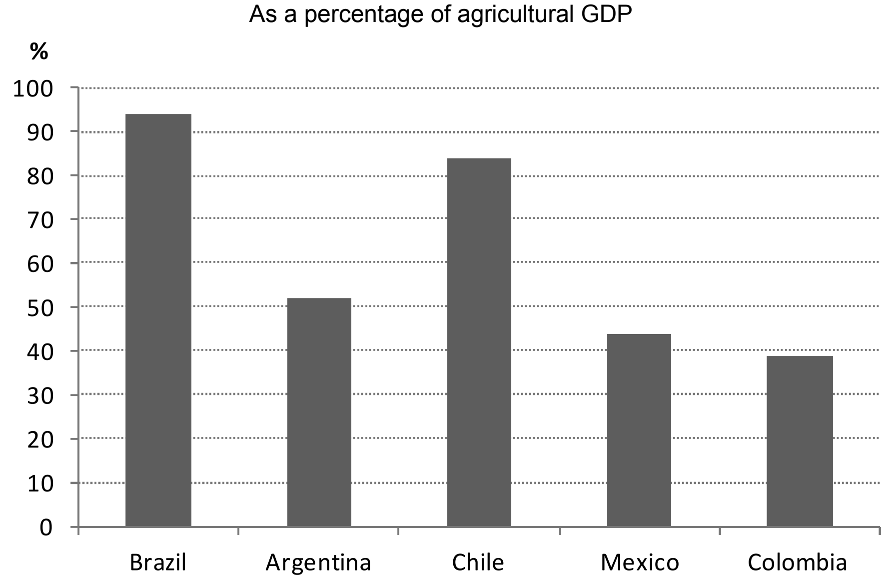
A collaborative network for innovation management

The magnitude and complexity of the problems of agriculture and the agri-food sector (mentioned previously in Changes and Challenges) exceed the individual capacities of countries to find solutions. These problems call for intensified cooperation programs that will aid in solving these problems, and will contribute to advancing competitiveness, sustainability and equity.

Figure 6.1 shows for 2004-05 investments in innovation in several Latin American Countries. Most of them invested less than 1% of their agriculture GDP on research, development and innovation. Although there has been an increase in investment trends in the past couple of years, overall investment remains low.

Figure 6.1. Investments in innovation in several Latin American countries, 2004-05

As a percentage of agricultural GDP



Source: World Bank.

Small investment in research and development, as well as poverty, climate change, environmental degradation, and the need to increase food security demand that these countries co-operate at an international level to minimize the negative impact on the global population, and specifically in rural areas

Because National Agri-food Innovation Systems (NAIS) contribute to the development, diffusion, transfer and management of innovation within a given country, it is important to implement effective NAIS in order to generate co-operation between countries and improve the rate of innovation.

The increasing influence of globalisation demands the creation of participatory forums such as networks in which international actors co-operate in order to integrate the creation, diffusion and management of knowledge. These forums should also strive to carry the knowledge produced by innovations to the market in order to achieve widespread adoption of new processes and information. For this reason, the Inter-American Institute for Cooperation on Agriculture (IICA) and COFUPRO have joined to promote an international network of innovation management in the agri-food sector, the INNOVAGRO Network.

At the international level, IICA is an institution that provides technical co-operation for the development of innovation and specialised knowledge in order to contribute to the competitive and sustainable development of agriculture in the Americas, therefore improving the lives of millions of rural workers in member countries. IICA has extensive experience in joint programmes in the Americas, and their experience confirms that collaborative programs aimed at problem solving can really contribute to the development of technological capabilities and improvements in efficiency and effectiveness, while at the same time providing benefits for all participating institutions.

On a national level, COFUPRO has been working in catalyzing innovation from other actors, optimizing interactions and enhancing productivity and innovation in small-scale farmers and producers. COFUPRO also works as a facilitator, extending cooperation and articulating the needs and composition of the network of Produce Foundations.

The INNOVAGRO Network contributes to the empowerment of all innovation management processes in the agri-food sector. As an example of how this network can improve and optimize innovation management, IICA and COFUPRO can, through a joint-venture, eliminate duplication of efforts, improve efficiency and make optimal use the few resources are available.

The INNOVAGRO Network aims to boost innovation management processes in the agri-food sector by exchanging knowledge, information, cooperation and expertise, and taking advantage of all synergy available between the members. The network shall foster to create and to promote encounters and meetings between members. More specifically, the network will strive towards: facilitating cooperation and participation among member countries, as well as implementing collaborative actions; fostering socialisation, dialogue and analysis of innovation management processes; spreading the word regarding successful innovation and technology transfer experiences.

INNOVAGRO seeks to integrate the following actors as members:

- Private actors linked to agri-food chains.
- Public institutions as well as national agri-food innovation institutes or equivalent institutions, such as those in charge of innovation management.
- Universities and other learning institutions.

- Ministries linked to innovation processes and innovation management.

Currently, the network consists of 39 institutions, representing 13 different countries listed in Table 6.2. These institutions range from high level research and innovation institutions to financial institutions, as well as public sector institutions, national systems, universities and Science, Technology and Innovation Ministries.

Table 6.2. Membership of INNOVAGRO network

Argentina	Bolivia	Brazil
Chile	Colombia	Costa Rica
Dominican Republic	El Salvador	Spain
Guatemala	Mexico	Nicaragua
Peru		

Conclusions

This section has presented the changes that arise as a result of a number of variables both internal and external to the agri-food sector. These variables range from sustained productivity and economic growth, to global elements such as climate change. These changes are correlated to a growing number of challenges that cannot be ignored and require the attention and efforts from the agri-food sector as a whole.

As a response to the changes and challenges in the global context, different approaches to Agricultural Knowledge and Innovation Systems have been created. While AKIS are different between countries and regions, their emphasis must be on the process needed to make knowledge useful and applicable.

The challenges mentioned at the outset concerning the agri-food sector clearly demonstrate that innovation systems in the agri-food sector are key in generating value and wealth.

Agricultural Innovation Systems provide significant benefits in countries that devote themselves to agricultural development, as they contribute to reducing poverty, decreasing hunger and improving health and nutrition. They can also lead to environmental sustainability, improved methods, practices, and yields. Additionally, Agricultural Innovation Systems generate interactive mechanisms to improve institutional co-operation between different actors at the national and international level.

Furthermore, investment priorities have to change and both public and private institutions must work together to reinvigorate research, growth, development, and innovation in the agri-food sector.

Consequently, the best solution is the participation, cooperation and coordination through networks involving different actors from all countries: private and public sector, higher education, research centres, producers, extension services, institutions specialised in technology transfers, to name a few.

Networks are facilitators of change. The INNOVAGRO is part of an approach in which knowledge is used for collaborative projects. Its goal is to transcend borders and continents in order to collaborate internationally and foster communication with the purpose of working together to find solutions to the greatest challenges faced by the agri-food sector.

Notes

1. Inter-American Institute for Cooperation on Agriculture (IICA).
2. "Collectively, the United States and global agricultural R&D trends point to two disturbing developments: first a pervasive slowdown in the rate of growth of agricultural R&D spending, and second, a growing rich country/poor country divide in the conduct of and thus the innovations emanating from agricultural R&D" (Pardley and Alston, 2010).
3. See World Bank (2006) for more information on this subject.
4. "In simple terms, such innovation systems can be defined as the set of agents, interactions, policies towards the creation and diffusion of knowledge and technology that can improve productivity, competitivity, sustainability and the equity of companies and agri-food chains." (IICA, 2011).

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Part II.

Institutional framework for improving the responsiveness of Agricultural Knowledge Systems

7. Perspectives from the UK foresight global food and farming futures programme

J.F. Muir[1]

Most future projections suggest that to meet expected demands of growing and wealthier global populations, agricultural output will have to expand to some 70-100% of current levels, and to do so within increasing resource constraints, with increasing stress and volatility associated with climate change, and under increasing social, economic and political pressure associated with uncertainty and vulnerability. While greater food supply is itself a major task (see for example Bruinsma, 2009), food security, and the means to maintain and improve equity of food access amongst the world's most vulnerable people will be a particular challenge. The recent *UK Foresight Review on Global Food and Farming Futures* (Foresight, 2011) concluded that while the technical means might exist to deliver proposed output levels, scenarios of rising and more volatile prices, ecosystem limits, hunger alleviation, and biodiversity demands would require concerted responses to intensify sustainably, improve supply chain efficiencies, improve consumer awareness and reduce waste. To avoid substantial real term price rises and minimise ecosystem and climate change impact, rates of change of agricultural productivity would have to increase above current levels, and this would require more effective Research and Development (R&D), uptake and capacity building.

Within the broader arena of the expansion, diversification and the social and economic importance of the food and agriculture system, the role of knowledge, its generation, exchange, application and impact clearly represents an indispensable element (see, for example, Piesse and Thirtle, 2010). While it is recognised that knowledge systems can work effectively and deliver effectively in well-established science and technology contexts with significant market incentives, good educational environments and strong human and institutional capital, these conditions are the exception in many parts of the world (see, for example, Röling, 2010). Indeed recent decades have seen not just that knowledge systems have become increasingly dysfunctional even in well resourced environments, but that the gap between global needs and knowledge capacity, at most if not all points in the food supply and value chain, is widening, and with more complex interactions of climate change, market development and global investment is likely to require a far more comprehensive and integrated framework

The institutions of knowledge creation and exchange are extremely important in defining and developing this capacity; not only is investment required, but function, objectives and outcome-defined performance will become increasingly significant in our approaches to meeting food needs within positive social and economic contexts. The choice of approaches (see, for example, Rosegrant *et al.*, 2008) will be critical, as will the means of delivery, responsiveness and resilience to change, potential for expansion, and the extent to which these will engage within other policy agendas such as poverty alleviation, equity and local empowerment. The present examples show how a selection of current agricultural knowledge systems are evolving to meet such challenges, how they may demonstrate their effectiveness and how they may develop further as demands increase.

Note

1. Professor, Lead Expert Group, Foresight Global Food and Farming Futures.

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8. Experiences with CGIAR reorganisation

CGIAR Consortium

As the Consultative Group on International Agricultural Research (CGIAR) celebrated its 40th anniversary in May 2011, it also embraced a new business model that has positioned it to play a central role in delivering the science needed to feed the earth's growing human population while protecting the environment and the resource base upon which future food production depends.

This section goes behind the evolution of the CGIAR, beginning with its establishment four decades ago, when it had four international agricultural research centres under its umbrella; looks briefly at its growth during subsequent years; the reasons for its reform process, which started in 2009; its new vision and how it now does business differently; and the ways in which it proposes to strengthen linkages between the various components of agricultural knowledge systems.

Introduction: Origins of the CGIAR

The CGIAR was established in 1971 as the result of the international response to the growing concern that population growth in many developing countries would soon lead to widespread hunger. Indeed, experts had been predicting since the 1950s that devastating famines would claim hundreds of millions of lives between 1970 and 1985. In a bid to help avoid such a global catastrophe, the CGIAR was formed based on the convincing evidence that agricultural science is necessary to combat hunger.

However, CGIAR roots go back many years before the organisation's formal inauguration, beginning with a collaborative programme between Mexico and the Rockefeller Foundation that developed high-yielding semi-dwarf varieties of wheat in Mexico (1950s) and rice in the Philippines (1960s). The programme demonstrated the potential of publicly funded international agricultural research to unlock the productivity of smallholder farms in the developing world.

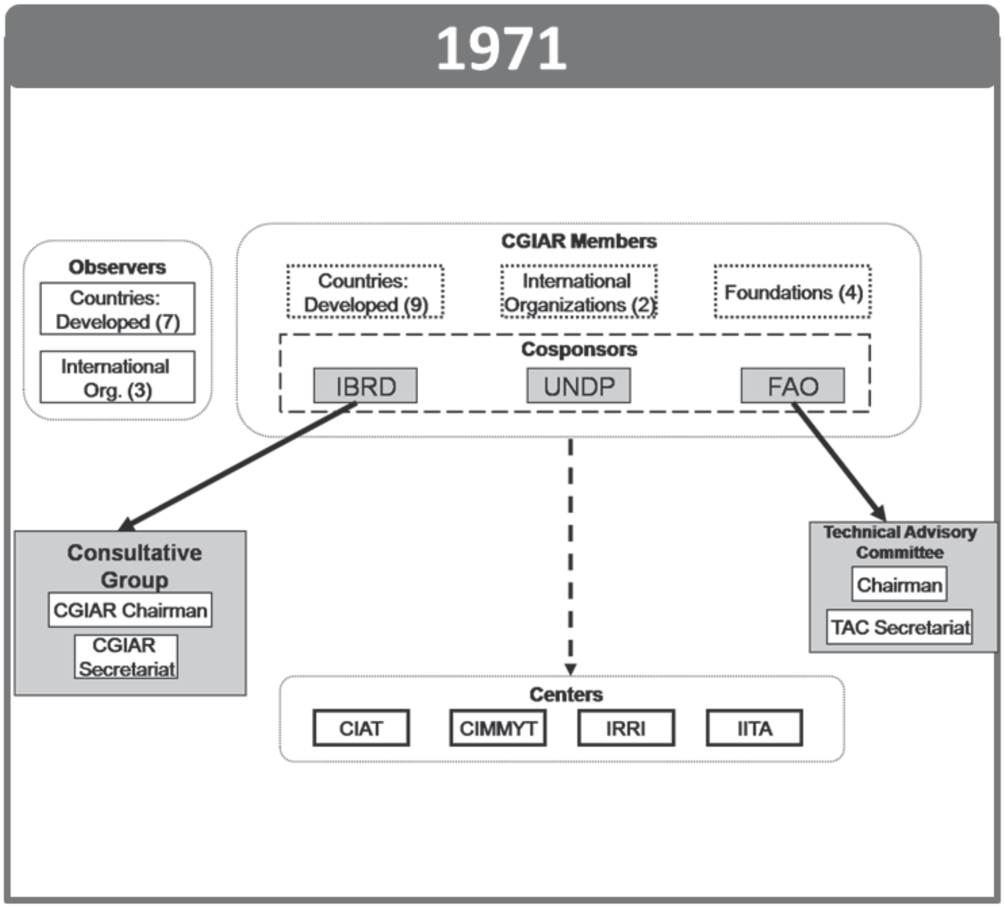
Then a series of consultations beginning in 1969 explored how best the international community could:

- Consolidate and spread the benefits of agricultural research globally;
- Respond to the call for an "intensive international effort" to support "research specializing in food supplies and tropical agriculture;" and
- Protect and strengthen the four international agricultural research centres established on four continents with the support of the Ford and Rockefeller foundations and their partners:
    - International Centre for Tropical Agriculture (CIAT) in Colombia,
    - International Maize and Wheat Improvement Centre (CIMMYT) in Mexico,
    - International Institute of Tropical Agriculture (IITA) in Nigeria,
    - International Rice Research Institute (IRRI) in the Philippines.

Together with the heads of the Food and Agriculture Organisation (FAO) of the United Nations, the United Nations Development Programme (UNDP), and the World Bank (IBRD), the Ford and Rockfeller foundations persuaded influential donors that agricultural development and, therefore, agricultural research deserved high priority on the international development agenda. These efforts and further consultations resulted in the establishment of the CGIAR in early 1971 (Figure 8.1).

Thus it was a humanitarian concern, mixed with a science-based conviction, that brought together the agricultural researchers and development donors that led to the creation of the CGIAR. Their shared objective was to extend the early gains made possible by modern agricultural science by developing a workable formula for mobilizing resources to support research on a "long-term continuing basis".

Figure 8.1. The CGIAR in 1971



CGIAR growth and the changing mission statement

During the CGIAR's **first decade**, a period that saw the Green Revolution continuing to make great strides, CGIAR research focused on rice, wheat and maize. CGIAR science resulted in dramatic increases in agricultural productivity made possible through the widespread adoption of new high-yielding cereal varieties combined with the increased use of irrigation, fertilisers and pesticides. However, the organisation's research portfolio was soon broadened to include other food crops and also pasturage. The emphasis on improving the availability of affordable food brought great benefits to developing countries. The CGIAR also branched out into several new areas of research: livestock, farming systems, the conservation of genetic resources, plant nutrition, water management, policy research, and services to national agricultural research centres in developing countries. As the scope of CGIAR research widened, the number of international Centres in the CGIAR grew from 4 to 13.

The organisation's **second decade** saw the research objective being redefined as increasing sustainable food production in developing countries in such a way that the nutrition and general economic well-being of the poor were improved.

During its **third decade**, the research interests of the CGIAR grew to include livestock, agroforestry, forestry, fisheries, water management, and banana and plantain, in addition to crop agriculture. The number of centres rose to 18, although this number was reduced to 16 after consolidation. The CGIAR mission statement was reformulated again to read as follows: "through international research and related activities, and in partnership with national research systems, to contribute to sustainable improvements in the productivity of agriculture, forestry and fisheries in developing countries in ways that enhance nutrition and well-being, especially of low-income people."

Concerns were expressed about the adequacy of CGIAR governance, resource mobilisation, and financial management to meet new challenges and changing needs. Others issues raised included the impact of research, and linkages with national agricultural research systems in developing countries and civil society organisations.

In 1994, the CGIAR undertook an eight-month renewal programme to address these concerns and restore the organisation to full vigour. Measures were taken to ensure greater transparency in the organisation. Impact assessment was emphasised, and the research agenda increasingly focused on the nexus of agriculture, poverty and the environment. The mission statement of the CGIAR was as changed to read: "to contribute, through its research, to promoting sustainable agriculture for food security in the developing countries."

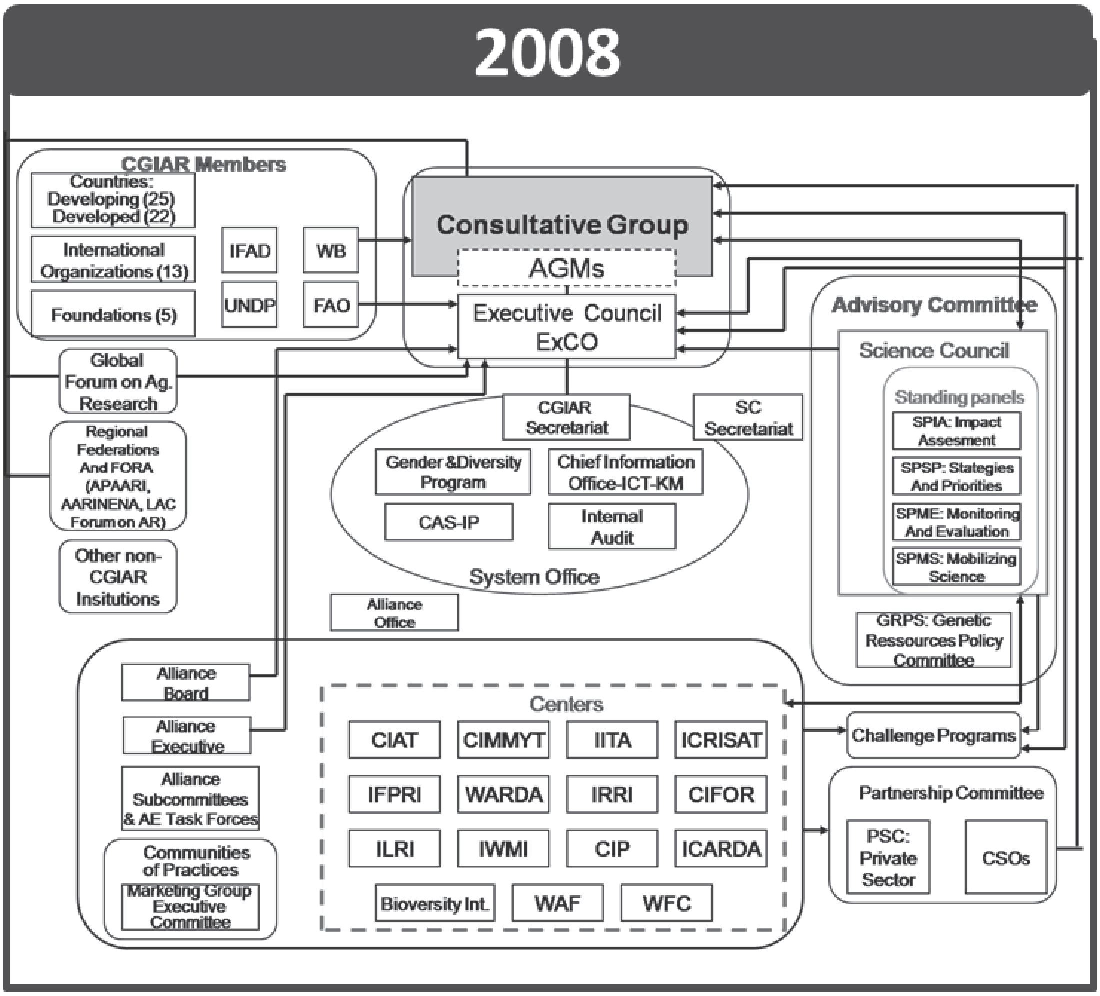
With the advent of the **new millennium**, the CGIAR faced several challenges:

- maintaining science and research at the highest levels;
- exercising the "new age" institutional assets of lightness, agility, responsiveness and cost-efficiency;
- strengthening the role of the CGIAR as a producer of global public goods;
- creating a new framework for partnerships;
- providing the Centres with stable and secure funding; and
- devising the most effective means of linking CGIAR-supported research with the development programmes of countries in the South.

Further consolidation in 2004 reduced the number of Centres to the current 15.

By the time 2008 rolled around, the CGIAR System had become increasingly complicated with multiple donors, centres, and national priorities. From the beginning, the CGIAR was conceived as a loose association of autonomous research centres and independent donors that shared objectives but did not necessarily pursue those objectives with a great deal of strategic coordination, and this *modus operandi* had, for the most part, remained unchanged over the years (Figure 8.2).

Figure 8.2. The CGIAR in 2008



CGIAR successes

Although it faced challenges in its governance and a less-than-optimal level of inter-Centre collaboration in 2008, the CGIAR has had an unprecedented number of successes. Millions of lives have been saved and the livelihoods of millions of people around the world have been improved as the result of CGIAR research.

Studies on the impact of CGIAR work state that if we lived in a world without a CGIAR, developing countries would produce 7-8% less food, and some 13 million more children would be malnourished. A further study showed that CGIAR research enabled almost 700 million people to escape poverty between 1981 and 1999. Stories about the impact of the CGIAR research can be found at *bit.ly/tRNjC2*, a publication prepared on the occasion of the CGIAR's 40th anniversary.

CGIAR reform: A new business model

In December 2009, the CGIAR opened a new chapter in its history by adopting a new business model that embraced reforms that had been two years in the making, all of which were designed to improve the organisation's delivery of research results in response to global food security and climate change challenges. This resulted in the establishment of the CGIAR Fund and Fund Council, the Consortium, and the Independent Science and Partnership Council (ISPC), a standing panel of world-class scientific experts (Figure 8.3).

The purpose of the Consortium, which is headquartered in Montpellier, France, is to provide leadership to the CGIAR System and co-ordinate activities among the 15 member Centres and other partners within the framework of the CGIAR Research Programmes (CRPs). This enables the Centres to enhance their individual and collective contributions to the achievement of the CGIAR vision. The Consortium also integrates some "backroom" services to improve the efficiency of CGIAR operations, and provides a single contact point for donors.

Similarly, CGIAR donors join together in the CGIAR Fund and its smaller Fund Council, with the aim of harmonising their contributions to agricultural research for development, improving the quantity and quality of funding available, and engendering greater financial stability.

Desired outcomes

The aim of the CGIAR reform is to:

- Move away from a mission statement that tried to embrace everything to one that has a clear and succinct focus, and priorities that respond to global development challenges.
- Facilitate collaboration between the centres, enabling them to work towards a common System agenda and priorities, and clear impact delivery.
- Implement an effective system-wide level of governance with clear lines of accountability.
- End static partnerships that do not enable scalable impact and research adoption. Strong, innovative partnerships that enhance impact are being established with the National Agricultural Research Systems (NARS), private sector and civil society.
- Overcome the past lack of coordination amongst investors, and strive to have strengthened, coordinated funding mechanisms that are linked to the System agenda and priorities.
- Stabilise and support the growth of core resources.

Partnership at all levels

The new CGIAR model emphasises clear lines of accountability and balances the partnership between those who conduct research and those who fund it. This model encourages stronger collaboration, communication and partnership with other research and development actors. Such a business-like structure, along with its clarified roles, responsibilities and decision-making processes, promises to enable the CGIAR to achieve more in the fulfilment of its mandate.

The new CGIAR fosters stronger and more dynamic partnerships that can generate high-quality research outputs while strengthening national research institutions. Stakeholders, including donors, partners and beneficiaries, provide input into the design of the Strategy and Results Framework (SRF), and the CGIAR Research Programmes (CRPs).

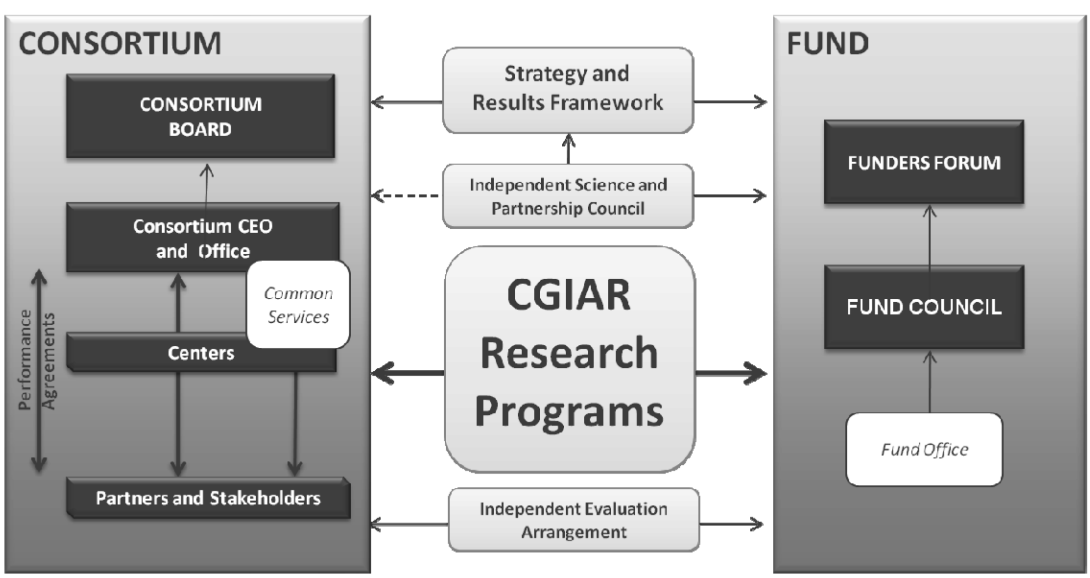
The common SRF provides the basis for collective action by the 15 centres and their hundreds of partners through the CRPs, a radical change from the previous loose coalition of independent research institutes.

The SRF identifies the evolving context of international agricultural research and the CGIAR's role over the coming few years on the basis of its comparative advantage (see "**The CGIAR's comparative advantage"** below).

It also defines the four strategic System Level Outcomes (SLOs) to be pursued, all of which have been derived from the CGIAR's vision and the Millennium Development Goals:

- Reduce rural poverty.
- Increase food security.
- Improve nutrition and health.
- Ensure more sustainable management of natural resources.

Figure 8.3. The new CGIAR, partnership at all levels



CGIAR vision

The vision of the CGIAR is to reduce poverty and hunger, improve human health and nutrition, and enhance ecosystem resilience through high-quality international agricultural research, partnership and leadership.

The CGIAR's comparative advantage

The CGIAR has a comparative advantage in addressing its vision challenges as a result of the following key characteristics.

- It is an autonomous organisation with a global public mandate and funding for scientific research to find solutions that can eradicate poverty and hunger on a global scale.
- It has a critical mass of leading scientists with multidisciplinary knowledge of key agro-ecosystems that especially target the poor and under-supported areas.
- It has an extensive global research network, including research stations with strong links to farmers and national agricultural research and innovation systems.
- It has a 40-year track record in addressing Research for Development (R4D) issues.
- It is the guardian of collections of genetic resources for agriculture held in trust for the world's current and future generations.

Delivering on the vision: CGIAR Research Programmes

The CGIAR Research Programmes (CRPs) are the main mechanism by which the CGIAR will achieve the greater alignment of research outputs with the four SLOs. The CRPs are also the main instrument for planning and conducting research and represent a joint venture between the Funders and the Doers.

The CRPs seek to unlock the development potential of diverse food staples and agricultural systems, while simultaneously addressing other issues affecting agriculture and food security, such as climate change, nutrition, and access to markets. The CGIAR has identified key themes — such as gender, capacity strengthening, and partnership — that cut across the programmes to ensure that research and resulting benefits are as effective and equitable as possible.

These CRPs represent an unprecedented level of collaboration between Centres to ensure food security, improve lives, and safeguard natural resources. The CRPs will build on the Centres' past achievements, adding value by linking activities and creating dynamic synergies between them. They will benefit from the CGIAR's critical mass of leading researchers and its strong links with national research programmes and other partners, especially farmers.

The CRPs, each of which is to be implemented by a lead Centre, with multiple partners and appropriate partnerships at all stages of the R4D process, are built and measured on three core principles:

- Impact on the SLOs, ensuring consistency between the SRF and the CRPs.

- Integration across CGIAR core competencies, strengthening synergies and avoiding overlaps.
- Appropriate partnership at all stages of R4D.

Before commencement, each CRP sets out its expected achievements, clearly defines risks and assumptions, and provides verifiable targets and indicators for progress monitoring.

Basis for CRPs approval

- Strategic coherence and clarity of objectives.
- Delivery focus and plausibility of impact.
- Quality of science.
- Quality of research and development partners, and partnership management.
- Appropriateness and efficiency of CRP management.
- Accountability and financial soundness.
- Efficiency of governance.

Portfolio of CGIAR research programmes

As of 2011, 15 CRPs form the new CGIAR research portfolio – most have approved funding and some are already in operation.

The CRPs cover the following.

- Major agro-ecological systems
  - Dryland systems
  - Aquatic agriculture
  - Forests, trees, and agroforestry
  - Humid tropics
- Major food staples
  - Rice
  - Wheat
  - Maize
  - Roots, tubers, and bananas
  - Livestock and Fish
  - Grain legumes
  - Dryland cereals
- Broad issues
  - Nutrition and health
  - Policies, institutions and markets
  - Climate change
  - Water, land and ecosystems

The CGIAR research portfolio of CRPs is now better able to address complex, global issues that demand a more diverse and responsive range of skills and knowledge than any of the Centres could offer individually, and the new structures (the CGIAR Fund and the CGIAR Consortium) provide fiscal efficiency and greater clarity of roles and responsibilities between those who pay for the research and those who conduct it.

The vision of the CGIAR is to move forward with one voice. For the first time in the CGIAR history, the 15 centres have a common strategy to guide their research. The CGIAR now functions as a unified system based on the CRPs, and the centres collaborate with each other and with partners in pursuit of shared outcomes.

Strengthening linkages between the various components of agricultural knowledge systems

The CGIAR will strengthen AKS linkages by focusing on crossing the divide: between sectors, cultures, institutions, and national/regional/international levels. Partnerships are critical, and communications and governance are key in partnering.

The CGIAR is working to re-establish and strengthen strong and innovative linkages along impact pathways with several key sectors.

- Farmers and those that serve them such as extension agents and small and medium sized enterprises (SMEs)
- National governments, NARS and regional research partners.
- Civil society and NGOs that serve farmers, their communities and the environments with which they interact.
- Private sector – large, medium and small enterprises, including entrepreneurs and local businesses serving the farmers.
- Academic institutions of the North and South, including technical training of the trainers of adults and youth.
- Donor-funded research and value-chain initiatives.

The overall aim is to move from supply driven to demand and value chain driven research with holistic and participatory approaches, sensitive to diversity, society, and environment using information and communication technology (ICT) and other collaborative tools.

Conclusion

The impact of 40 years of collaborative work by the CGIAR Centres and their partners is without parallel in the international community. The new CGIAR now has the structure and capacity to meet the challenges of the 21^{st} century, delivering improved food security in the developing world while maintaining its environmental heritage for future generations.

9. Institutional Agricultural Knowledge System reforms in New Zealand and international networks

Karla Falloon[1]

Agriculture in New Zealand is a significant component of the New Zealand economy accounting for 9.1% of GDP. This is in part due to the long term investment in research to support the agricultural sector. The New Zealand agricultural knowledge system (AKS) has undergone significant reform over the last two decades with a key feature being the close alignment of the public and private sectors in setting research priorities, funding and non-financial support. International networks are considered important for New Zealand and the global AKS, and a significant effort in the last two years has been put into establishing the Global Research Alliance on Greenhouse Gases to respond to the need to reduce global greenhouse gas emissions while at the same time maintaining productivity.

Introduction

This chapter provides a summary, from a public policy perspective, of some of the policy and institutional support for New Zealand's agriculture and agricultural knowledge system (AKS). This is an accompaniment to the presentation given at the OECD Agricultural Knowledge Systems Conference on 15-17 June 2011. Key institutions and their role in New Zealand's AKS are described, as well as the role of government and its investment. Trends in New Zealand's AKS that have been seen over recent years and are likely to continue in the future are summarised. Finally, two examples of international networks in which New Zealand is involved are highlighted: the Global Research Alliance on Greenhouse Gases and the International Knowledge-based Bio Economy (KBBE) Forum.

New Zealand agriculture has been, is and is likely to remain in the foreseeable future, of key importance to New Zealand. In the financial year to June 2010, agriculture exports made up 55% of total merchandise exports. Farming directly accounts for around 5% of Gross Domestic Product (GDP), while the processing of primary food products accounts for a further 4.1%.[2] Downstream activities, including transportation, rural financing and retailing related to agricultural production, also make important contributions to GDP (depending on export prices).[3]

In the recent 2010 survey on New Zealand's Research and Development (R&D) by Statistics New Zealand[4] 16% of Gross Expenditure on R&D (GERD) was spent on research related to the primary industries. This was second only to the manufacturing area which accounted for 18%. Government remains the dominant funder in this area, with around 34% of Government Expenditure on R&D (GOVERD) spent on R&D related to primary industries, that is plant and animal production, and non-energy-related mineral resources. Research for primary industry is a significant research strength in New Zealand.

Institutional landscape of the New Zealand AKS

The New Zealand AKS involves a mix of government and private enterprise institutions and entities. Higher education and research are dominated by government funded and owned entities, while development and extension are considered to be largely a matter for the private sector.

New Zealand has a unique organisational form that carries out research for the benefit of the country. Known as Crown research institutes (CRIs) they were formed in 1992 when the Department of Scientific and Industrial Research (DSIR) and the Ministry of Agriculture and Fisheries science divisions were reformed into ten research companies to carry out research for certain sectors. The formation of CRIs occurred at a time of significant reform in the New Zealand state sector generally, resulting in the separation of policy and the purchase and provision of services to a number of sectors including science and technology.

CRIs are state-owned enterprises, governed by their own Act[5] with independent boards of directors. They have a requirement to deliver beneficial economic social and environmental outcomes for New Zealand through effective partnerships with stakeholders as well as a commercial rate of return on assets which they own. Activities of the CRI's are monitored by the Ministry of Science and Innovation (MSI) and the Treasury. A significant and increasing proportion (approximately 50%) of CRI funding comes from sources outside of government, but public funds are still critical for the continued operation of the CRIs.

Following the disestablishment of one[6] and the merger of two others[7], there are now eight CRIs, of which three are focussed on research for the primary industry. The first, AgResearch,[8] aims to create sustainable wealth in the pastoral sector through the application of leading-edge knowledge and technologies. It focuses on five major areas — creating the future dairy; meat; textiles and biomaterials industries; helping achieve a pest and disease-free New Zealand and enabling capacity for change in agriculture and its future communities. The second, Plant & Food Research,[9] provides research and development that adds value to fruit, vegetable, crop and food (including seafood) products. The third, Scion Research,[10] is dedicated to building the international competitiveness of the New Zealand forest industry and building a stronger bio-based economy.

A further two CRIs are focused on areas related to supporting the primary industries. Landcare Research[11] focuses on the sustainable management of land resources optimising primary production, enhancing biodiversity, increasing the resource efficiency of businesses; while the National Institute of Water and Atmospheric Research (NIWA)[12] conducts environmental science to enable the sustainable management of natural resources.

New Zealand has eight universities, of which two, Lincoln University[13] and Massey University[14], dominate the teaching of agricultural disciplines and conduct agriculture-related research. More specific agricultural training courses are offered by a mix of state-owned Polytechnics and private training establishments. An Agricultural Industry Training Organisation[15] develops the required specifications for agricultural training courses in association with the relevant agricultural industries.

Centres of Research Excellence are funded through the Tertiary Education Commission and are a collaborative model, hosted by a university, but bringing together expertise from other research institutions, including the Crown research institutes. Three of the eight Centres of Research Excellence perform research with agricultural application: the National Centre for Growth and Development,[16] which has a focus on early stages of mammalian development; the National Centre for Advanced Bio-Protection Technologies,[17]which focuses on finding new, non-pesticide and sustainable solutions that protect New Zealand's plant-based, productive ecosystems from existing and potentially invasive pests, diseases and weeds; and the Riddet Institute[18] which conducts biomaterials science and digestive physiology relating to nutrient absorption and metabolism.

Research tends to be the preserve of the CRIs and universities, though some research is also carried out at polytechnics and by private research firms. A notable and significant research effort is performed by Fonterra, the world's leading exporter of dairy products which performs research both in New Zealand and in other countries close to its customers. New Zealand’s primary industries and firms are relatively low investors in research and development compared to the rest of the OECD[19]. Most agricultural industries use compulsory levies to fund industry R&D. Other uses for levies include agricultural related education. (A Commodity Levy Act (1990) empowers producers to self-impose levies on agricultural products at the farm gate through a vote in order to finance “industry good activities”. Once voted, the levy becomes obligatory for all commercial producers of the products in question. For each product, farmers vote every six years to decide whether to continue to impose the levy.

Agricultural extension before the early 1990s was funded by the government as part of the Ministry of Agriculture and Forestry, but following reform, private consultants now dominate agricultural extension. Private consultants are supplemented by a number of industry organisations offering more limited consultancy services to farmers but usually on a lower cost basis. Some extension is carried out by the primary sector CRIs and limited extension is carried out by universities or Centres of Research Excellence.

Staying ahead of the game, within a changing domestic and global context

New Zealand's primary sectors have been built on a number of undeniable strengths, including a temperate growing environment conducive to pastoral production, a relatively disease free status and an effective biosecurity regime. New Zealand food has a reputation for quality, safety and innovation. Consequently there are significant branding opportunities to position New Zealand food products as safe, natural, and pure.[20] This New Zealand food 'brand' is a critical factor in the country's successful positioning on the global stage. It also has flow-on implications for industries such as in-bound tourism and the growth of food and wine destination regions like the Hawke's Bay, Marlborough and Martinborough.

Business models for global expansion by the larger players in the food and agribusiness sector in New Zealand are constantly evolving. In-market production coupled with the export of integrated production systems and the retention of intellectual property ownership within New Zealand are on the rise.

The successful examples have come about through a mix of factors including: industry cohesion; supply chain innovation; control of supply; decades of investment in research and development; smart intellectual property management; branding in the global marketplace and, above all else, product quality, consistency, and safety.

Issues of sustainability, climate change, competitiveness and improving productivity are also inextricably linked for New Zealand producers. While the effects of climate change on New Zealand are projected to be relatively modest compared to many other countries, New Zealand is projected to be drier in the east, wetter in the west and growing warmer. This, in turn, will lead to more severe weather events, the need to use more irrigation on the east coast, and an increased number of bio-security incursions as pests survive in warming conditions, all of which will require a coordinated scientific and technical response.[21]

Recent trends in land-use also indicate an increase in intensive pastoral land-use (for example; higher stocking rates, increased use of fertilisers and agricultural chemicals, and increased irrigation use).[22] New Zealand is also facing and will continue to face related pressures on water quality and water quantity. Demand for water is increasing, particularly in areas where water is scarce, like regions of Canterbury and Otago. The impact of intensive farming practices risks compromising water quality, with rivers, streams and lakes in pastoral catchments suffering from animal effluent and fertiliser runoff and the health of soils.

As consumers and retailers in many of New Zealand's key markets increasingly demand that food and beverage producers prove their sustainability credentials, New Zealand producers will need to ensure they can comply. This is both a threat and, for a country such as New Zealand with such high food quality and production sustainability standards, an opportunity.

Government working with industry to progress sector development in this changing environment

Government and industry have long taken a partnership approach to progress sector development, and now more than ever need to continue to do so. This partnership approach has resulted in co-investment in public private research partnerships and working together to respond to sustainability and market access issues.

A pervasive trend in the government's industry good research investments has been the active prioritisation of research needs by industry partners for applied research investments. This is resulting in co-investment partnerships between industry and government in initiatives like Research Consortia.

Government and industry have distinct, but closely linked investment roles across this continuum.

Government supports:

- Long term investments in underpinning science capabilities;
- higher risk research which is further from market;
- bearing the risk in early-stage investment seeding of industries of the future;
- partnering with primary industry and investing in high-potential firms; and
- research to underpin policy in respect to environmental and social impacts.

Industry and government tend to co-invest in applied research, while industry invests in the market driven end of the spectrum.[23]

Government research strategy to support the AKS

New Zealand, through the Ministry of Science and Innovation invests significantly[24] in research performed by Crown research institutes, universities and the private sector to support productivity growth and sustainability in the primary industries and the development of premium food and industrial biological products and technologies that meet global demand. This research also promotes diversification of the sector by investing in research to develop new biologically-based industries and firms producing higher margin food and industrial biological products, processes and technologies to service niche global markets.

The primary driver for investment in research in New Zealand in the biological industries is to achieve export-driven economic growth and to attain sustainable management of resources. The government has identified as a priority the need to directly boost economic growth through investment in market-driven R&D and to streamline the pathway of science from the lab bench to the marketplace. The government has also signalled the need to improve the way that New Zealand invests in public good science that underpins the economy.

The scope of research in the Biological Industries research area covers the following two broad areas:

- Primary sector productivity and sustainability.

  This encompasses research underpinning the development, sustainable production, processing and delivery to global markets of foods and materials from New Zealand's primary industry. This includes the pastoral, horticultural, arable, seafood and aquaculture, and forestry sectors. It also includes broader cross-sector research programmes in areas important to all primary sectors such as biosecurity research.

- High-value food and industrial biological products, processes and technologies.

  This encompasses research underpinning the development of food and industrial bio products, processes and technologies. These products will have embedded technology and intellectual property derived from processing and manipulation. This includes research to develop functional and manufactured food products and ingredients, nutraceuticals and supplements. It also includes the development of non-food natural products, such as renewable industrial biomaterials, and bio-sensing and bio-processing technologies.

Trends in the AKS

Over recent years there have been a number of trends in New Zealand's research sector and its role in the AKS. These include:

- **Increasing research critical mass and enhancing collaboration.** Two CRIs, Crop & Food Research and HortResearch were merged to form Plant and Food Research. The Centres of Research Excellence will continue to provide an important contribution to the basic research underpinning the AKS. The New Zealand Greenhouse Gas Research Centre[25] with a number of New Zealand partners has recently been established. The Centre's role is to find ways for New Zealand to meet its international greenhouse gas emission obligations without reducing agricultural output.
- **Reform in policy and funding for research.** Restructuring has also occurred in the government policy and funding agencies for science, with the merging of these two functions through the amalgamation of the Ministry of Research, Science and Technology and the Foundation for Research, Science and Technology into a single ministry - the Ministry of Science and Innovation, which came into being on 1 February 2011. Recently the Ministry of Agriculture and Forestry has also re-emerged as an important funding agency for investment projects in new innovations in agriculture (refer to Primary Growth Partnership below). The Ministry of Agriculture and Forestry has also merged with the Ministry of Fisheries and the New Zealand Food Safety Authority and Biosecurity New Zealand.
- **Increased direct funding to CRIs.** Following the review of CRIs by the CRI Taskforce in 2010,[26] the government has decided to provide a greater amount of direct funding to the CRIs, to support research delivering on a long term strategy and statement of core purpose agreed with Government.
- **Enhanced Partnership with industry.** The government through the Primary Growth Partnership (PGP),[27] will invest NZD 70 million per year with at least matching funding from industry. The PGP is a government-industry initiative that will invest in significant

programmes of research and innovation to boost the economic growth and sustainability of New Zealand's primary, forestry and food sectors. The programmes will focus on boosting productivity through ongoing investment in innovation and delivering long term economic growth and sustainability across the primary sectors, from producer to consumer. Investments can cover the whole of the value chain, including education and skills development, research and development, product development, commercialisation, commercial development and technology transfer. Industries included in the Primary Growth Partnership are: pastoral (including wool) and arable production; horticulture; seafood (including aquaculture); forestry and wood products; and food processing (including nutriceuticals and bioactives).

- **A more network approach both domestically and internationally**. For example, a Food Innovation Network of New Zealand (FINNZ) has been established to provide open access pilot plant facilities for smaller companies through a series of regional hubs, with equipment to support the types of R&D and technical support needed by the companies in that region. Examples of international networks will be described in the sections below.

Networking internationally: The Global Research Alliance on Agricultural Greenhouse Gases

As noted earlier in this section, a significant proportion of New Zealand's greenhouse gas emissions come from agriculture. Global agricultural emissions are estimated to be about 14% of global annual greenhouse gas (GHG) emissions. Current projections could see global agricultural emissions increase to 8 400 metric tonnes of carbon dioxide equivalent by 2030.

From a global perspective there are a number of challenges. These include, *inter alia*, the very few mitigation options that have been identified, and those that are difficult to implement; one-off technological fixes that will not necessarily work for agriculture and, for many, a priority not of mitigation but of adaptation and food security.

There is therefore a challenge to reduce agriculture emissions, while at the same time a need to ensure sustainable development. Declining agricultural yields associated with climate change and water shortages could exacerbate global food insecurity, also add to the global challenge.

These challenges are immense, but there are also opportunities. The key opportunity is to meet the multiple objectives of food security, adaptation, mitigation, development, through increased agricultural productivity and efficiency. In many cases this is positively correlated with reduced emissions intensity, resilience and food security, opening a wide potential field for research and technology development.

These issues require sound information, research and viable options. Research and development is considered critical to the measurement and estimation of emissions, improving our knowledge of production systems, and to be the only way that mitigation options that are real, low-cost and that fulfil multiple objectives of climate change and food security can be developed.

The Global Research Alliance on Agricultural Greenhouse Gases (the Alliance)[28] was established in 2009 in the margins of the United Nations' climate change conference in Copenhagen. The New Zealand government has committed NZD 45 million to this initiative.

The aims of the Alliance are as follows.

- Bring countries together to find ways to grow more food (and build more climate-resilient food production systems) without growing GHG emissions.
- To find ways to reduce the emissions intensity of agricultural production and increase its potential for soil carbon sequestration, while enhancing food security.
- Improve understanding, measurement and estimation of agricultural emissions.
- Improve farmers' access to agricultural mitigation technologies and best practices.

As of September 2011, there were 32 partner countries. At the centre of the Alliance are three research groups: livestock (led by New Zealand and the Netherlands); paddy rice (led by Japan and Uruguay); and croplands (led by the United States), and two supporting or cross cutting research groups: soil carbon and nitrogen cycling (led by France and Australia), and inventories and measurement (led by Canada and the Netherlands).

Networking internationally: The Knowledge-Based Bio Economy (KBBE) Forum

New Zealand's engagement with Europe through the European Commission was significantly enhanced when a Science and Technology Cooperation Agreement came into force in 2009. A priority area for this engagement is in the area of food, agriculture and biotechnology, and fisheries. An important development has been, alongside the European Commission, Canada and Australia, the establishment of an International Knowledge-Based Bio-Economy, or KBBE Forum. The key objective of the KBBE Forum is to enhance the research and innovation policy dialogue and scientific cooperation between the European Union, New Zealand, Australia and Canada regarding the most important issues of the knowledge-based bio-economy. It will support and align research in common areas, through mechanisms such as twinning of research programmes and staff exchanges as well as jointly prioritise research that is considered mutually beneficial.

Currently there are four different thematic strands which are being progressed: food and health; non-food bio-based products, sustainable agriculture, and fisheries and aquaculture. Each strand will develop a roadmap of activities, while the overall Forum will meet once a year to ensure the activities are well aligned with research priorities in the respective partners' jurisdictions. The second annual KBBE Forum meeting took place in Ottawa, Canada from 5-6 October 2011.

Conclusion

Institutional reform in New Zealand's AKS has been significant and continuous over the last twenty years. A pervasive trend has been the strong interaction between government and the private sector in priority setting and funding of research and innovation, as is a more networked approach both domestically and internationally. These trends ensure that research has direct and relevant outcomes to the agricultural sector to maximise productivity within natural resource limitations.

Notes

1. Counsellor (Science and Technology), Ministry of Science and Innovation, New Zealand Mission to the European Union, Avenue des Nerviens, 9-31, 1040 Brussels, Belgium. Email: karla.falloon@msi.govt.nz.

   This section heavily draws on internal documents drafted by colleagues at the Ministry of Research, Science and Technology in New Zealand, now the Ministry of Science and Innovation, and the Ministry of Agriculture and Forestry's response to the questionnaire on the organisation, objectives and outcomes of AKS as input into the OECD Agricultural Knowledge Systems Conference, 15-17 June 2011.

   In particular, the author would like to thank Jane Cameron, formerly of the Ministry of Science and Innovation now at Ministry of Economic Development and Tony Brenton-Rule, at the Ministry of Science and Innovation for significant input into the paper and presentation at the conference. Hayden Montgomery of the Ministry of Agriculture and Forestry provided information related to the Global Research Alliance on agricultural emissions.

2. *Source*: Statistics New Zealand and New Zealand Ministry of Agriculture and Forestry

3. *www.treasury.govt.nz/economy/overview/2010/nzefo-10-3.pdf*

4. *www.stats.govt.nz/browse_for_stats/businesses/research_and_development/ResearchandDevelopmentSurvey_HOTP2010/Commentary.aspx*

5. *www.legislation.govt.nz/act/public/1992/0047/latest/DLM264292.html*

6. Institute for Social Research & Development Ltd was disestablished in 1995

7. Crop and Food Research and HortResearch were merged in September 2008 to form Plant and Food Research.

8. *www.agresearch.co.nz*

9. *www.plantandfood.co.nz/*

10. *www.scionresearch.com/*

11. *landcareresearch.co.nz/*

12. *www.niwa.co.nz/*

13. *www.lincoln.ac.nz/*

14. *www.massey.ac.nz/*

15. *www.agito.ac.nz*

16. *www.nrcgd.org.nz/*

17. *bioprotection.org.nz/*

18. *riddet.massey.ac.nz/*

19. OECD (2010), *Main Science and Technology Indicators*, OECD Science, Technology and R&D Statistics (database).
20. Food and Beverage Taskforce (August 2006), *ibid.*
21. Ministry of Agriculture and Forestry (2007), Future Focus – Signposts to success for New Zealand's primary industries.
22. Ministry for the Environment (2007), State of the Environment.
23. For a private sector perspective on New Zealand's AKS refer to the presentation given at the OECD Agricultural Knowledge System Conference by Phil O'Reilly, Chief Executive of Business New Zealand *www.oecd.org/dataoecd/16/57/48166197.pdf*
24. Around NZD 170 million per annum.
25. *www.nzagrc.org.nz/*
26. *www.morst.govt.nz/current-work/CRI-Taskforce/Final-Report/*
27. *www.maf.govt.nz/agriculture/funding-programmes/primary-growth-partnership*
28. *www.globalresearchalliance.org/*

10. Innovative institutional approaches for Agricultural Knowledge System management in India

V. Venkatasubramanian[1] and P. Mahalakshmi[2]

In India, a multipronged institutional arrangements is involved in the management of Agricultural Knowledge Systems (AKS). At the national level, the Indian Council of Agricultural Research (ICAR) has established a Directorate of Knowledge Management in Agriculture (DKMA) with a focus on inclusive knowledge management approach. Agropedia and Open Agri are the other recent national level initiatives for strengthening AKS in the country.

A single arrangement for the delivery of relevant technology and technology products is being implemented through Agricultural Technology Information Centres (ATICs). At the grass-root levels, Krishi Vigyan Kendras (Farm Science Centres) and Agricultural Technology Management Agencies (ATMA) have the responsibility of knowledge resource management. There are 200 such centres within a network which includes eight Zonal Project Directorates and that is co-ordinated through a central hub located in New Delhi.

A vast network of Rural Knowledge Centres was established by the South Asian University (SAU), governments and Non-Governmental Organisations (NGOs) also play an important role in AKS management to reach millions of farm families living in diverse agro-climatic zones under wide geographic dispersion.

Knowledge plays an important role in increasing agricultural production and productivity by improving farmers' ability to use human, natural and technical resources in a judicial way and to make good decisions about farming. Geographic dispersion and the autonomous nature of the individual farmer make it difficult to access, aggregate and analyse available knowledge in such a way as to draw benefit from the information gathered. In a vast country like India, with its varied agro climatic zones and where farming is the source of livelihood for more than 60% of the population, availability and accessibility of relevant agricultural knowledge, technology and innovation play an important role for the technology generation, and the application and transfer system. There is vast scope for managing agricultural knowledge through public, private and non-government organisations; in India, a multi-pronged institutional arrangement is involved in the Agricultural Knowledge System (AKS) management.

The National Agricultural Research System (NARS) is comprised of a vast network of research institutes, bureaus, and state and central agricultural universities. At the national level, the Indian Council of Agricultural Research (ICAR) has established a Directorate of Knowledge Management (DKMA) with a mandate to ensure Agricultural Knowledge access for all. Population growth, increasing demand from changing consumption patterns, dwindling land and water resources for agriculture, higher energy costs, and the huge uncertainties regarding the effects of climate change present scientists and policy makers with additional challenges.

Addressing these challenges successfully depends on the technological and knowledge empowerment of the socially and economically under privileged sections of society. Historically, technology has been an important factor in the rich-poor divide. If technology has enlarged social and gender divides in the past, the challenge today is to enlist technology as an important instrument for achieving social and gender equity. If agricultural technologies and innovations are to serve this purpose, access must be based on the principle of social and gender inclusion.

Food security provided by home grown food is not only important for strengthening rural livelihood security, but essential for both internal security and external sovereignty. Revolutions in agriculture were usually the fruitful outcome of public research supported by government and ICAR through its chain of research institutes. Innovative approaches have strengthened the Indian Agriculture system with inclusive innovations for sustained growth. The sustainability of Indian agriculture needs to be measured in ecological, economic and equity terms and ICAR plays an important role to help the country to achieve self-sufficiency in food production and to make India a major player in the international food production system. This section discusses the innovative institutional arrangements operational in India with respect to AKS management.

National Knowledge Commission

The National Knowledge Commission (NKC) is a high-level advisory body to the Prime Minister of India, with the objective of transforming India into a knowledge society. In its endeavour to transform the knowledge landscape of the country, the National Knowledge Commission (*www.knowledgecommission.gov.in*) has submitted approximately 300 recommendations on 27 focus areas during its three and a half year term. The NKC was constituted as an advisory body to the Prime Minister to help to restructure knowledge-related institutions and infrastructure to meet the challenges of the 21st century, with a particular focus on meeting the aspirations of the 550 million young in an increasingly global knowledge society. NKC has recommended concrete steps to modernise and stimulate agricultural research institutions, co-ordinate research, and to make research support more flexible.

NKC observed that agriculture provides the principal means of livelihood for over 60% of India's population. Despite a steady decline in its share of the GDP, it remains the largest economic sector in the country. Low and volatile growth rates and the recent escalation of agrarian crisis in several parts of the Indian countryside are a threat not only to national food security, but to the economic well-being of the nation as a whole. NKC believes that appropriate application of knowledge in agriculture is essential to boost the agrarian economy and give the Indian farmer a competitive edge in the global market. However, despite the diverse mix of actors engaged in knowledge generation and application in agriculture, its realisation and utilisation at the ground level remains poor. The scope of research and extension must be expanded beyond technology transfer to encompass a wide range of services relating to knowledge creation, exchange, access and use.

NKC has, therefore, placed emphasis on improving the organisation of agricultural research, directing more research to neglected areas, providing more effective incentives for researchers and reforming the curricula in agricultural universities. To improve the scope and efficiency of extension, NKC has stressed that knowledge applications in agriculture be community-driven and farmer-led, and has worked towards providing an integrated range of services.

NKC has recommended restructuring the Agricultural Technology Management Agency (ATMA) to make it more decentralised, participatory and locally responsive, as well as enhancing the role of private players in agricultural technology application and delivery system.

The following are the terms of reference and objectives of the NKC:

- Build excellence in the educational system to meet the knowledge challenges of the 21st century and increase India's competitive advantage in fields of knowledge.
- Promote the development of knowledge in Science and Technology (S&T) laboratories.
- Improve the management of institutions engaged in intellectual property rights.
- Promote knowledge applications in agriculture and industry.
- Promote the use of knowledge capabilities in making government an effective, transparent and accountable service provider to the citizen and promote widespread sharing of knowledge to maximise public benefit.

Objectives

The overarching aim of the NKC is to enable the development of a vibrant knowledge-based society. This entails a radical improvement in existing systems of knowledge and creating avenues for generating new forms of knowledge.

Greater participation and more equitable access to knowledge across all sections of society are of vital importance to achieve these goals.

In view of the above, the NKC seeks to develop the appropriate institutional frameworks to:

- Strengthen the education system, promote domestic research and innovation, and facilitate knowledge application in sectors like health, agriculture**,** and industry.
- Leverage information and communication technologies to enhance governance and improve connectivity.
- Devise mechanisms for exchange and interaction between knowledge systems in the global arena.

National Agricultural Research System (NARS)

National Agricultural Research System (NARS) in India is a vast network of research institutes (49), project Directorates (25), National Research Centres (17), Bureaus (6), All India Co-ordinated Research and Network projects (78), Agricultural Technology Information Centres (44), 594 Krishi Vigyan Kendras (Farm Science Centres), etc., under the Indian Council of Agricultural Research (ICAR). There are currently about 55 State Agricultural universities and one Central Agricultural University currently in the country. NARS is one of the largest in the world with respect to human resource engagement and infrastructure, and ICAR is the apex body of the National Agricultural Research System. About 29 780 scientific workers engaged under NARS carry out research, teaching, and technology application, and frontline extension activities. Administratively, ICAR is an autonomous organisation under the Department of Agriculture of the Government of India and is involved in co-ordinating, guiding, and managing research, education, and extension in agriculture, including horticulture, fisheries, and animal sciences.

The research programmes under the umbrella of the ICAR are designed to ensure food, nutritional and livelihood security for all. In the past, it played an enabling role in ushering green revolution and subsequently enabled the country to increase since 1950/51 the production of food grains four fold, horticultural crops six-fold, fish nine-fold (marine five-fold and inland 17 fold), milk six-fold, eggs 27-fold. Its impact on the national food and nutritional security of India is clear. ICAR has also played a major role in promoting excellence in higher agricultural education. It is engaged in cutting-edge technology development in several agriculture and allied sectors. The Agriculture knowledge management frame work in India is given in Annex 10A.

AKS management: An overview

At the national level

The DKMA, Indian Agriculture Statistical Research Institute and Intellectual Property Right and Technology Management unit are important institutional institutions at the national level to deal with the agricultural knowledge management.

As a commitment to deliver cost-effective and production-oriented technologies for the welfare of farming community, ICAR has adopted the ICT-based information dissemination system. There are considerable resources of knowledge and information in the ICAR system that can be harnessed for realising the full potential of technological interventions developed to date. Several information and communication technologies

(ICT)-driven information delivery mechanisms have been developed for quick, effectual and cost-effective delivery of messages.

The e-connectivity of ICAR institutes has been strengthened and a state-of-art data centre has been established to cater to ICT services and provide connectivity to various stakeholders. E-linkage has been provided to 192 Krishi Vigyan Kendras (Farm Research Centres) in order to establish an interactive interface between farmers and scientists. Research journals are available in open-access mode for the benefit of students, researchers, farmers, and various stakeholders belonging to national and global communities. The ICAR research journals are made available on the internet with a provision of online submission of manuscript, review and downloading of articles. Web-based knowledge dissemination, weather-based agro-advisory and news updates are some of the important features of ICAR's user-friendly website. Use of database, expert system, decision support system and web-based dissemination of knowledge, inter and intranet services, i-telephony and video conferencing are some of the major initiatives by ICAR for knowledge sharing and AKS management in the country.

Information technology-based interventions for sharing of knowledge. The ICAR website was developed using an open source content management system called DRUPAL and is a unique platform for the sharing and dissemination of information to a wide range of users and stakeholders in the agricultural sector. The News section is updated daily with inputs from the National Agricultural Research System centres across the country. Interesting success stories of Indian farmers are presented weekly on the homepage to inspire and motivate the farming community. The Weather-Based Agro-Advisory, developed by experts, is also updated weekly for the direct use of farmers. The website provides links to international agricultural organisations and to ICAR library and other libraries of interest. A useful link connects visitors to the global agricultural news released from various international agencies. More than two lakh visits are recorded per month from 157 countries.

ICAR research journals (*The Indian Journal of Agricultural Sciences* and *The Indian Journal of Animal Sciences*) are available in open-access mode and have been downloaded in 157 countries from a knowledge portal developed and hosted by the DKMA of the Council. The online research journals provide facilities such as registration for reviewer, author, reader and manuscript submissions for publishing. The status of articles submitted may also be viewed (*epubs.icar.org.in*) along with a host of other useful publications including newsletters. The Hindi (national language) version of the website is also available with regular updates. Around one lakh farmers/visitors are making use of updated information on website every month. The website has proven its potential for sharing and delivering knowledge at national and global level.

National Agricultural Innovation Project (NAIP) Initiatives. Under NAIP ten crop knowledge models have been developed along with portal-based decision support services. In addition, there is an advanced Questions and Answers (Q&A) forum designed for content management. There were about 2.2 million SMS texts transacted with over 26 000 farmers. It was adjudged as best ICT-enabled agri-project in 2010. A rice knowledge management portal and re-usable learning objects (RLOs) in open distance learning (ODL) systems were developed under this project. Nine communication centres were set up to increase public awareness of ICAR.

At the zonal level

ICAR has established the Zonal Technology Management and Business Planning units to ensure a strong Intellectual Property Management system. The Zonal Technology Management and Business Planning units (ZTM-BPD) are one stop shop for entrepreneurs who can receive pro-active, value added support in terms of technical consultancy, access to critical tools such as entrepreneur ready technologies, vast infrastructure and other resources that may otherwise be unaffordable, inaccessible or un known. The units will provide links to industries; business support services to enhance and develop business; upgrade skills and techniques; technological advice and assistance with intellectual property protection; initial test marketing and also provide access to potential investors and strategic partners.

The services of the unit can be availed upon by start-up and established companies looking for product diversification or to test new technologies or innovations. The facilities can be used to test processes and new products. The ZTM-BPD units will identify promising technologies through market potential analysis and give feedback to the institutes for appropriate scaling–up, change of product-mix, and possible refinement of selected technologies based on entrepreneur and end-user demands. Business project reports are prepared with details of the technology, infrastructure, marketability, and financial aspects in close association with the technology creators.

Knowledge-Innovation Repository in Agriculture for North-East (KIRAN) is an umbrella arrangement to harness the power of scientific knowledge and technology innovations to strengthen the food production system in the north-eastern region through partnership and convergence among stake holders. KIRAN aims to create a knowledge and technology repository for this region. It acts as an information, knowledge and technology gateway and also provides a platform for interface among stakeholders in agricultural development. KIRAN also helps to foster linkage among partners and collaboration with State and regional organisations; and acts as a catalyst to strengthen the existing institutional capacity through convergence and networking. It provides technology and development consultancy along with the details of technology dynamics and kinetics. KIRAN helps to programme a sustainable agriculture development in the region and provide support for strategy formulation for research and extension.

At the state level

At the state level, ICAR has established Agricultural Technology information Centres (ATICs) to provide direct access to the institutional resources to the farmers and stake holders. ATIC is a single window support system linking various units of a research institution with intermediary users and end users (farmers) in decision making and problem solving exercise. It has an in-built mechanism for providing feedback to scientists and research managers.

There are 55 State Agricultural Universities in India imparting agricultural education and carrying out research and extension activities to meet the local needs of the state. The agricultural universities through their zonal agricultural research stations, and district level university research, training and extension centres cater to location-specific needs of the farmers and other stake holders like agri-entrepreneurs. Wider knowledge dissemination is carried out through their knowledge portals, community radio stations, and mass media channels. For example, Tamil Nadu Agricultural University (TNAU) has taken up ICT for its transfer of technology and it is attempting to develop a new mode of link between the extension officials and the farmers (Vadivelu *et al.*, 2010). The knowledge management models functioning at TNAU is presented below as a case study.

e-Agriculture service for accelerating agricultural development and living standards of farmers through TNAU Agritech portal

Since integrated information on agriculture knowledge is not available to farmers under the National Agricultural Development Project (NADP), TNAU designed an integrated knowledge portal involving all stakeholders in the farming profession. Apart from the standard search engine feature, web portals offer other services, such as e-mail, news, stock prices, information and entertainment.

The TNAU Agritech portal is developed by scouting information from various trusted sources such as State Agricultural Universities, State Departments of Agriculture, Horticulture, Engineering, Animal Husbandry and other concerned departments. Information about private input dealers, marketing, export and import, Krishi Vigyan Kendras, indigenous technologies, government schemes, food science and technologies, self-help groups, NGOs, entrepreneurs, agro industries, etc., were collected and validated with the help of specialists. The content is converted into knowledge pages; the special feature of this portal is that it is bilingual, designed in English and Tamil.

The core areas in the portal are agriculture, horticulture, agricultural engineering, sericulture, forestry, fisheries, animal husbandry and marketing. The other issues covered are crop production, protection, organic farming, sustainable and indigenous farming, soil and water management, government schemes, banking, insurance, self-help group and NGOs, post-harvest technologies, daily events (market information, news paper clippings, radio and TV programmes, water level in dams, and streamed audio from TNAU community radio), Patents, Environment and Pollution, Inputs Source, etc.

The major areas such as weather, soil, water, nutrition, enterprises, and biotechnology and bio fuels are also covered. Some of the specialised information on technologies such as System of Rice Intensification (SRI), Precision Farming Systems, Good Agricultural Practices, Good Laboratory Practices and Good Manufacturing Practices, availability of input sources, minimal support prices, Agricultural Action Plan for the district and linkages with different service providing agencies were also included in the content.

The unique feature of PORTAL is the "*Message Board and Ask your Expert feature"* with a multimedia-based dynamic network that includes audio and video streaming. The message board allows users to add any message they would like to share and the user may also forward suggestions to improve portal services and corrective measures as a feed back. In the case of Ask Your Expert, it provides links with experts in the field of agriculture and allied sectors to ensure corrective measures and implementable action plans for the problems posed by the farmer with in a stipulated time of 24 hours. Both the Message Board and Ask Your Expert are linked through live video conferencing from a hub centre or from the clientele or users node.

The portal information also focuses on "more visuals/images with dynamics, and less on text of a more routine kind of nature." The science behind the facts is emphasised as is distinctive and holistic information to educate field extension officials, farmers and stakeholders.

Dynamic market information support for agri-horti produce through www.tnau.ac.in /www. indg.in portal: Linking farmers with markets

India produces 150 million tonnes of fruits and vegetables. It is estimated that about 50% of its agricultural produce is available as marketable surplus. More than 72% of vegetables and fruits are wasted in the absence of proper retailing. In order to reduce this wastage and to develop a direct link between the farmers and the markets, the State Agricultural Management and Extension Training Institute (SAMETI) and Directorate of Extension Education, Tamil Nadu Agricultural University in collaboration with C-DAC (Centre for Development of Advanced Computing), Hyderabad is operating this project.

Market coverage and information reach. In Dynamic Market Information (DMI), the market rates of perishable commodities (both whole sale and retail are collected and uploaded in the website (*www.tnau.ac.in* and *www.indg.in*) on a daily basis. Presently, 13 markets are covered. Project analysts are placed in different marketing zones, and they collect market data which is uploaded on to the portal. As of today, 152 commodities have been added to the DMI list. The rates are ready to be viewed by 13.00 hours daily. The information is given in Tamil and English.

The additional features of the website include market profiles with photographs, traders profile, and addresses of traders, traders business in the market, farmers association details, best practices adopted by other successful farmers, Minimum Support Price of major commodities, regulated Markets in Tamil Nadu and Krishi Vigyan Kendras(Farm Science Centres) in Tamil Nadu. The site also provides space to access previous data for comparison. As a value added service the price details of selected commodities are also sent to the farmers through mobile.

The holistic market-related information is on trends, quality preferences, daily market prices, demand and supply analysis for different produces, composition of suppliers, packaging and transport mode for different produces are analysed and informed to the producers, buyers and consumers through online portal (*www.tnau.ac.in* and *www.indg.in*).

Periodical publishing of market support information with regional specific inferences for different produces benefits different stakeholders. Farmers are often exploited by middlemen and unable to receive the actual benefits of their end produces. Thus this initiative facilitates farmers and field extension officials to understand the daily prices of important markets located in south India. Ultimately, this should help growers to obtain real market prices for bulk commodities. If the farmers are not able to mobilise their produce individually, they can organise themselves into groups and take their commodities to the market that gives them a better economic return.

m-Velanmai (m-agriculture) Agro-Advisory Services for Improving the Livelihood status of the Farming Community of Tamil Nadu

m-velanmai is an innovative mobile based advisory service initiated on public-private partnership by Tamil Nadu Agricultural University. Farmers can receive relevant information and advice on various topics in farming on their mobile phones. It also enables farmers to send by phone specific queries about their land and crops, and to receive personalised replies from agricultural experts.

e-Velanmai (e-agriculture)

This is an ICT-based demand driven participatory extension system to provide timely agro advisory services by TNAU scientists to the registered farmers using ICT tools (Internet, Computer, Digital Camera, Mobile phone etc.) on a need and/or regular basis. It includes farmers enrolled for the service, expert team of scientists from TNAU, field co-ordinators to develop the capacity of farmers, ICT tools to link farmers and experts, information about the agricultural problems (data) collected from farmers for advice. The other components include the technical message delivered by the experts to solve agricultural problems faced by the farmers and follow-up actions on the advices adopted by the farmers. Farmers pay a membership fee based on the farm size owned by them to avail the extension services under e-Velanmai as a mark of their participation in the system of technology transfer. Scientists attend the farmers queries based on their call (demand) or need and hence it is demand driven for technical advice or scientific farming.

In a similar way, different state agricultural universities in India have their own knowledge management models according to local needs and resources.

At the district level

As per the policy of the government of India, each rural district in the country will be provided with a Krishi Vigyan Kendra; 605 Krishi Vigyan Kendras (KVKs) have been established so far against a target set 667 KVKs by the end of 12th plan (i.e. March 2012). KVK is an innovative grassroots level institution established to undertake technology application through technology assessment, refinement and demonstration of proven technologies under different micro farming situations in a district. It is a farm-based model with a focus on farming systems and vocational training. It serves as a knowledge and resource centre in the district.

It is a farm-based model with a focus on farming system and vocational training. It serves as a knowledge and resource centre in the district. As an initial step, 194 KVKs and eight Zonal Project Directorates were provided with e connectivity facilities and the staff was provided with adequate knowledge management training for the development and management of the contents.

KVK e-Linkage Project. ICAR, as part of its mega ICT driven knowledge management and technology application strategy, has envisioned for providing e-linkage to its networks of KVKs and Zonal Project Directorates (ZPDs) during the eleventh Five-Year Plan (2007-12). The linkage facilities helped to achieve an enabling environment for KVKs to develop close and fruitful partnerships and collaborations between specialists of KVKs and research scientists, extension personnel and farmers for sharing and improving agricultural knowledge and technologies, best practices and innovation amongst themselves and other stake holders. Initially, this facility was to be created in 192 KVKs and all eight ZPDs. Over time, this linkage will be expanded to all KVKs in India. The major objectives and rationale behind this initiative is to improve KVKs connectivity with:

- technology-generating institutes, such as SAU, ICAR institutes and other related national and global centres of excellence;
- farmers, grassroots level organisations such as co-operatives, self-help groups and commodity interest groups; and

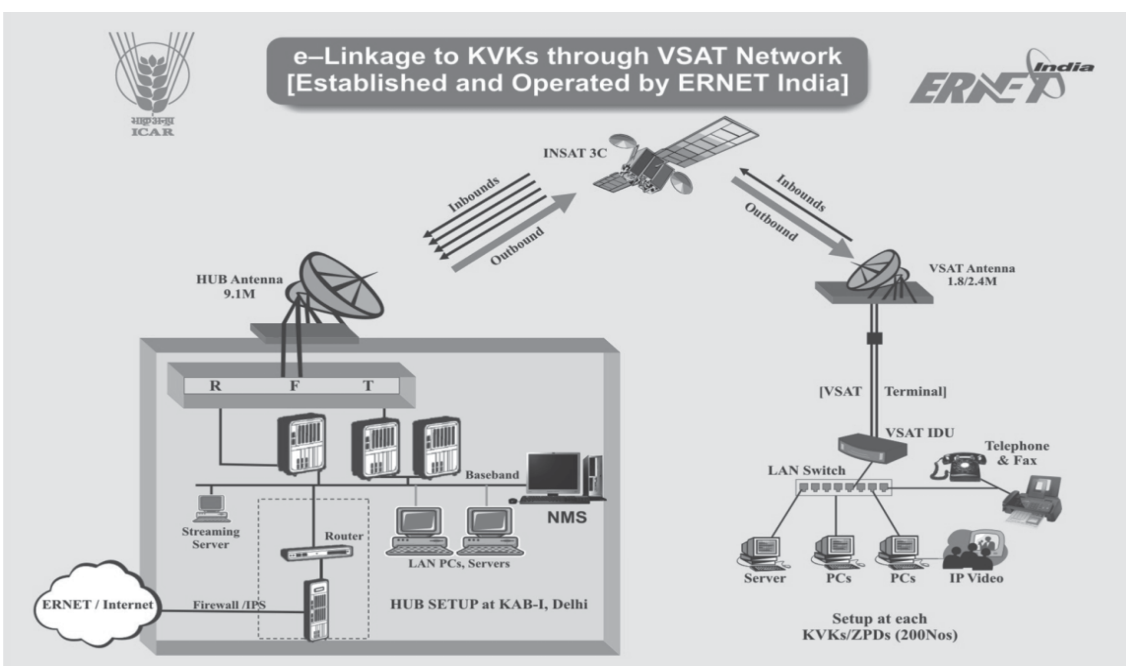
- technology delivery systems and public and private extension service providers at the district level.

Under this mega initiative a state of art net-work operation centre/hub was established at ICAR HQs New Delhi is connected with satellite earth station antenna with a lease of 18 MHz transponder space on INSAT-3C satellite (Figure 10.1). About 1 400 officials of KVKs and ZPDs were trained in the knowledge management. It helped the KVKs in content development and access to global agriculture knowledge.

KVKs developed data base on agriculture, weather advisory services, technology inventories and computer generated agro-advisory alerts to farmers in their mobile. For example: aAqua – A Bilingual Portal, a virtual university model was developed jointly by KVK, Pune and Indian Institute of Technology (IIT), Mumbai. The KVK is responsible for content development while IIT is associated in software development and maintenance of the site. Broad based digital content on agro technologies for various crops grown in the state was made. Expert and decision support systems, and query based redressal in local language and keyword browsing are in built facilities in the portal.

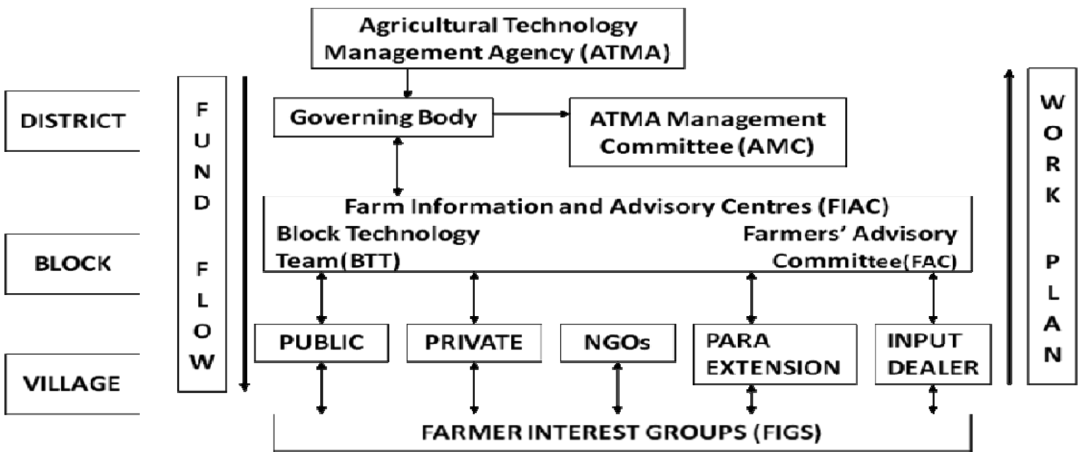
The KVKs are also providing mobile SMS services called agro-advisory services to the farmers. Similarly, KVK Ahmed Nagar, Maharastra successfully demonstrated the use of ICT in AKS management and disseminating improved agricultural technologies. *Vasundhara, software* for soil and water test based nutrient recommendations developed by KVK-Ahmed Nagar pioneered the pest and disease forewarning through its SMS based alert system to the registered users. A number of technology CDs has been developed on crops, livestock and other agri-enterprises for use by the farmers.

Figure 10.1. AKS in Krishi Vigyan Kendras (KVKs) through e- connectivity



Agricultural Technology Management Agency (ATMA) is a district-level organisation involved in AKS management. ATMA is composed of stakeholders in agriculture for sustainable agricultural development in the district, and provides a focal point for integrated research and extension activities endowed with the responsibility of all technology dissemination activities at the district level. The Government of India launched Kissan call centres to leverage the extensive telecom network in the country to deliver extension services to farmers. The purpose of these call centres is to respond instantly to queries and issues raised by farmers in the local language. The organisational structure of ATMA is given in Figure 10.2.

Figure 10.2. Organisational structure of the Agricultural Technology Management Agency



AKS management at the grass roots level

India has rich experience in implementing large number of ICT-based knowledge management projects that attempt to bridge the digital divide. The goal is to develop an evolving knowledge and innovation led society for an inclusive rural development. ICT based knowledge management projects provided a range of services in the villages and they proved that technology and innovations could make a difference in the quality of rural life.

Farmers Dairy Co-operatives play an important role in AKS at the grass root level/village level. The village milk collection centres are provided with automatic milk collection facilities. These centres are provided with Dairy Information and Services Kiosks (DISK) which provides database, internet connectivity to dairy co-operative societies. Farmer are provided with individual ID code/ smart card which helps them to access the DISK database which contains details about their livestock, such as breed and history of diseases, details on artificial insemination performed in their cattle and pregnancy. Further, data on milk production by individual farmers, forecasting milk collection, and feed back to farmers is provided with respect to the technology and package of practices for their dairy cattle management.

Research studies on the assessment of ICT on AKS revealed that farmers not only benefitted by easy access to relevant knowledge, but were able to save planting costs and get better market prices for their produce. By using soya e-choupal of ITC, farmers could save about 68% of their transaction costs due to the information on when and where to sell their soya bean. The ICT based agricultural knowledge delivery system at the grass roots level also helped the farmers and buyers of their produce. A brief about important grass roots level knowledge management projects currently under operation in India is given in Table 10.1.

Table 10.1. Brief on important grass root level knowledge management projects

	Project name	Promoting agencies	Number of kiosks	Information and services provided	Technology used at	
					Central network	Rural kiosk
1.	Akshaya	Local bodies of Malapuram and Thrissur districts, Kerala state	565	e-Governance, net based communications, e-krishi, agri-marketing, general web applications	Web based; software for local content & transaction	Dial-up and wireless WiFi access
2.	Gyandoot	District Admin. Dhar, MP	40	Agriculture, commodity-auction, education, training, banking, government related and other services	Web based; software for land record and transaction; Servers placed at District office with CorDect WLL Tech	Dial-up and some kiosks connected by CorDECT WLL; solar powered batteries
3.	Bhommi	Government of Karnataka	800	E-Governance, 20 million land record of 6.7 million farmers in Karnataka, weather, package of practices	Web based; Public key infrastructure enabled access	Dial-up; generator for backup; Simputers in districts for field use
4.	WWV	Warna Wired Village	70	Agriculture, news, market prices, sugar coop software, web browsing etc	Web based; Wireless WLL tower, software for sugar co-operative functions	Dial-up &CorDECT WLL
5.	Choupal	ITC-Private	6500	Agriculture, agri-inputs, government schemes, agri-news, market prices, weather and general FAQS. Business tie up with more than 10 input suppliers	Web based; software for transaction; Central content development	Dial-up VSAT and wireless connectivity; solar power and back up batteries.
6.	Drishtee	Drishtee Dot Corn Ltd. 90	90	Rural marketing, Agri-marketing, training, general web applications. About 17 private companies for specific business.	Web-based; Drishtee portal with software for transactions; Central content development in local languages;	Dial-up with BSNL and airtel
7.	n-logue	n-logue communications	3500	Agriculture, education, computer training, jobs, health, government schemes and procedures, news and market prices.	Web-based; weather monitoring system; software for email, video conferencing and transactions	CorDECT WLL connectivity from access centre with 64 kbps connectivity to kiosks in 25 km range.
8.	Tarahaat	Development alternatives	10	E-governance, agriculture, market prices, training and IP services	Client-server architecture with customised software; Services from IGNOU, AIIMS, Agriwatch	Dial-up and VSAT
9.	IVR	MSSRF	80	Knowledge empowerment, internet access, e-mail, training, citizen centric services	Client-server architecture with local nodes; Central VSAT as hub; Wireless 802d, 11b & 2-way VHF radio	Radio link to hub; PA system for broadcasting, solar panels for power
10.	Ashwini	Byrraju Foundation	32	v-agri and v-aqua for farmers, agri-marketing, tele-medicine, education, computer training and host of web services	Web based; WiFI tower on 802.11 b/g technology; tele-ECG machines; Teleservice through IBM Voicegen; Gram IT a rural BPO; trade link up to safal exchange	Wireless access; tele-conferencing;

Source: Jafri *et al.* (2002); Mahalakshmi *et al.* (2009); Mahalakshmi and Krishnan (2009); Mahalakshmi (2010).

Features of successful ICT-based AKS management projects

- The *Bhoomi* project (digitalised land records) in Karnataka serves as an excellent example of governance in its ideal form; it is transparent and accountable.
- *e-Shringula*, a one-stop, web-enabled portal for information and services relating to the government-citizen interface creating an "e-Shringula" ("electronic chain") of information and e-governance.
- *Drishtee* provides technical expertise and management consultancy to build the IT infrastructure and the human capacity to link service providers (government department and private firms) with rural citizens.
- *Info-Village* of Puducherry by MS Swaminathan Research Foundation (MSSRF) developed community ownership and collective action with a "pro-poor", "pro-nature" and "pro-women" approach to development (MSSRF, 2003).
- The *Gyan Ganga* project, of Gujarat state, provided comprehensive education, support and services including agriculture and animal husbandry.
- *e-Choupal* is a huge private sector investment by ITC India Ltd., which revolutionised agricultural commodity marketing in India by procuring soya, coffee, and prawns at the doorsteps of the villagers and providing real time data on crop prices, products and services and facilitate supply of high quality farm inputs in partnership mode (Venkatasubramanian *et al.,* 2009, 2011; Mahalakshmi and Krishnan, 2011).
- *Info knowledge Village* at Puducherry, *Warna Wired Village* project in Maharashtra, *Krishi Vigyan Kendras* of ICAR provide quality online content management, including packages of practices, locally relevant technologies and recommendations, government schemes, FAQ, etc., in local languages.
- Women empowerment through SEWA project in Gujarat, mobile classrooms through IT buses in rural Pune, Project *Shiksha* for computer literacy, Action Aid at Bolangir, Orissa, *Akshaya* at Malappuram, Kerala, and EDUSAT address the issue of capacity building and empowerment of farmers, farm women, rural artisans and also large number of extension personnel.
- *SATCOM*, Madhya Pradesh, Teja TV in Andhra Pradesh and E-TV telecasted programmes on location specific agricultural technologies integrated and Interactive live question answer sessions in local languages resulting in high percentage of farmer-viewers.

Scalability of ICT-based knowledge management projects

The importance of ICT projects in India depends on factors such as:

- the value addition in the services for farmers;
- appropriate management model;
- government role through supportive policy environment;

- institutionalizing public-private-community partnership models at the grass root level;
- appropriate and affordable technologies that can be adopted by the end-users; and
- increase in the functional literacy level of farmers.

The most important role of AKS management is to foster knowledge for a sustainable and secure livelihood system in rural areas since it enables to reach people that are usually excluded from the system and to provide information, knowledge and training that had remained unavailable. The issues of importance are: access, content, capacity building, and establishment of Rural Knowledge Centres (RKCs). Access to information and knowledge is impeded for much of our population due to poverty, illiteracy and isolation. Linkages among professional partners are essential to reach those who cannot be reached by ICT, and especially those under the greatest risk of being left out of knowledge societies (rural population, urban poor, illiterate and marginalised).

Promoting the free exchange of knowledge has never been more relevant, and therefore promoting diversity of content in the media and information networks is needed. ICTs increase access to information and knowledge from a rich variety of sources. As information streams become more globalised, AKS management need to keep in mind cultural and linguistic diversity and genuine pluralism through local content production. Therefore, it is necessary to ensure a strong public domain of information that is readily accessible to all.

Alliances are crucial to increase the scope and scale of knowledge centres. Research and extension linkages help to improve the synergy between scientists and farmers. Partnership improves the quality and relevance of information service as public private partnership (PPP) helps to scale up the ICTs/ knowledge centres throughout the country. For example, the *AKSHAYA* project has brought together a state player (Kerala government) and a private sector player (TULIP IT services) to create an internet network for the state which can be used as a platform to launch a number of infrastructure initiatives. Similarly, NABARD e-governance services in Himachal Pradesh and SBI – rural information KIOSKs in Tamil Nadu are some successful examples of Partnership approach in knowledge management.

Centre for development of advanced computing (CDAC) in AKS Management. CDAC is a Government of India organisation established to help AKS management in the country with customised knowledge management products. For example, development of visual solutions by CDAC helps meet the needs and requirements of digitally impoverished communities which are to be addressed with suitable application of ICT. The selected ICT solutions are investigated for their possible adaptation, customisation and/or localisation as the case may be to address such requirements of the sectors covered under agriculture, health care and education. The important role played by the CDAC in AKS management is:

- to establish and support mechanisms for information dissemination on ICT-based developments;
- to design and deliver specialised training programmes in the use of ICT solutions relevant to the farming system;

- to investigate the selected ICT solutions with a view to possible adaptation, customisation and/or localisation as the case may be for addressing such requirements;
- to pilot test the solutions developed in selected areas and critically analyse the effectiveness and impact of these solutions;
- to establish and support mechanisms for information dissemination on ICT-based developments;
- to design and deliver specialised training programmes on the use of ICT solutions developed, its relevance to the farming system; and
- to develop open source office productivity tools that suit across platforms to enable the creation of documents and other information in Indian languages so that relevant content is available in local languages.

Some of the knowledge management products for AKS by CDAC are Bharateeyaoo, Matrubhasa, DAAL, ECKO, e-kamps, Vyapar and multilingual Virtual class room.

Agriculture knowledge products from ICAR. ICAR through its sustained efforts involved in the creation of data bases, information and expert systems for the benefits of various stake holders. The summary of the same is given here under.

***Information system*.** There are more than 60 information system products developed and some of the most important products among them are: Plant Variety Information System, Plant Variety Germplasm Registration System, NORV-Notified and Released Varieties of India, INDUS-Indian Information System as per DUS guidelines, National Information System for Pest Management (Bt–Cotton), Phenotypic Characterization of Animal Genetic Resources of India (AGRI-IS), Water bodies information systems for West Bengal, E-Pest: Awareness-cum-surveillance programme for the management of major pests, Digital Herbarium of Medicinal and Aromatic plants, Networking of herbal gardens in India, Fodder Resources and Waste land of Bay Islands, NISM-National Information Sharing Mechanism for the PGR-GPVR (Germplasm and Plant Varieties Registration), National Information System on Long Term Fertilizer Experiments, Project Information and Management System Network for NATP, Personnel Information Management System Network (PERMIS NET) and National Information System on Agricultural Education Network in India (NISAGE NET).

***Decision support systems/Expert systems*.** There are more than 20 decision support systems available**.** Most important among them are: wheat crop management, marine fisheries management, advisory system for potato crop scheduling, nutrient management in tuber crops, GIS-based decision support system for aquaculture in cold water region, rice-crop doctor, expert system for sericulture, expert system for ground nut crop, KMART-decision support system for farmers, researchers, policy makers and development officials, poultry expert system on poultry farming, etc.

E-advisory/E-learning resources. There are more than 20 e-advisory and e-learning resources available with ICAR. The most important among them are: Geo spatial Village Knowledge Management System (GVKMS -Web Based), Knowledge Management for Agricultural Research and Technologies - KMART (web-based) and e-GRANTH for strengthening Digital Library and Information Management under NARS. Under Consortium for e-Resources in Agriculture (CeRA), libraries in NARS and contents from 2 917 journals were covered. In addition, ICAR created a data warehouse with more than

59 databases and a web-based integrated National Agricultural Resources Information System.

Collection, documentation and validation of indigenous technical knowledge (ITK) and farm innovations. A major initiative was undertaken by ICAR to document and validate the Indigenous Knowledge Systems practiced by the farmers in the country. Through this country wide initiative, a total of 4 880 Indigenous Technical Knowledge (ITK) in 23 thematic areas were collected, validated and published in seven volumes. Further, seven ITK e-Books and a resource book for training on ITK was also published. Potential innovative ideas, methods and inventions made by the farmers were also documented and published for cross-country reference by various stake holders.

AKS national projects and products. Some of the most important AKS projects under NARS and their output are given in Table 10.2.

Table 10.2. Details of important national projects on AKS and their output

Project	Major focus
FERTNET	Network for Integrating Nutrient Management
VISTARNET	Agricultural Extension Information System Network
PPIN	Plant Protection Informatics Network
APHNET	Animal Production and Health Informatics Network of 42000 Animal Primary Health Centres
FISHNET	Fisheries Informatics Network
LISNET	Land Information System Network
AFPINET	Agricultural and Food Processing Industries Informatics Network
ARINET	Agricultural and Rural Industries Information System Network
NDMNET	Natural Disaster Management Knowledge Network
Weather NET	Weather Resource System of India
AGRISNET	Network of Agricultural Offices for Extension & Agribusiness Activities
AGMARKNET	Network of Agricultural Produce Wholesale Markets (7000) & Rural Markets (32000)
ARISNET	Agricultural Research Information System Network
SeedNET	Seed Informatics Network
CoopNet	A Network of Agricultural Primary Credit Societies (PACS) and Agricultural Cooperative Marketing Societies (93000)
HORTNET	Horticultural Informatics Network

Issues and the way forward

It was planned to have a knowledge centre in every village with a target to reach all six million villages by 2007 for the 60th anniversary of Indian independence. There is still a long way to reach this target. Domestic software development and applications need to be strengthened, keeping in view linguistic plurality, content diversity, and local demand. Reaching the unreached is possible only through an integrated ICT system and the development of a consortium of content providers for each agro climatic zone.

Participatory agricultural knowledge system management is needed. The Farmer Participatory Knowledge System could replace the existing beneficiary and patronage approach to knowledge dissemination. The need to promote participatory methodology, inclusiveness and replicability of the approach is more important and should serve as the bottom line in the development of a National Action Plan for the village knowledge centre movement towards Food Security and Rural Prosperity.

The most important aspect is the availability of trained manpower at the grass root level and their dedication to provide quality content to the stake holders. Content development is an important area which is otherwise weak in terms of inclusiveness, relevance, timely availability and accessibility. Aspects such as population metrics, technology and infrastructure metrics, process metrics, knowledge metric and econometrics need to be studied and evaluated for building a sustainable knowledge management platform.

In addition, strengthening the resource base in terms of funding and manpower is a priority today keeping in view the complexity of the challenges faced by Indian agriculture. At least 15 000 additional people are required to strengthen the NARS, and an additional 35 000 to strengthen the extension and technology delivery system in India. The current level of funding is inadequate and a minimum requirement of INR 20 000 crores (IRN 200 billion) is required for the XII plan (2012-17) by the NARS system, keeping in view the higher cost of hiring quality manpower and the operational costs involved in the research and extension system.

The challenge, once again, is the establishment of consortium partners and collaborators, at both the national and international levels, to address the requirements of developing cutting edge technologies, climate change impact, and carrying out research for business. Agricultural research and extension need to focus on gene revolution and to emphasize the application of biotechnology-tissue culture for the multiplication of elite germplasm, genetically modified crops, marker assisted breeding, translational research, etc.

The use of bio-fertilisers, bio-pesticides and bio-remediation of ground water; addressing issues like sustainability, resource integration and technology integration need to be the future thrust areas.

Application of precision farming and mechanisation for optimal use of precious resources and human labour; linkage with industry, market driven and export oriented agriculture; increase application of cutting edge technologies are to be properly addressed.

Areas like minimising post-harvest losses, food processing and value addition; highlighting quality in addition to increasing the quantity of agricultural produce; protecting IPR and farmers' rights; integration of livestock, fisheries and other allied agro-enterprises with crop production and exploiting the advances in information technology for AKS management in the country need to be given due importance and preference in the coming years for achieving a sustainable agricultural production system to ensure food, nutritional and livelihood security for millions in the sub-continent.

Notes

1. Corresponding author: Assistant Director General (Agricultural Extension), ICAR, Krishi Anusandhan Bahvan-I, Pusa, New Delhi –100012. E-mail: vvsmn@yahoo.com

2. Scientist (SS), Central Institute of Brackishwater Aquaculture, (I.C.A.R), 75, Santhome High Road, Raja Annamalai Puram, Chennai – 600 028, Tamil Nadu, India

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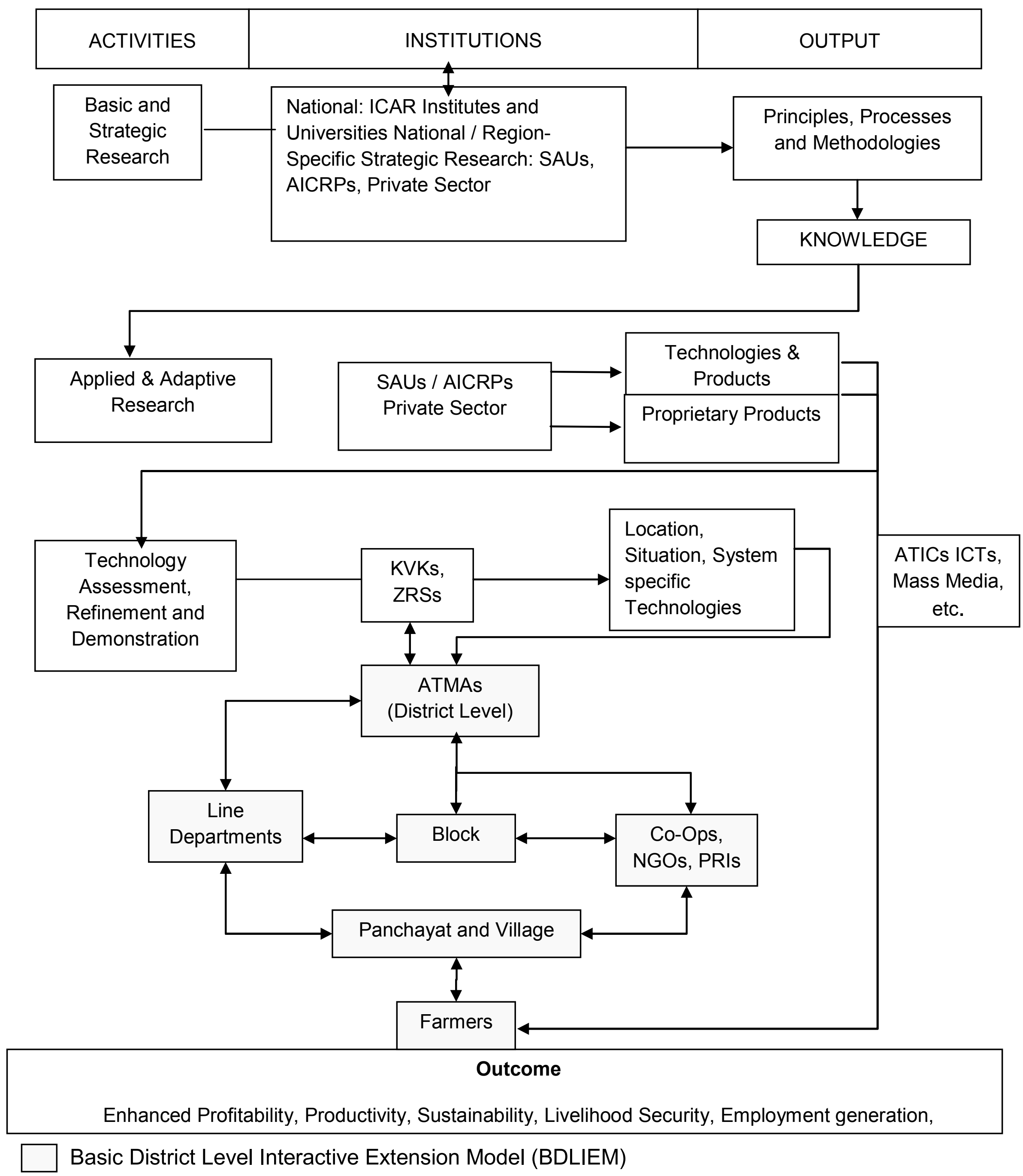
Annex 10A.

Framework for Agricultural Knowledge System management



Source: ICAR, New Delhi.

11. Raising awareness of agricultural knowledge and information system in Spain: From personalised transfer services to internet platforms

Gerardo Garcia Fernandez[1]

Agricultural and rural development is increasingly dependent on the efficient functioning of agricultural knowledge systems. More specifically, it depends on how the production, transmission and implementation of scientific knowledge and available technologies are managed. It is thus crucial to improve the interface between the production of knowledge and its adoption in food businesses related to agriculture, fisheries and rural areas. To that end, two initiatives developed in Spain, which are based on the use of new information technologies, can be identified as agricultural knowledge system (AKS) successes: The knowledge platform for rural areas and fisheries (MARM), and The RuralCat of the Generalitat of Catalunya.

The Spanish agricultural knowledge and information system and its components

The socioeconomic development of agriculture and rural areas is increasingly dependent on the efficacy of agricultural knowledge and innovation systems (AKIS). Namely, how the production, the transmission and the practical and effective application of available scientific and technical knowledge is managed.

The processes leading to agricultural and rural progress are often summarised in three main points:

- ***Basic research.*** The objective is to gather new scientific knowledge regardless of its immediate utility or application.
- ***Technical research and technological development.*** This is geared to achieving practical purposes and objectives aimed at developing new materials and products, improving production systems and processes, and developing production methods adapted to the economic, social and environmental circumstances at a given time and in a particular region.
- ***Technological innovation.*** When the innovatory process is successfully completed, this allows the agribusiness and food industries to use the confirmed knowledge available and include it in their production activities.

The following players, agents and institutions from public and private sectors are involved in this scientific and technical process:[2]

- ***Universities.*** These produce and transmit scientific knowledge, impart higher education (agronomy, biology, veterinary science, socio-agricultural sciences, etc.), conduct basic research projects across many disciplines, and contribute to the training of new investigators.
- ***Institutions and public and private research centres.*** They also carry out basic research projects (geared to a greater or lesser degree towards utilitarian purposes) but, primarily, carry out the bulk of adaptive and applied research.
- ***Experimental centres.*** On the basis of scientific advances, they carry out testing, and adapt and develop these advances for application to specific local conditions.
- ***Professional teaching centres.*** They are responsible for the professional training of farmers and workers to acquire the skills and abilities required to carry out their jobs.
- ***Technical services.*** Whether in the public or private sector, they further improve the productivity, competitiveness and sustainability of the agri-food industry, disseminate new materials, products or production techniques, and provide technical and financial advice to farmers and the industries which decide to adopt these technologies and include them in their daily production activities. Among these technical services, particular mention must be made of the agricultural extension services, which, under various names, exist in most countries to foster the modernisation of agriculture, technological innovation, and the on-going training of farmers.

Public bodies assign functional objectives to this institutional framework and establish models of political and administrative organisation which are very similar across countries. However, there are highly notable differences between some countries with respect to the resources allocated and the degree of efficiency with which the system (AKIS) functions in each case.

This efficacy should be measured in each country by three parameters:

- The new knowledge produced at the actual centres and included in the AKIS.
- Knowledge gathered from other sources and adapted to their own conditions.
- The effective use that end users (namely, farmers and industries) make of this knowledge.

It should be understood (and this has not always been the case) that agricultural innovation is not a one-way process which translates scientific matters from research to the users in a linear and mechanical manner. It should also be remembered that the model described does not correspond exactly to the institutional specialisation and co-ordination that it appears to suggest.

In fact, this "linear" innovation model often works in a distorted and poorly integrated manner. This happens when, for example, research projects are not born from actual problems affecting agribusiness and agro-industrial companies. General practice and accumulated experience indicate that projects often serve the scientific interests of investigators and their desire to publish works of impact according to the criteria of the scientific and academic community. Nor does the "linear" model achieve complete success when the research results take a long time to be produced and published, or when, once published, they are inaccessible to potential users because there are no services or institutions (public or private) within the AKIS specialised in selecting knowledge, assessing its usefulness in the specific local setting, and in disseminating and promoting its real and effective implementation. This distortion and inefficacy on the AKIS also occurs when there are no operative systems to allow good communication between investigators and technicians in direct contact with agricultural issues (advisors, trainers, experts, extensionists, etc.). Without fluid communication, results take longer to reach technicians and users, and investigators will not have the chance to know and take into account the points of view of the various parties concerned as regards the problems and needs to be studied.

These examples demonstrate that the model which aims to transfer available technology in a linear and immediate manner from the scientists and technologists who produce it to the users who need to use it has limitations which reduce its efficiency. This is the case in developing countries, partially-developed countries, and even in the less advanced areas of the most developed countries. The most common and significant conceptual limitation is the belief that the main obstacle for farmers to make use of useful innovations is their lack of technical information. It should be enough, therefore, to provide them with the information so that they can make the most suitable technical changes. This belief is not realistic since it does not take into account that the attitude of farmers towards change and innovation does not depend merely on the information and technical knowledge that they possess or can acquire. Essentially, there are other factors such as age, education, family, social and cultural circumstances, the type of business, etc., and above all, existing agricultural policies[3] which determine individual and collective attitudes towards technical changes and the evolution of the agri-food industry.

In most countries, there is a wide discrepancy within the AKIS between what is discovered, what is known, what is disseminated, and what is actually used. In addition, there is always a delay between the time knowledge becomes available and the time it is used on farms and industries. Indeed, a strength of modern, competitive agriculture is that new knowledge takes less time to be developed and put into general use than in traditional, undeveloped agriculture where the processes of innovation are very slow. There is no doubt that the "linear" model of transfer which has dominated the AKIS in the majority of countries needs to be revised to improve knowledge management, to speed up technological innovation and development, and to make these more effective, the basic objectives of which, within the current paradigms, should be sustainability and competitiveness.

In this overall revision of the AKIS, it must be taken into account that the existence of new knowledge does not guarantee their use, but that this, above all, depends on the final players (farmers and food industries) knowing, wanting and being able to develop innovative initiatives to do things in a new or different way or to improve what they are doing. A key reason for carrying out this revision is that, in addition to the scientific and technological institutions which generate and develop knowledge, AKIS reinforces services (public or private) which promote and contribute to the ongoing training of farmers, helping them to acquire and develop their innovation capacities *in situ*. In other words, these departments (whatever their name may be, whether advisory, technical assistance, agricultural extension, etc.) should be geared towards educational methods and objectives which encourage innovatory attitudes. Since the financial resources and social effort that must be invested in each of the successive links in the innovatory process grow as the process advances, it is not easy to harmonise all the phases in the chain in a balanced manner. However, greater efficacy must be sought from the AKIS because only when effective innovation is produced in the last phase will the system have reached its maximum social and economic utility.

The Spanish case: Development and situation

The AKIS has traditionally been considered as an essential component of Spanish agricultural policy. As such it has been linked organisationally and administratively to the Ministry of Agriculture, which directly managed research in a targeted manner; technical agricultural, stock keeping and forestry services; extension services, responsible for furthering technological innovation in the rural setting; and high quality training. The Institute of Agricultural Research (INIA) conducted targeted research at their regional centres, located in each of the eleven large agricultural regions in Spain. This work was approved, financed and supervised by the senior management of the institution. The extension and training services for farmers had a wide network of 750 local agencies, 58 professional training centres which had facilities for teaching and carrying out agricultural testing in matters of regional interest, as well as 183 vocational colleges. The AKIS had institutional elements which depended on other Ministries, such as higher education and university research and all the industry-level and all the multidisciplinary research of the Upper Council for Scientific Research (CSIC), within which agri-food has a significant presence.[4]

As a result of challenges in the technical (related to competitiveness in production systems), political (evolution and development of the Common Agricultural Policy – CAP), and institutional (decentralisation configuration of the State) areas in the last 30 years, AKIS has evolved remarkably, particularly, for example, with respect to the following elements.

- The capacity of agri-food research in universities and industry-related centres has developed considerably, with greater volume of human resources and grants for projects. The research potential has also increased because the autonomous communities, by taking on the research responsibilities incumbent to them under the Constitution, as well as managing the regional centres previously managed by the INIA (but not those under the CSIC) and the testing centres conceded by the Ministry, have created and set up new research and testing centres. At the beginning of the current decade, and in overall terms, the agri-food industry has 136 centres that employed around 4 800 investigators and technicians. This potential is in line with the relative weight of Spain as an economically and scientifically intermediate country.
- INIA, as manager and administrator of the resources which State allocate to agricultural research, is no longer part of the ministerial department responsible for agriculture. It has become part of the organisation of the ministry that manages science and innovation, and to which the CSIC is attached. This is to avoid the overlapping of projects and to achieve better co-ordination of research programmes and better efficacy in fund allocation.

Additionally, it is obvious that in recent years certain elements of the AKIS have become weaker and have not been developed in keeping with the potential capacity of other elements. In particular, the efficacy of the phase of effective inclusion of innovations into the production activities of businesses and small and medium companies is suffering because the components of this final link in the innovatory process are too disperse, with marketing and post-sales services of the suppliers of consumables, public or private agricultural consultancies, technical services being provided by professional organisations and co-operatives to their members and associates, etc. What's more, these services are often not specialised in furthering innovatory change and lack the right methodological strategies.

In summary, this is an AKIS which is:

- relatively strong, involving numerous institutions and considerable human and economic resources;
- has a complex management system due to its high degree of administrative and political decentralisation in the autonomous communities, which determines the capacity of the system to establish institutional co-ordination and online functioning; and
- has incomplete or insufficient links, principally with regard to on-going training for farmers in their vicinity and agricultural extension.

Present and future challenges

Over the next few decades, food production requirements will increase considerably,[5] whether to meet the increase in world population and global demands for more and better food, or to meet the growing demands on agricultural production for non-food use (biofuels, for example). To meet these needs, agriculture should be more efficient and productive, yet should not harm the environment or use natural resources irresponsibly. To consolidate this new paradigm of competitiveness-productivity-sustainability, the AKIS has a new decisive role: they have to generate, develop and, above all, further the effective application of production methods based on clean technologies.[6]

It is generally acceptable to consider agriculture as one of the anthropic causes affecting climate change which, in turn, affects agriculture by altering the natural conditions in which it develops. Although it is uncertain how, when and how far this two-way influence works, it is obvious that the AKIS has new scientific challenges ahead regarding the improvement and increase in production on which world food security depends, compatible with the demands of the environment, specifically with regard to climate change.

These challenges include those which impinge on the competitiveness and sustainability of production sectors and farms, aimed at, for example, the following.

- Improving the unit yield of crops and livestock. An area in which genetic engineering, with its necessary biosafety mechanisms, plays an important role.
- Developing and implementing production methods and systems which help to curb spiralling production costs (electricity, fertilisers, etc.)
- Encouraging the use of good agricultural practice and compliance with environmentally-friendly techniques by farms, as expected by today's social awareness on these matters.

It is very likely that to tackle some of these challenges there are already sufficient, useable and validated data available. In this case, no additional research is needed. However, the ability of the AKIS to put this knowledge into use is slow and weak because it lacks robust structures and active methodologies to provide direct and immediate support to farmers and industries[7].

A dual perspective should be considered with respect to climate change. On the one hand, agriculture needs to adapt to the possibly irreversible changes already observed in the climate (adaptation), with respect to the increase in the atmosphere of CO_2 and other greenhouse effect gases, global warming and reduced precipitations and rainfall measurement changes; and on the other hand, agriculture must minimise its negative impacts on the climate (mitigation) as far as possible. From both perspectives, it is to be hoped that research, whether original or adaptive, and the development of material or new knowledge gathered, and finally its practical application to production activities will afford decisive contributions to adaptation and mitigation, such as:[8]

- obtaining and disseminating new drought, salt and acid proof plant varieties;
- production systems using the minimum water consumption;
- soil management aimed at increasing capacity for organic carbon and water retention; and
- advances in genetics and livestock management for reducing harmful emissions.

These and similar lines of action are a challenge for the AKIS, especially for research centres, since the knowledge available for tackling climate change is still scarce.

Some useful experiences

Regarding generic and strategic objectives of agricultural policies, one which often arises is the improvement and technical innovation of agriculture to meet the demand for greater productivity and competitiveness, yet with environmentally-friendly and sustainable production methods and systems. The success of these objectives depends on how knowledge is produced, distributed, evaluated and shared; current information technology and communication play a significant role in these matters. To help the AKIS to become more proactive in studying and resolving problems in agriculture and the rural environment, the Ministry has devised a raft knowledge management strategies as a basis for innovation and supporting innovators. These strategies, which have also been followed by the regional governments, are included in the "Knowledge Platform for Rural and Marine Affairs" which can be accessed from the Ministry website *www.marm.es*.[9]

This platform contains the "Observatory of Tried and Tested Technology." This observatory provides systematic and co-ordinated technical and economic data on the numerous innovations carried out at some farms and industries which have been accredited, proven and guaranteed as recommendable by reliable scientific institutions and which should be expanded and generally adopted. The observatory currently provides material in the following six areas of knowledge: plant material, diagnosis of plagues and diseases, animal production and nutrition, agricultural machines, irrigation equipment and a series of videos demonstrating these technologies. The aim is also that within this observatory knowledge networks appear in the different areas around which it is structured, whether imported or purpose-made, turning this into an effective medium for keeping up-to-date as well as a technological forum in which innovation-related matters are discussed.

Within this platform there is also an "Observatory of Best Practice" providing the latest information and images of the best or newest practices in the agricultural, marine or food sectors. The Observatory seeks to strengthen the demonstrative effect, encourage socio-economic agents to adopt best practice, and give society a real picture of the endeavours in innovation being made in these sectors. The Observatory is structured in the form of a guide of the new technical and legal aspects of cross-compliance, a series of informative audiovisuals on best practices, and a guide on nutritional issues. Best practice cases in any format can be accessed using a filtered search in a database which expands as new material is added. In the case of audiovisual items, the user accesses a summary of the content and then the full video file can be downloaded. The storage resources required and approximate download time appear.

To provide the socioeconomic players of the agricultural sector (technicians, farmers, industries, etc.) with information on what is known and who knows what, a "Map of Agri-Food Knowledge» is included in the platform. The idea of this map is to collect, co-ordinate and update the information provided by the technological and research centres. It also seeks to raise awareness of the projects completed by the various groups and centres, the level of knowledge available in the different areas, where the sources of knowledge are located, how to contact them for consultations and requests for information or advice from the investigators and technicians. So that the contents available can be updated and new projects included as they are completed, the application includes an interactive feature for the continuous updating and modification of contents and addition of new data the investigators or centres wish to include. The use of the platform has been growing since its conception in mid-2006, reaching a total of 3.9 million hits in 2010.

The CHIL project

The Polytechnic University of Madrid (Professor Pascual Carrión) in co-operation with the MARM has been developing the social network *www.chil.es*. This is a professional industry-level network to link people, institutions and companies in order to build bridges for communication between the main players in the rural, food, agricultural, and environmental settings. CHIL is configured as a tool facilitating personal, institutional and business connections to create links, share knowledge and disseminate innovatory experiences, promote best practices, etc. The CHIL network is open without restrictions to the whole industry. It is a collaborative and participatory platform centred on 12 thematic sub-portals (water, markets, innovations, agricultural and livestock production, nature, etc). Each sub-portal has its own design and content of active users, blogs, forums, groups, etc. This CHIL network should lead to better co-ordination between all the links in the innovation chain.

The RuralCat project in Catalonia: A successful model of regional knowledge management

Although most of the regional agricultural administrations use internet to disseminate knowledge, the case of Catalonia should be mentioned because of its pioneering character and because it is an integral model of construction of a knowledge transfer system using new technologies. This website started operating in 2003 with the aim of being the virtual community of the agri-food industry and the rural world in Catalonia, a region which aspires to be the most advanced in Europe in the implementation and use of information and communication technologies (ICT) in a rural setting in order to build up training, the flow of knowledge, and the interchange of experiences among all agents involved in agri-food and rural development, as well as to provide information to consumers on the origin and quality of products and services.

RuralCat is based on four areas:

- *In the area of information*: Access to knowledge is provided by the Plans for Technological Transfer and Technical Dossiers geared to technicians and business people.
- *In the technological services area*: Simple, personalised and accessible knowledge and information are provided (irrigation, fertilisation, plague control, etc).
- *RuralCat provides a permanent e-learning service*, 24 hours a day, open to anyone who requests it. This training option combines the opportunities afforded by technology with a personal tutor and the occasional class-based session.
- Finally, *RuralCat presents itself as a virtual community of experts* in which advisors, entrepreneurs, trainers and sponsors, acting in a network, manage (generate, request and interchange) knowledge.

The RuralCat project was developed in the Catalan language. It has managed to position itself as a successful instrument, not only due to its wide acceptance, with 16 000 registered users, more than half of whom are agricultural business people, but also because of its great potential for development and the added value it provides to the agri-food business, thanks to the creation of technical content, the publication of information relevant to economic activity, the generation of free technological services such as tools for decision-making, alerts via SMS texts to mobiles, and online training. The total number of visits in 2010 was 282 305, with a total of 1 207 266 pages visited. The total number of people trained via the e-learning programme of the portal was 2 300.

Conclusion

AKIS has undergone certain changes over the last 20 to 30 years, both in developed countries and in many developing countries. In the generation of knowledge, universities and public research centres are no longer clearly predominant, as they were in the past. The private sector is increasing its participation in many scientific areas, such as biotechnology, agrochemistry and others in which there are business prospects. At the other end of the chain, agricultural extension in many countries is no longer a free public service, or, in the case of technical assistance, this has been reduced and now forms part of the technological "packs" offered to farmers by the suppliers of consumables for commercial purposes or as after-sales services. In certain geographical areas (Latin America, in particular) and in keeping with the trends towards privatisation and supporters of less state intervention during the 1990s, extension services have all but disappeared. These changes must be taken into account if the aim is to revitalize or reinforce the AKIS in the face of the current challenges in food security and climate change.

To tackle these challenges with any hope of success it is advisable to consider the following.

- Scientific knowledge exists that is little used or unused.
- It is known that some of this knowledge (although not all) generates innovations which work adequately. The socioeconomic utility of this can be verified in the real conditions of farms and industries.
- Despite their availability and utility, it has been proved that only a minority adopt these innovations and uptake is not generalised among the potential users. If an innovation is adopted, this is done only gradually.

In the face of this evidence, the AKIS is generally said to be deficient in the final phase of "technological transfer." However, as pointed out earlier, cracks in the innovation process can be found more in the conventional "linear" concept of the process itself. This concept must be rethought, with the model of innovation based on the available offer of knowledge being re-directed towards a model based on the technological demands derived from the problems faced by producers, the study, definition, diagnosis and prioritisation. This must involve all players in the innovation chain (not only the investigators). To this end it would be advisable to establish interactive mechanisms of technological networks in which problems, solutions, innovatory experiences, etc., are confronted and shared. We need to move towards more consolidated AKIS which is more in line with the desired result. This result is none other than fostering technical and organisational innovation in the agri-food industry in a speedy and continuous manner. Hence, when investigators plan and select areas for study, they must be open to the points of view and the perception of the problems of end users, including consumers and intermediate players (technicians, trainers, extensionists, advisors, etc). These agents play a decisive role in ensuring that useable knowledge is translated into effective innovatory actions. This means they require sound technical training, but, above all, they must be specifically skilled in the design and development of appropriate strategies and methodologies for fostering innovatory action and change in farms and industries. Otherwise, a new model of technological innovation that is more effective than the conventional "linear" model is unlikely.

Notes

1. General Technical Secretariat of the Ministry of Environment and Rural and Marina Affairs (MARM, Ministerio de Medio Ambiente y Medio Rural y Marino), Spain
2. The private sector generally enters into research when patentable or marketable results can be obtained (plant varieties, plant protection products, GMOs, seeds, etc.). The majority of research carried out in new systems of cultivation, managing farms and resources or improvement of production systems do not produce patentable results. In addition, it is usually commissioned by public centres. In the innovation phase itself, many private companies (machinery, fertilizers, different types of supplies) carry out technological transfer for commercial reasons, and provide technical assistance to their clients.
3. Studies have been performed which demonstrate that when agricultural policies include subsidies and financial assistance representing a significant part of a farmer's income, technological investment and innovation slow down or reduce in intensity.
4. Over the last ten years, this sector accounted for about 25% of the CSIC budget.
5. Some estimates indicate that current agricultural production will have to double by 2050.
6. Many experts are convinced that the current technological offer will allow production and productivity to improve while respecting nature. For this, the mechanisms and incentives needed for fostering the generalised application of these technologies in industries and farms must be coordinated.
7. The absence of these structures has led the European Union to require member states to set up advisory services to help farmers adapt to the regulations and requirements of Eco-cross-compliance.
8. These lines of action are suggested in the resolution of the European Parliament of 5 May 2010, on "Agriculture in the European Union and climate change".
9. For example, the Regional Government of Catalonia developed the "RuralCat" website to strengthen the AKIS in the Catalan language.

12. Responses of the French Agricultural Knowledge System to new agricultural challenges

Pascal Bergeret[1]

The French agricultural knowledge system (AKS) has maintained a structure and organisation inherited from the post-war period based on a strong agricultural research organisation (INRA), a technical and academic educational system with campuses across the country, and applied research and advisory services linked to farmer organisations. The Ministry in charge of agriculture plays a major role as it oversees INRA and the public agricultural education system. In partnership with agricultural professionals, it manages applied research and advisory services. This structure has successfully accompanied the modernisation of the French agricultural sector, which has been accomplished on the basis of open innovation and the collective organisation of different actors involved in this area.

The nature and intensity of today's challenges have changed. Issues, which used to be purely agricultural, are now horizontal; they are shared with society as a whole and global in nature. European integration has created both new opportunities and new constraints, and it is in this context that the French AKS continues to undergo profound changes, while keeping its basic structure. Against a background of major reforms and large public investment, one can observe a rapid restructuring of the agricultural sector, with the development of institutions that focus on research, higher education, economic development, globalisation, and integration with the private sector. The actions of stakeholders and the combination of knowledge and local initiatives remain, however, are at the heart of the innovation process.

Knowledge is the main resource that society has to face today's challenges and to anticipate those of tomorrow. A society that does not produce knowledge cannot achieve sustainable growth. In an extremely competitive global environment, innovation and the economy of tomorrow are founded on an open-knowledge approach. Guided by the Ministry of Higher Education and Research (MESR), the first edition of the national research and innovation strategy (SNRI), covering the period 2009–12, will enable France to meet society's needs and expectations more effectively and to confront global scientific and economic competition. It defines three priority research areas: 1) health, welfare, food and biotechnology; 2) environment and environmental technology; and 3) information, communication and nanotechnology.

This section looks at the current organisation of the French agricultural knowledge system (AKS) and its individual components (education, research and development) and reviews its objectives, priorities and performance, as well as co-operation and networking, before going on to identify challenges for the future.

Structural organisation of the French agricultural knowledge system

In France, there are three pillars to the agricultural knowledge system: 1) technical and higher education; 2) research; and 3) development.

Agricultural, veterinary, agro-industrial, forestry and environmental education

A number of salient features distinguish France's system of agricultural technical and higher education from that of its European partners. In France, agricultural education comes within the remit of the Ministry of Agriculture, Food, Fisheries, Rural Affairs and Spatial Management (MAAPRAT), making it the second largest educational network after national education.

This network is comprised of over 800 public and private institutions, engaged for teaching more than 170 000 students. Local public institutions of agricultural education and vocational training (EPLEFPA) often include a state-run agricultural general and technical secondary school (LEGTA), an apprentice training centre (CFA), an agricultural vocational training and extension centre (CFPPA), a farm and/or an agrifood technology workshop. Between them, EPLEFPAs and privately-run institutions award around 10 000 advanced agricultural technicians' diplomas (BTSA) every year. The fact that this education system covers the entire country makes it strategic in terms of spatial planning. The pathways for obtaining a diploma or an agricultural education certificate are currently through initial training, accredited continuing education, apprenticeship, and experience.

MAAPRAT also has a network of 19 institutions of higher education in the strict sense, including seven private institutions under contract with the state, totalling 15 000 students. They are all higher education institutions, under the terms of articles L. 123-1 *et seq.* of France's education code *(Code de l'éducation)*, performing education and research tasks in the fields defined in article L812-2 of its rural code *(Code rural)*. This includes providing training for: engineers in agricultural, environmental, agrifood, horticultural and forestry science and technology; specialist managers; teachers; veterinarians and landscape architects (holders of the DPLG[2] diploma awarded by the government). Each year these institutions award diplomas to 2 000 engineers, 500 veterinarians and 50 landscape architects.

Finally, the law on social modernisation of January 2002 gave new impetus to the accreditation of prior learning in France and the law on lifelong vocational training and social dialogue of May 2004 allowed it to develop. The accreditation of prior learning offers people who have acquired a total of at least three years' vocational experience, whether or not they have diplomas, the opportunity of requesting a vocational diploma, certificate or certification. The law also introduces a new official pathway to obtaining a diploma or certificate apart from initial training, accredited continuing training and apprenticeship**:** the experience pathway.

Mission-oriented agricultural research

MAAPRAT shares responsibility for three research organisations: the national institute for agricultural research *(Institut National de la Recherche Agronomique* [INRA]), the national centre for agricultural machinery, rural engineering, water and forestry (*Centre National du Machinisme Agricole, du Génie Rural, des Eaux et des Forêts* [CEMAGREF]), the French research institute for exploration of the sea (*Institut Français de Recherche pour l'Exploitation de la Mer* [IFREMER]). It also shares responsibility for a public research institute: the national agency for food safety, environment and labour (*Agence Nationale de Sécurité Sanitaire de l'Alimentation, de l'Environnement et du Travail* [ANSES]). All these major research organisations focus on mission-oriented research.

In addition, MAAPRAT administers the agricultural research centre for international development (*Centre de Coopération Internationale en Recherche Agronomique pour le Développement* [CIRAD]).

Other organisations with a mandate to conduct research, such as France's Research Institute for Development (*Institut de Recherche pour le Développement* [IRD]), or the National Institute for Health and Medical Research (*Institut National de la Santé et de la Recherche Médicale* [INSERM]), may have links with the above institutions, depending on the areas of interest to them and each partner's sphere of expertise.

Boxes 12.1, 12.2 and 12.3 below present the research institutions that are an integral part of the agricultural knowledge system, to provide more insight into their structure, mandates and specialist areas.

Box 12.1. *Institut National de la Recherche Agronomique*
(National Institute for Agricultural Research, or INRA)

INRA is a public institution for science and technology, under the joint supervision of the Ministry of Agriculture and Fisheries and the Ministry of Higher Education and Research, and was established in 1946.

In terms of publications, INRA is the leading agricultural research institute in Europe and second in the world, and carries out mission-oriented research into safe, wholesome food, competitive and sustainable agriculture and environmental protection.

INRA has 14 scientific departments, based on disciplines or subject areas, in the fields of agriculture, food and the environment, together with 19 research centres.

Staff: 8 600, including 4 200 researchers and engineers and 4 400 technicians and administrative staff.

INRA budget: EUR 770 million.

INRA mandate: set out in government policy, in the decree establishing the institution:

- to organise and conduct scientific research of interest to agriculture and related industries;

continued

- to help to draw up a national research policy in areas relating to its sphere of competence;
- to publish and disseminate its findings and, more generally, help to promote scientific information and disseminate scientific knowledge;
- to support training in and through research;
- to help to promote its own research and know-how;
- to conduct scientific assessments within the scope of its activities.

INRA research policy

- research for and with society, supported by various partnerships;
- three highly inter-related research fields: agriculture, food and environment within a sustainable development framework;
- excellence in each discipline and interdisciplinarity between life science, materials science and social science;
- openess to Europe and the world.

Box 12.2. *Institut de Recherche en Sciences et Technologies pour l'Environnement*
(National Centre for Agricultural Machinery, Rural Engineering, Water and Forestry, or CEMAGREF)

CEMAGREF, is a public institution for science and technology under the joint supervision of the ministry of agriculture and fisheries and the ministry of higher education and research, was established by decree in 1985.

CEMAGREF has nine regional centres and three research departments: water management, environmental technology and land management.

Staff: 1 000, including 450 researchers and engineers.

CEMAGREF budget: EUR 64 million.

CEMAGREF mandate: set out in government policy, in the decree establishing the institution:

- To conduct, promote and make optimum use of all forms of work involving research, technology, technical support, testing and certification relating to country planning and rural development/farming facilities.
- To help to draw up technical and economic benchmarks and provide technical support for farming.
- To implement a scientific and technical policy for a variety of socio-professional groups.
- To support training in and through research.
- To help promote French technology abroad.

CEMAGREF research policy

- Environmental quality: "combining methods and technologies to aid understanding and action."
- Sustainable water and land management: "mainstream multisectoral approaches to improve the integration of water and land management'".
- Management of natural hazards: "broaden the approach to hazards by studying the viability of environmental systems".

Box 12.3. *Agence Nationale de Sécurité Sanitaire de l'Alimentation, de l'Environnement et du Travail* (National Agency for Food Safety, Environment and Labour, or ANSES)

ANSES is a public administrative institution under the responsibility of the ministers for health, agriculture, environment, labour and consumer affairs.

ANSES was established on 1 July 2010 from a merger between the French food safety agency (AFSSA) and the French agency for environmental and occupational health and safety (AFSSET). It has 12 laboratories on 16 sites.

Staff: 1 350, over one-third of whom are senior scientists.

ANSES budget: EUR 130 million.

ANSES mandate: set out in government policy, in the decree establishing the institution:

ANSES provides independent and multidisciplinary scientific expertise.

Its main contribution is to ensure human safety in the fields of environment, labour and food.

It also contributes to:

- safeguarding animal health and welfare;
- safeguarding plant health;
- assessing the nutritional and functional properties of food.

In addition, it performs tasks relating to veterinary drugs.

ANSES is responsible for risk assessment within its sphere of competence, providing the competent authorities with full information on such risks and with the scientific technical expertise required for drafting legislation and regulations and implementing risk management measures.

- It performs monitoring, warning, surveillance and reference tasks.
- It defines, implements and funds scientific and technical research programmes.
- It proposes to the competent authorities any measures for protecting public health. When public health is at serious risk, it recommends the necessary health policy measures to the competent authorities.
- It participates in the work of European and international bodies, representing France at the government's request.

ANSES research policy

- To discharge its health and safety brief with scientific assessments and high-level research.
- To meet the requirements for independence, transparency and openness to all stakeholders by controlling its processes.
- To develop its monitoring and warning capabilities, with particular reference to emerging risks.
- To extend its scope and influence at European and international level.

IFREMER, the French research institute for exploration of the sea, is a public industrial and commercial institution under the joint supervision of the ministry of agriculture, food, fisheries, rural affairs and planning, the ministry of higher education and research and the ministry of transport and infrastructure. IFREMER has a budget of EUR 240 million (almost two-thirds of which comes from the national budget) and has 1 350 staff working at five centres covering all France's coastlines. Its mandate is to conduct and promote basic and applied research as well as technological and industrial development work designed to understand, evaluate and develop ocean resources and rationalise harvesting, to gain more insight into the marine environment and ways of protecting it, and to promote social and economic development in the sector.

Applied agricultural research and agricultural advisory services

The technical institutes in the farming and agrifood sectors are the key players in the field of applied research in France, while agricultural advisory services are provided primarily by the chambers of agriculture, co-operatives and suppliers of agricultural inputs.

The key players in applied research are the technical farming institutes (ITAs), grouped within the association for technical co-ordination in farming (*Association de Coordination Technique Agricole* [ACTA]), and the technical agro-industrial institutes (ITAIs), grouped within the French association for technical co-ordination in the agrifood industry (*Association de Coordination Technique de l'Industrie Agro-alimentaire* [ACTIA]). Since 2006, vocational technical institutes and centres with a national remit have, at their request, been entitled to be accredited as either a technical farming institute or a technical agro-industrial institute if they perform the public-interest missions listed in article D. 823-1 of France's rural code and meet the specifications approved by the minister of agriculture's decree. A total of 15 ITAs and 16 ITAIs were accredited in 2008. They represent an applied research potential of around 1 500 engineers and technicians, with a budget of roughly EUR 260 million, almost 80% of which comes from taxation, "compulsory/voluntary levies" (CVO) and own capital, topped up by domestic and European public funds.

Each chamber of agriculture operates across its own *département* and co-ordinates the development work for a multi-annual programme drawn up by farmers and their representatives, with a variety of professional partners. The programme focuses on high-priority issues and supports joint initiatives involving more than one institution. The work of the departmental chambers of agriculture is co-ordinated through the national multi-annual agricultural and rural development programme (PNDAR).

The chambers of agriculture represent:

- 116 public institutions: 94 departmental chambers of agriculture, 21 regional chambers of agriculture and one national organisation covering all France's chambers of agriculture (*Assemblée Permanente des Chambres d'Agriculture* – APCA);
- a total budget of EUR 650 million, of which 50% comes from the additional tax on undeveloped land (TATFNB), 23% from services provided by the chambers of agriculture to their "constituents" (including farmers, agribusinesses and communes), 19% from contracts and agreements (government, local authorities, European Union, etc.) and 8% from other sources;
- 4 200 elected representatives (2.5 million voters, 50 000 professional associations, 10 electoral colleges);
- 7 800 staff, including 5 800 engineers and technicians.

Further partners that play a major role in agricultural development at local and regional levels include economic bodies (co-operatives and producer groups) providing farmers with advisory and training services.

Four aspects of the system are worthy of note:

- It is a decentralised system bringing together grassroots players, particularly in the chambers of agriculture.
- The farming industry is a partner in a developmental approach based on the transfer of knowledge and the provision of vocational training.
- Central government channels the funding raised from the sector.
- Solidarity operates between regions, production sectors and members of the industry, in that quasi-fiscal levies are redistributed on the basis of priorities, needs and the collective nature of development initiatives.

This development support is boosted by other government organisations such as the FranceAgriMer commodity board, which helps to orient production and manage Community support in these industries, or local authorities, some of which provide backing for farmers or the agrifood industry.

In the agrifood industry, development support operates and is financed differently. First, ACTIA, the association for technical co-ordination in the agrifood industry, was overhauled in 1995 to set up networks on specific scientific and technical themes within the association; second, the broad mandates of its member centres, which include transfer, research, development, technical support and service provision, and the very nature of the relations between ITAIs and their partners in industry (usually small and medium-sized enterprises [SMEs] and industries [SMIs]), create direct links between development players and the industry and, to a lesser extent, government and semi-professional organisations.

Boxes 12.4 and 12.5 below present the technical co-ordination associations – ACTA and ACTIA – that are an integral part of the agricultural knowledge system, to provide more insight into their structure, mandates and specialist areas.

Box 12.4. *Association de Coordination Technique Agricole* (Association for Technical Co-ordination in Farming, or ACTA)

ACTA is a non-profit association established in 1956.

ACTA brings together 15 technical farming institutes (ITAs), each focusing on a different branch of the industry, depending on the needs of the profession or group of professions.

ITA staff: 1 500, including 1 100 engineers and technicians

ITA budget: EUR 180 million

Their funding comes from: (i) the CAS-DAR earmarked tax for agricultural and rural development (26%); (ii) subsidies from the ministries of agriculture and research and from FranceAgriMer (13%); (iii) compulsory/voluntary levies (27%); (iv) sector taxes assigned directly to the ITAs (11%) and (v) own capital: research contracts, service provision, training, publications (23%).

Mandates of the ITAs and ACTA:

- to define a technical policy for farm production to suit the economic environment, mainly in the form of scientific advice;
- to conduct applied research, either in their own testing stations or on a partnership basis, in stations where follow-up is carried out by research institutes upstream;
- to provide development support in two areas of information and training, in particular for technicians and advisors in the chambers of agriculture.

ACTA activities

- unintended effects of agricultural practices;
- agricultural practices and biodiversity conservation;
- food quality and safety of agricultural products;
- organic farming; and
- low-input agriculture.

Box 12.5. *Association de Coordination Technique de l'Industrie Agro-Alimentaire* (Association of Technical Co-ordination in the Agrifood Industry, or ACTIA)

ACTIA is a non-profit association established in 1981.

ACTIA brings together 16 technical agro-industrial institutes (ITAIs), each focusing on a specific theme based on the needs of the trade (SMEs and SMIs) with strong local links between the institutes and those in contact with them.

ITAI staff in the 16 centres: 760, including 305 engineers.

ITAI budget: EUR 80 million

ITAI and ACTIA mandates

- To help to define technical policy for the institutes based on the needs of industry and the economic environment, largely in the form of scientific advice but also partnerships between institute directors.
- To conduct applied research either in their own structures or in partnership with upstream research institutes and industry, in particular the creation of technological concepts.
- To support development and technology transfer by focusing on a number of areas, including information and training, as well as service provision and business matchmaking.

Changes in the agricultural knowledge system in the past ten years

The implementation of an SNRI national research and innovation strategy for 2009–2012 has been a key development in the French agricultural knowledge system in recent years. Changes in public agricultural training have resulted in closer links or mergers between institutions of technical training or of agricultural and veterinary higher education, in order to clarify training provision and raise the profile of the institutions concerned both nationally and internationally.

Since 1 January 2007, the Ministry of Agriculture has promoted a policy of grouping schools into public scientific, cultural or vocational institutions (**EPSCP**), which are a special type of public administrative institution (EPA). These institutions take the form of a "major institution" *(grand établissement)*, as defined in article L. 717-1 of France's education code, and the rules governing their organisation and operation are laid down in a special order in Council of State. Currently these major institutions are: *Institut des Sciences et Industries du Vivant et de l'Environnement* (AgroParisTech); *Centre International d'Études Supérieures en Sciences Agronomiques* (Montpellier SupAgro); *Institut Supérieur des Sciences Agronomiques, Agroalimentaires, Horticoles et du Paysage* (AgroCampus Ouest); *Institut National Supérieur des Sciences Agronomiques, de l'Alimentation et de l'Environnement* (Agrosup Dijon [an institute under the joint supervision of the ministries of agriculture and higher education]); *Institut d'Enseignement Supérieur et de Recherche en Alimentation, Santé Animale, Sciences*

Agronomiques et de l'Environnement (VetAgro Sup, Lyon and Clermont-Ferrand) and *École Nationale Vétérinaire, Agroalimentaire et de l'Alimentation, Nantes-Atlantique* (ONIRIS).

Six agricultural and veterinary research and higher education stakeholders (INRA, CIRAD, AgroParisTech, Montpellier Supagro, Agrocampus Ouest and *Ecole Nationale Vétérinaire de Toulouse*) joined forces to found 'Agreenium' to strengthen 'higher education–research' links and raise the profile of their work both nationally and internationally. This new public scientific co-operation institution (EPCS) harnesses and co-ordinates its members' resources and skills at the interfaces between "research, training, development and the international dimension" (RFDI).

ANSES was created by merging AFSSA and AFSSET on 1 July 2010 to carry out risk assessment in addition to its research mandate.

On 1 January 2006, MAAPRAT introduced an agricultural and rural development policy funded from a farm turnover tax, 85% of which is paid into the CAS-DAR special appropriation account for agricultural and rural development. MAAPRAT uses it to guide, co-ordinate and administer the PNDAR national multi-annual agricultural and rural development programme, two strands of which concern applied agricultural research: the applied research programmes of the ITAs and initiatives financed by calls for projects.

As a policy and co-ordinating body, the CAS-DAR special appropriation account for agricultural and rural development provides technical and financial support but is not involved in the actual implementation of development programmes in a particular sector or part of the country. Instead, it relies on two networks.

- At national level: technical farming institutes, funded by CAS-DAR to the tune of EUR 50 million, in partnership with research and educational institutions.
- At local level: priority goes to agricultural development services (SUAD) in the chambers of agriculture, which implement the necessary resources (technical services, programmes, etc.) in liaison with the technical organisations found at this level. CAS-DAR funding totals EUR 45 million.

Following this development, MAAPRAT concluded target contracts with ACTA and ACTIA, which are recognised government operators. Finally, the accreditation process for agricultural and agro-industrial technical institutes set up by MAAPRAT in 2008 ensures the quality of the public-interest missions carried out for the industry, based on a set of specifications.

The current reform of the chambers of agriculture should strengthen the role of the regions.

Government and the agricultural knowledge system

Within the French government, two ministries share primary responsibility for the agricultural knowledge system: MAAPRAT and MESR.

MAAPRAT is responsible for:

- developing sustainable agriculture and fisheries: balancing the economic viability of farms with environmental concerns and society's expectations in terms of sustainable development has become a major plank of the ministry's mandate;

- ensuring safe, diversified and sustainable food: the ministry is leading the action plan for a policy to ensure the supply of safe, diversified, tasty and nutritious food that is accessible to all and produced using sustainable methods;
- local and regional development: deploying new local economic activities to create jobs, provide access to new technologies throughout France and meet the need for public services;
- developing products and regulating markets;
- supporting forestry production and management and conserving biodiversity; and
- guiding training, research and development.

MESR develops and implements government policy on the development of higher education. It proposes government research and technology policy and implements it jointly with the other ministries concerned. It is responsible for land use policy. It prepares government decisions on earmarking the public resources and funds allocated under the inter-ministerial research and higher education mission (MIRES).

The drive for convergence between the two ministries, which began in 1995 with the decision to share responsibility for the public institutions for science and technology (EPSTs) specialising in life sciences, has been broadened to foster greater co-operation between higher education, research and the world of work. The two ministries are responsible for three research organisations – INRA, the national institute for agricultural research; IFREMER, the French research institute for exploration of the sea; CEMAGREF, the national centre for agricultural machinery, rural engineering, water and forestry – and a government research agency, ANSES, the national agency for food safety, environment and labour.

- Other organisations with research mandates (IRD, France's research institute for development and CIRAD, the agricultural research centre for international development) have special links with one of the two ministries but actually come under the Ministry of Foreign and European Affairs (MAEE).
- While the Ministry of Ecology, Sustainable Development, Transport and Housing (MEDDTL) is involved in the research policy of some institutes via agreements, it does not supervise them.

Changes that have occurred in the past ten years include:

- MAAPRAT now focuses on food and local and regional development.
- MESR merged the general directorate for research with that for technology into a new general directorate for research and innovation.

Funding the agricultural knowledge system

Funding for the agricultural knowledge system comes from both public and private sources. Public funding comes largely from the inter-ministerial research and higher education mission, which has annual appropriations of EUR 10 billion, 8% of which is for the agricultural knowledge system. These appropriations are managed mainly by four ministries: MESR, MAAPRAT, MEDDTL and MAEE.

INRA, CEMAGREF and IFREMER are government mission-oriented research institutes. They receive subsidies for the provision of public services totalling EUR 650 million, EUR 79 million and EUR 159 million respectively. More than three-quarters of the government funding allocated to these three leading research organisations is spent on payroll costs.

Funding under programme 142 of the finance law for public agricultural higher education amounts to:

- EUR 175 million for payroll costs (2 600 full-time equivalent jobs [FTE], of which 1 040 are teaching/research staff);
- EUR 47 million for operating expenses (basic operating grant, contractual grant, administration of students and civil service trainees, special missions, investment).

In private-sector higher education, staff are paid by the institution. The government's draft budget for 2011 earmarks EUR 24 million for helping to fund these private institutions. This comes within the new regulatory framework defined in decree 2009-791 of 23 June 2009 concerning contracts between the government and private agricultural higher education institutions.

In both research institutes and agricultural and veterinary higher education institutions, the policy is to offer high incentives for private funding, mainly in the field of research, service provision and further training.

In the past ten years, funding agencies such as the French National Research Agency (ANR), the state-owned company OSEO (funding for innovation and business support) and the French environment and energy management agency (ADEME) have planned and financed research in all sectors through calls for competitive and thematic research projects. The ANR receives annual funding of 640 million, 13% of which is earmarked for agricultural research, while the innovation programmes, led by OSEO, receive funding of EUR 600 million, 10% of which is for agriculture. In addition, the European Union's Seventh Framework Programme for Research and Technological Development (FP7) is one of the main sources of EU research funding. Research theme 2 of the FP7 concerns food, agriculture and fisheries and biotechnology.

Additional French government measures to support research and innovation include the following.

- "Investment for the future" projects *(Investissements d'Avenir)* receive funding of EUR 35 billion, earmarked for supporting health research and promoting the emergence of a bio-economy, based on life sciences and new ways of using renewable biological resources.
- The research tax credit is an incentive to promote basic research granted on company research and development (R&D) expenditure: a total of EUR 1.5 billion in relief on corporate R&D spending was provided in 2007.

Regional and departmental authorities (*Conseils Régionaux, Conseils Généraux*) are also major funding providers to agricultural technical education and agricultural research.

In the development and advisory sectors, funding for chambers of agriculture and technical farming and technical agro-industrial institutes comes from:

- the CAS-DAR earmarked tax for agricultural and rural development totalling EUR 110 million;

- subsidies from the ministries of agriculture and research and from FranceAgriMer totalling EUR 25 million;
- compulsory/voluntary levies totalling EUR 50 million;
- taxes allocated directly to the technical institutes or chambers of agriculture;
- own capital: research contracts, service provision, training, publications.

The budget of the technical institutes totals around EUR 250 million, almost 80% of which comes from taxes and compulsory/voluntary levies. The budget of the chambers of agriculture totals EUR 650 million, of which 50% comes from the additional tax on undeveloped land.

In conclusion, France spent EUR 39 billion on R&D in 2008. This represents a total R&D investment of 2% of France's gross domestic product (GDP), around 0.75% of which is government R&D, with corporate R&D averaging 1.27% in 2008. The figure varies between economic sectors and is estimated at less than 0.5% of GDP in the corporate agricultural and agro-industrial sector.

Agricultural knowledge system objectives, priorities and outcomes

Agriculture is at the heart of strategic, economic, environmental and social issues. Its performance as regards food output, together with its economic importance in terms of jobs, the extent to which it is embedded in the local and regional economy, links with the food export sector and contribution to the environment, make agriculture one of France's most strategic sectors.

French agriculture must now rise to the many challenges facing it.

- ***Economic challenge*:** the forthcoming changes in the rules of the World Trade Organisation and the common agricultural policy will shape the new economic framework for French agriculture. The issue of adapting French farming, in particular maintaining farm competitiveness, will be crucial to ensuring outlets for agricultural products in European and international markets. The performance of France's agricultural economy will rely on the introduction of technological innovations.
- ***Challenge of growing markets*:** population growth and rapidly rising living standards in emerging countries will double the demand for food in the next 20 to 30 years. This will test France's ability to mobilise agricultural production potential and the agrifood industry to meet rising global demand for food. The use of biomass for energy production, biomaterials and the development of 'green chemicals' will gradually increase in importance as outlets for agriculture.
- ***Environmental challenge*:** agriculture is a key sector for natural resource and biodiversity conservation. It will therefore have to balance economic performance with environmental efficiency within a sustainable development framework.
- ***Challenge of localised growth*:** by distributing production centres among many rural areas with limited options, involving a network of locally-based SMEs, the agriculture and agrifood sectors support regional cohesion and offer real growth and employment opportunities.

The policies of the PNDAR national multi-annual agricultural and rural development programme for 2009–2013, financed by CAS-DAR, are designed to boost the economic, environmental and social effectiveness of research and development programmes, making them easier to understand and providing the best possible response to the issues and challenges facing agriculture. Four policy priorities were selected for the preparation of target contracts with the various research and development networks:

- agriculture as a source of innovation;
- products (creating or retaining value added);
- promoting the emergence of local projects; and
- innovation in professional practice.

PNDAR actions are part of a drive to improve the overall performance of farms, in agri-environmental and health terms, and to match output to the real needs of the markets. The objectives are to:

- anticipate and generate both organisational and technological innovations by combining environmental excellence with economic performance and to develop joint innovation initiatives;
- boost the dissemination of results to farmers and encourage their use, by adopting both specialised and general approaches;
- provide quality local advice accessible to a wide range of farmers and geared to the changing nature of farm structures. As farmers' individual responsibility operates within an increasingly extensive and complex web of knowledge, development must provide the tools required to practice their profession under optimum conditions of effectiveness, freedom and safety for themselves and others;
- manage diversity: the French farming sector is diverse owing to the size of France's territory and the wide range of trades, skills and traditions it encompasses. Agricultural and rural development, which is intended to serve agriculture as a whole, must set itself the goal of managing this diversity;
- increase farmers' freedom of initiative and decision-making autonomy and encourage them to take an active part in the development of innovative joint projects; and
- position innovations within the European and global context.

More generally, France's research and innovation priorities are described in the SNRI national research and innovation strategy for 2009–2012, which is divided into four fundamental pillars.

- First and foremost it is a strategy is based on an analysis of the major challenges of tomorrow, which are also priorities for French research.
- It is a truly national strategy: the priorities are therefore defined on the basis of the nation's needs, reaffirming the social value of research and innovation and rebuilding dialogue between science and society.
- The strategy focuses mainly on research: the priorities that it sets must therefore take their rightful place in the planning of research organisations, which will be responsible for making the strategy work.

- It aims to transform research into innovation by strengthening the interactive continuum between research and the needs of markets and society, creating an ongoing dynamic between fundamental discoveries and their technological applications, as well as their dissemination within France's universities and *grandes écoles*.

This has led to the definition of five guiding principles and three priority research areas.

While it remains part of a global system of competition and collaboration, within a European context, French research must abide by the following principles:

- Basic research is vital for any knowledge-based society. Every aspect of basic research must be promoted, especially in very large research organisations. It is a policy choice.
- Research that is open to society and the economy is crucial to growth and employment. The competition imperative is pushing France to renew the link between public research institutes and businesses, with greater trust and co-operation, in order to meet specific medium- to long-term objectives. This overarching vision calls for the promotion of an innovative society, where the community not only accepts innovation but also generates and spearheads it.
- Better risk management and security are particularly important in today's society and should be priority components of social, cultural and technological innovation.
- The human and social sciences must play a major role within the three priority research areas; they help to build interdisciplinary interfaces in all key fields.
- Multidisciplinarity is vital for the most innovative and appropriate approaches to social issues.

The current national research and innovation strategy identifies three priority development areas relating to the agricultural knowledge system. A common feature is that they all address identified social issues, target emerging economic fields with high innovation potential and require multidisciplinary research in spheres where France is able to field a group of top researchers.

These three priority areas are:

- ***Health, welfare, food and biotechnology***, in a context of increased life expectancy, the emergence of infectious diseases and changing lifestyles.
- ***Environmental emergencies and environmental technology***, to meet the triple challenge of natural resource depletion and the functional division of territories, climate change and the need for a degree of energy independence. These issues are interlinked and require a joint response.
- ***Information, communication and nanotechnology***, now present in every aspect of daily life as a result of the internet revolution. Some of the multiple challenges posed in this area are security, ambient intelligence, complex systems and parallel and distributed computing.

While continuing to promote scientific excellence, the removal of barriers between disciplines and interdisciplinary approaches are encouraged by means of alliances. For example, the aim of the national alliance for environmental research (AllEnvi) is to help to make France a leading authority in environmental and food science and technology within the European research area. AllEnvi comprises 12 founding members: BRGM (the French geological survey), CEA (the French atomic energy commission), CEMAGREF, CIRAD, CNRS (the national centre for scientific research), CPU (the conference of deans), IFREMER, INRA, IRD, LCPC (the public works research laboratory), *Météo France* (the national meteorological service) and *Muséum National d'Histoire Naturelle* (the natural history museum).

AllEnvi objectives are to:

- ensure strategic and operational co-ordination in systemic environmental research and to raise its profile in mainland France and its overseas territories, as well as in Europe;
- co-ordinate operators' planning so that they set scientific priorities in accordance with the main national research guidelines;
- set up and co-ordinate thematic focus groups for each field of action identified;
- promote and organise co-financed joint programmes on 'emerging' issues by supporting (or generating) innovative interdisciplinary projects;
- increase the synergies between research operators, universities, schools and economic actors in relation to national priorities, especially innovation and development;
- encourage and strengthen collaboration with southern countries, together with the French inter-institutional development research agency (AIRD);
- ensure coherence between and provide leadership to all types of research infrastructure, particularly environmental monitoring, testing and research systems;
- conduct or incorporate forecasting.

To raise the profile of France's agricultural and veterinary research and higher education activities both nationally and internationally, a new public scientific co-operation institution called Agreenium was set up. It currently comprises six players (INRA, CIRAD, AgroParisTech, Montpellier Supagro, Agrocampus Ouest and *Ecole Nationale Vétérinaire de Toulouse*) and was set up to co-ordinate its members' resources and skills at the interfaces between research, training, development and the international dimension. It is responsible for promoting and implementing specific actions to meet the needs of its founders, as well as the expectations of its French and international partners.

Another important issue is co-ordination between national and European policy. France aims to enhance its integration into the European mainstream by increasing the involvement of its public and private research and innovation players in European research area programmes.

It was in this spirit that France promoted joint programming during its presidency of the European Union. Joint programming refers to co-ordination between national research programmes in order to find a European response to challenges where the urgency, risk and human and material resources required are too great for one country alone. Two joint programming initiatives relating to the agricultural knowledge system were accredited in 2010: one on agriculture, food safety and climate change and the other on "A healthy diet for a healthy life."

To strengthen research–education–innovation links nationwide and set up a triangle of operational knowledge in agriculture, the public authorities have successfully launched a number of initiatives to promote networking between partners in research, technical and higher education, technical institutes, civil society and business. This networking is based on instruments such as scientific interest groups *(groupements d'intérêt scientifiques)*, skills clusters *(pôles de compétences)* and competitiveness clusters *(pôles de compétitivité)*. Over the past ten years, in particular since the European Union Member States adopted the Lisbon Strategy, France has begun to overhaul its innovation ecosystem in order to stimulate corporate research and development and technology transfer. Increased non-technological innovation capacity (design and creation, organisational innovation) and better dissemination of information and communication technologies should also help to boost the French system in general and the agricultural sector in particular, especially among SMEs.

To achieve the objectives defined for the agricultural knowledge system, the ministries have signed target contracts with key government operators: mission-oriented research institutes, higher education institutions and accredited technical institutes.

The big issues facing society, such as climate change, food security, sustainable development and population ageing, have received special attention during discussions on the SNRI national research and innovation strategy, the PNDAR national multi-annual agricultural and rural development programme, *Ecophyto 2018* (France's pesticide reduction plan), *Objectif Terres 2020* (the new French agricultural model) and the national programme for food (PNA). This has shifted the priorities of the French agricultural knowledge system towards sustainable development and food.

What major changes have occurred in programs, staff numbers and funding levels of AKS and its components during the past decade?

Since 2005, France's research and innovation system as a whole has been the subject of far-reaching reform and heavy investment, involving the creation of competitiveness clusters, the ANR national research agency and the research and higher education assessment agency (AERES), strengthening the autonomy of universities, introducing major public investment programmes in research and higher education (*Plan Campus*, under France's "investment for the future" programme), the development of thematic and competitive calls for projects (including CAS-DAR, ANR, ADEME and OSEO) and support for public-private partnerships in the form of research tax credits and the Carnot institutes for developing partnership research for businesses. Although these measures were not targeted specifically at the agricultural knowledge system, it has nevertheless benefited.

Despite the economic crisis and budgetary pressures, over the past ten years the mission-oriented research and higher education sectors have been safeguarded and their resources have even increased slightly. Over the same period, resources earmarked for agricultural applied research and advisory services have remained stable or even fallen slightly.

Over the past decade, students at all levels have been more attracted by environmental and health occupations, while life sciences in general, and agrifood in particular, have seen falling uptake. Job opportunities in the agrifood sector have remained very buoyant. Finally, student numbers in agricultural education have remained constant.

Following the bovine spongiform encephalopathy (BSE) and dioxin health crises, consumers began to demand safer and more wholesome foodstuffs. This has resulted in a shift in the agricultural knowledge system in recent years towards sustainable agriculture. Nevertheless, competition in the domestic and international agricultural sector remains fierce and the challenge is to balance sustainability with competitiveness.

In any case, as recent health crises have demonstrated, the agricultural knowledge system needs to remain highly responsive to any new emergency.

Over the past ten years, MAAPRAT has commissioned a number of multidisciplinary scientific assessments (*expertises scientifiques collectives* [ESCos]) in support of public policy-making. Indeed, the assessment mission of public research in support of government policies was reaffirmed by the framework law on research in 2006. Scientific arguments to back government policies are now a requirement. An ESCo carries out a full review of the current state of knowledge on a particular subject by means of a multidisciplinary approach involving life sciences and human and social sciences. It highlights the options open to the government, based on an assessment of various public and private actions. ESCos on a variety of issues have been commissioned to provide MAAPRAT with clearer guidance for public policy-making, including: whether France should store carbon in agricultural soil; pesticides, agriculture and environment; drought and agriculture; fruit and vegetable consumption; agriculture and biodiversity; pain in animals and eating habits.

ANSES is the agency responsible for assessing risks, as well as for providing the competent authorities with full information about such risks and the scientific and technical expertise and support needed to draft legislation and regulations and implement risk management measures. ANSES also performs monitoring, warning, surveillance and reference tasks. It proposes to the competent authorities measures for safeguarding public health and, when public health is under serious threat, it recommends the necessary health policy measures to the authorities.

Relationships and networking

From the reviews carried out prior to introducing the SNRI national research and innovation strategy, it was concluded that research that is open to society and to the economy is crucial to growth and employment. To ensure the establishment of a triangle of operational knowledge in agriculture, the public authorities have successfully launched a number of initiatives to promote networking between partners in research, technical and higher education, technical institutes, civil society and businesses. Some of these instruments are specific to the agricultural knowledge system (skills clusters, joint technology units [UMTs], joint technology networks [RMTs], thematic networks and geographic networks), while others are more general (research and higher education clusters [PRES], competitiveness clusters, alliances, SNRI thematic focus groups and technology platforms [PFTs]).

France's research and higher education clusters were created by the 2006 framework law on research and now number 21. They enable universities, engineering and veterinary schools and research institutes to co-ordinate their various systems and to pool activities and resources in order to provide a more coherent and transparent research and training capacity that is better suited to local needs.

Technology platforms were set up to organise local innovation support for businesses through a network of educational institutions: general and technological schools, vocational schools, higher education institutions and public or private organisations with technical facilities focusing on a common theme. The PFT must specialise in one or a limited number of fields of activity.

A competitiveness cluster brings together companies, research laboratories and training institutions in a given area to develop synergies and co-operation. It must be based on synergies and on collaborative and innovative projects that enable companies to assume leadership in their respective fields in France and abroad. Around a dozen of the 70 accredited competitiveness clusters undertake activities relating to the agricultural knowledge system. The objective of these clusters is to boost the competitiveness of the French economy and to generate growth and jobs while promoting innovation and supporting industry.

Apart from its traditional partnerships with stakeholders in the agricultural knowledge system, MAAPRAT also involves economic actors and civil society representatives in its discussions through a range of multipartner actions. When formulating government policy, MAAPRAT systematically consults stakeholders from outside the agricultural knowledge system. A new five-way governance system was used throughout the process of developing the PNA national programme for food and the *Ecophyto 2018* and *Objectif Terres 2020* plans, which involved representatives of five stakeholders: government; social partners; trade unions and employers' organisations; civil associations and local and regional authorities.

Co-operation between actors in the agricultural knowledge system

MAAPRAT introduced RMT joint technology networks (a new partnership arrangement stemming from Article 91 of the framework law on agriculture of 5 January 2006) to break down barriers between research, education and development and to foster innovation. Each RMT network brings together, over a three- to five-year period, at least three accredited technical institutes or chambers of agriculture, a technical agricultural education institution (EPLEFPA) and a higher education institution or public research institute. There are currently 27 accredited RMTs. One example is the 'animal production systems and environment' RMT, whose partners are a research institute (several INRA research units), technical institutes (ARVALIS, CETIOM, IFIP, IE, ITAVI, UNIP), chambers of agriculture (Brittany, Pays de la Loire) and an institution of technical and higher agricultural education (Agrocampus Ouest), which are working to deliver and transfer tools for managing animal production systems to improve their environmental performance.

UMT joint technology units were also introduced as a result of the agriculture law of 5 January 2006 and aim to forge stronger working relationships between public research institutes or higher education institutions and technical agricultural or agro-industrial institutions, through mission-oriented research themes, in accordance with the target contracts of the network of technical agricultural or agro-industrial institutions. There are currently 31 accredited UMTs. A typical example is POLYGREEN, the UMT on biopolymers from agricultural resources, whose members are ITERG (the French institute for fats and oils), the University of Bordeaux 1, ENSCPB (the graduate school of chemistry, biology and physics of Bordeaux) and the CNRS. POLYGREEN seeks to diversify the use of domestic sunflower and safflower oils, using sustainable chemicals to produce polymers from agricultural sources while safeguarding the health of operators and the environment and reducing dependence on fossil resources. Annual funding for UMTs and RMTs totals EUR 4 million.

Law 2005-157 on rural development of 23 February 2005 broadened the mission of organising local and regional activities *(animation des territoires)* previously entrusted to agricultural schools to include developing all the social, economic, cultural and environmental aspects of regional development. The circular of 27 June 2008 also defined the role of agricultural education in this field, particularly that of EPLEFPA farms, in the emergence and dissemination of sustainable agricultural practices. Eleven thematic networks were set up to accomplish agricultural education's specific mission of organising local and regional activities, to support both government policies on agricultural education and those arising from the environmental round table *(Grenelle de l'Environnement)*, on such themes as: low-input technical pathways; organic farming; quantitative and qualitative water management; aquaculture; energy performance; horticulture and landscaping.

The thematic networks seek to foster the necessary changes by training future farmers and farm managers, to encourage the emergence of regional development projects and showcase relevant innovations, to incorporate farms associated with education institutions into the agricultural testing and development network, to promote knowledge and dissemination of new techniques and good practice, as well as to ensure fruitful interaction between professions in agricultural and rural development and in education.

International co-operation is brand new mission for agricultural education in France. It is enshrined in Article 121 of the framework law on agriculture of 9 July 1999, which states that agricultural education institutions play a part in international co-operation initiatives, in particular by promoting exchanges and hosting schoolchildren, apprentices, students, trainees and teachers. In 2011, a total of 27 geographic networks were asked to clarify and co-ordinate the international initiatives of institutions of technical and higher agricultural education.

In 2004, MAAPRAT set up seven skills clusters with the strategic aim of improving clarity in the context of building the European higher education and research area. The skills clusters pool the skills that exist in a particular geographic area in the fields of training, research and development in relation to the agricultural knowledge system. There are currently seven accredited skills clusters.

International co-operation

World population growth and the associated demographic changes, together with food security, the need to preserve natural resources, energy demand, pressure from climate change and economic globalisation, are all global challenges to which the agricultural knowledge system will have to rise during the course of this century. Meeting these challenges calls for an ambitious, united approach to international agricultural research.

Since the Lisbon treaty came into force, the European research area has become a reality and Member States now have a number of EU instruments at their disposal. ERA-Nets are designed to co-ordinate national research programmes on a given theme: for partner countries, this should result in joint programming and a long-term commitment, with one call for proposals each year. MAAPRAT is a partner in the CORE Organic ERA-Net (organic farming) and the RURAGRI ERA-Net (rural development). Another more recent type of instrument is the joint programming initiative (JPI): France co-ordinates the Agriculture, Food Security and Climate Change JPI, jointly with the United Kingdom, and is a member of the JPI entitled "A healthy diet for a healthy life."

At the international level, the Global Research Alliance on Agricultural Greenhouse Gases, led by New Zealand, is a platform that allows countries to pool their research efforts, thereby facilitating the implementation of joint research programmes. The Global Research Alliance focuses its research efforts on reducing emissions.

The Consultative Group on International Agricultural Research (CGIAR), founded in 1971 and based in Montpellier, plays a leading role in fighting hunger and poverty, improving human health and nutrition and boosting the resilience of ecosystems. This strategic partnership brings together a variety of donors in support of 15 international centres working in partnership with hundreds of governments, civil society organisations and private firms worldwide.

Looking ahead

The challenges for the agricultural knowledge system in the next decade are to:

- foster stakeholder excellence through new synergies between research, education and development/innovation;
- scale up this dynamic to European and international level by promoting the "triangle of knowledge;"
- build new public/private partnerships to consolidate research resources and the effective transfer of knowledge to innovation;
- tackle agricultural, environmental, food and energy challenges and issues;
- improve the social use of research findings to develop more robust public policies for addressing increasingly complex issues;
- help to modernise agricultural knowledge and innovation systems in order to deliver sustainable agricultural and food systems;
- encourage creativity and innovation in research by exploring interfaces between the sciences and by encouraging interdisciplinary approaches; and
- overhaul the instruments for dialogue between science and society.

Note

1. General Directorate for education and research (*Direction Générale de l'Enseignement et de la Recherche*, DGER) of the Ministry of Agriculture, Food, Fisheries, Rural Affairs and Spatial Management (*Ministère de l'Agriculture, de l'Alimentation, de la Pêche, de la Ruralité et de l'Aménagement du territoire*, MAAPRAT), France.
2. *Diplôme par le gouvernement* (DPLG), a state registered diploma.

Part III.

Public / private roles

13. Intellectual property rights and the role of public and levy-funded research: Some lessons from international experience

Richard Gray[1]

The introduction of intellectual property rights (IPRs) to protect knowledge created from agricultural research, development and extension (RD&E) has, in many instances, created strong incentive for private investment and has helped to address the chronic underfunding of agricultural RD&E. However, the privatisation of RD&E is not without its challenges given the non-rival nature of knowledge. Economic theory suggests that when protected by IPRs, knowledge becomes a toll good and creates the economic conditions for a natural monopoly. In an unregulated market, toll-good industries face the dilemma of market power in the case of monopoly, or the costly fragmentation of research effort when more than one firm exists. While this dilemma can be managed through other policies, efficient outcomes are difficult to achieve in the market place, as evidenced by the outcomes in the canola and corn hybrid seed industry. Models of levy-based, industry-controlled RD&E show some promise to address these toll-good issues. The Saskatchewan Pulse Growers invests research levies on behalf of growers and manages the intellectual property (IP) produced. The Grains Research and Development Corporation (GRDC) is a shareholder along with public and private firms in three wheat-breeding firms in Australia. France has a negotiated end point royalty system. More research is needed to understand the long run impact of these alternative institutional relationships.

Introduction

The need to have well performing agricultural knowledge systems is nearly self-evident. Productivity improvements allow more to be produced from a given set of inputs. Well-performing Agricultural Knowledge Systems (AKSs) foster productivity improvement by generating knowledge and developing technologies that are put into use by the agricultural sector. They not only increase profitability and economic surplus, but also contribute to the ability of the sector to address food security and environmental goals. While some important innovations have been generated by the private sector, the policies of the public sector have been critical in shaping AKSs.

Most OECD countries have a long history of public sector dominance in crop research. In North America, publicly funded crop research was seen as a key economic development tool for more than a century. Early policy makers recognised that the ability of farmers to save seed and mimic their neighbours made it impossible for firms to capture the value from many Research, Development and Extension (RD&E) activities. Recognising the lack of private incentives, governments created large publicly funded RD&E programmes. The long and extensive record of high returns to public research (Alston *et al.*, 2000; Alston *et al.*, 2010) demonstrates the benefits from public expenditure on research, while at the same time, revealing the persistent underfunding. This latter outcome emphasizes that agricultural research faces stiff competition from other government spending priorities.

The private sector has played a very important role in agricultural RD&E when Intellectual Property Rights (IPRs) have allowed firms to capture a return from their investments. Agricultural machinery and pesticides are good examples where this has occurred. Notably, the private sector has also played a large role in crop breeding where hybrid technologies, patented traits, or vegetative reproduction allow crop breeders to capture value from their innovations.

The issue

The questions posed here are: "What are the roles for private and public sector in education, Research and Development (R&D) and extension? What defines the boundaries: market failures, public goods? How to strengthen complementarities between private and public sector?

A standard policy approach addresses the question: "Are more effective IPRs the solution to research underfunding?" On the face of it, the underfunding of agricultural research has a simple solution: create stronger and more complete IPRs where possible, subsidize private RD&E where property rights are somewhat incomplete, and continue to do public RD&E where IPRs cannot feasibly stimulate enough private investment. Unfortunately, the policy problem of underfunded research is more complex, and cannot be solved by simply addressing incomplete property rights.

This chapter highlights an aspect of private research goods that helps to refine the discussion of private and public roles in AKS. The non-rival nature of knowledge makes protected RD&E a toll good. A toll good is a good that is non-rival but, unlike pure public goods, price excludable. The cost of producing the toll good is a fixed cost that does not vary with use while the variable cost is zero, resulting in a cost structure with declining average cost and average cost greater than marginal cost. This creates the industry cost structure conditions for a natural monopoly (Lesser, 1998). This cost structure in the private crop research industry results in one of two less-than-optimal outcomes: either 1) a concentrated private research industry with distortive market power, or 2) a less concentrated industry with more competitive forces but with more-costly fragmented research.

The existence of toll goods has implications for the roles of the private and public sector in RD&E. As in other toll-good industries, such as railways, ports, and electrical power, a wide variety of public/private structures have evolved in AKSs. In agricultural research, downstream private industry organisations funded by commodity levies can play an effective role in AKSs, by creating a better alignment of incentives and a voice for the downstream users.

The remainder of the paper is organised in sections. The first section employs well-established economic concepts to describe the relationship between knowledge spillovers and private knowledge creation, while introducing the role of industry voice in the provision of public goods. The subsequent section draws on the literature to frame protected knowledge as a toll good and discusses the implications non-rival inputs have for private industry efficiency and the role public policy. This section concludes with a discussion of the North American experience in well protected crop research sectors. The third section examines the role of industry-controlled, levy-funded research as a mechanism to fund crop research and drawing from the experience of the Saskatchewan Pulse Growers and the Australian Grains Research and Development Corporation. The final section briefly summarizes the chapter.

Spillovers, knowledge and market failure

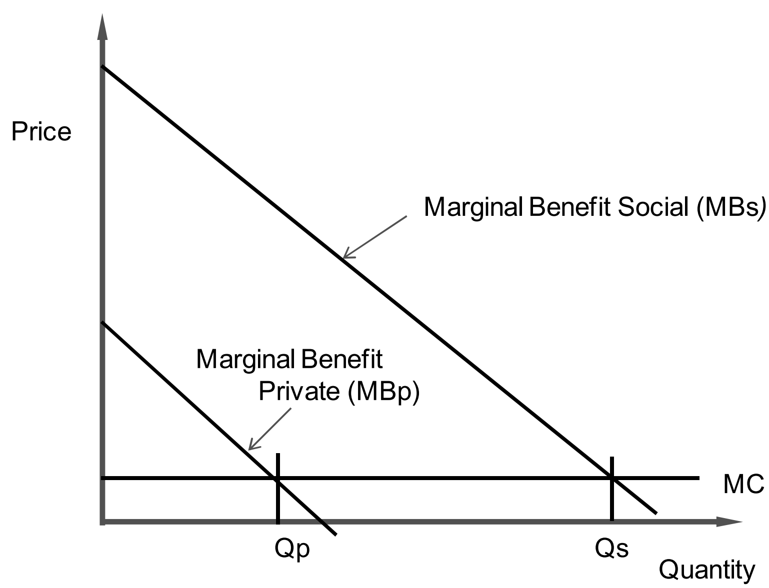
Knowledge spillovers

The simplest economic classification of private versus public goods hinges on whether a good is excludable or not. The right to exclude others from using a good is central to the notion of private property. Without the ability to exclude others, goods are essentially in the public domain and private individuals have no incentive to provide the good. If the ability to use a good "spills over" to others, and they are not obliged to pay for the good, the market demand will not reflect the good's full social value. The market demand will reflect only the flow of benefits that can be excluded if payment is not made. Economists use the term «spillovers» to refer to the benefits that are received but not paid for by the recipients in a market transaction.

Spillovers create a market failure because of the misalignment between the social marginal value of a good and the marginal cost of producing the good (Alston, 2002a). This effect is illustrated in Figure 13.1. The social marginal benefit curve represents the social value of each unit of the good provided. The private marginal benefit curve represents the market demand for the good. The spillover of benefits is represented by the vertical distance between social and private marginal benefit curves. These spillovers can be very widespread or "public" in nature (such as a reduction in greenhouse gas emissions), specific to the industry in question (such as a new agronomic practice freely adopted by producers), or specific to the individual firm (such as the benefit from replanting saved seed). Private individuals or the market will supply RD&E only to the point (*Qp*), where the private willingness to pay (*MBp*) is equal to the marginal cost (*MC*) of providing an additional unit, represented by *MC* in Figure 13.1. In this case, the market fails to provide the socially optimal amount of RD&E, (*Qs*) because at the point, *Qp* the social marginal benefit exceeds the marginal cost of producing another unit.

This market failure is commonly addressed in one of four ways: 1) the government can provide RD&E equal to *Qs*; 2) the government can create a non-market institution to provide RD&E equal to *Qs* (or the shortfall between *Qp* and *Qs*); 3) the government can provide a subsidy to private firms equal to the per unit value of the spillover; or 4) the government can correct the market failure by creating complete IPRs that allows the private firm conducting the RD&E to exclude others from using the resulting innovations. In this simple description, the IPRs would convert the innovation from a good that has to be provided by the public sector to a private good.

Figure 13.1. The private provision of goods in the presence of spillovers



Spillovers and voice

When spillovers exist and it is not feasible to create IPRs, the nature of the group that receives the non-market benefits is important for policy makers. Illustrating this point, Ronald Coase (1974) took issue with Samuelson's premise that government should pay for the provision of lighthouses because they create "public" benefits. Coase used the example of Trinity House, which was a non-profit organisation run by ship owners that had existed in the United Kingdom since 1594, to argue that it was more efficient to create a non-profit organisation that could levy a tax on ship owners to fund lighthouses because ship owners had both incentives and the knowledge to balance the cost of provision against the benefits created. In crop research, Alston, Freebairn and James (2004) argued that crop research levies are an effective crop research financing system because the burden of levy is shared by consumers and producers in roughly same proportion as the benefits that accrue from the research. Given this relationship, under a range of conditions, a producer-controlled levy-funded research organisation has the economic incentive to undertake the socially optimal amount of research.[2] Taking Coase's point, industry organisations are often very effective in AKS because they also have a superior understanding of their research requirements. Consequently, it is appropriate to give them voice in the total amount of investment and the allocation among projects and programmes.[3] More subtle questions concern how much voice ought to be given to other groups in society, and which groups.

At one end of the spectrum is a board comprised entirely of producer representatives. Under some circumstances, such a board operating to maximise benefits to its producer constituents will maximise benefits to the broader community. But industry organisations will appropriately focus on the benefits to their members, and may undervalue investments for which the benefits entail substantial spillovers that are very broad or public in nature. Likewise, producers may not be well-informed about scientific possibilities, and producer-dominated boards may not well appreciate or give appropriate priority to the interests of downstream processors and consumers in product attributes and the like. In view of these considerations, it is likely to be appropriate to include a range of representation on boards administering levy-based funds, including scientific and other specialists and representatives of processors and consumers; and in some instances it might make sense to have government or some other broader body undertake the taxation and investment decisions.

Knowledge as a toll good

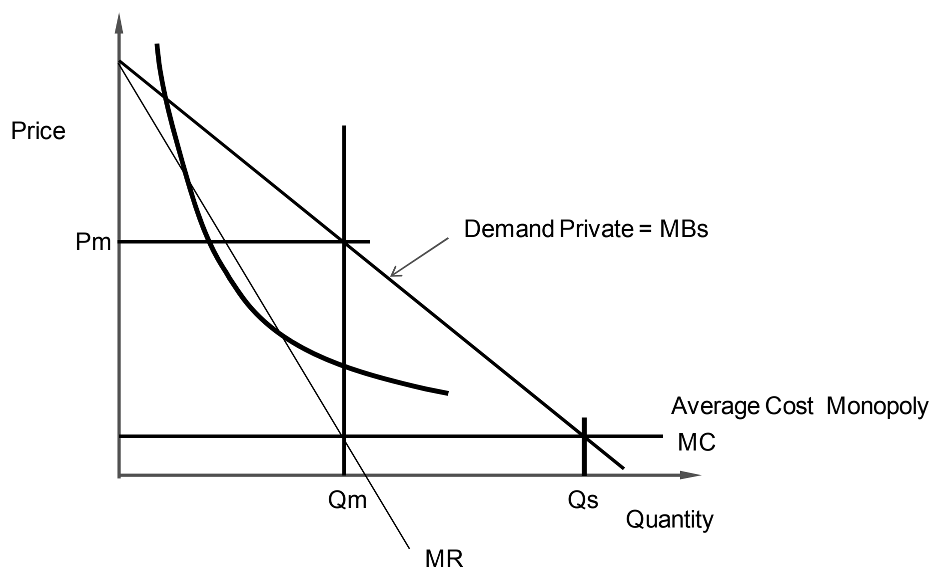
Excludability and non-rivalry

The economic literature also draws another important distinction between good types (e.g. Romer, 1994). In addition to excludability, goods differ in the extent to which use of them is rivalrous (often referred to as subtractability). Most economics goods are "rival," such that if they are used by one individual they cannot be used or consumed by another. For example, a sandwich is only eaten once, or a litre of gasoline is burned only once. However, some goods, including knowledge, are non-rival and are not diminished by use. Once created, these non-rival goods can be used any number of times and shared without incurring a marginal cost. In many cases knowledge is a classic public good in the sense that it is both non-rival, and non-excludable. Such goods will not be produced privately and, if produced by the government, must be provided for free to users.

Knowledge, when protected by IPRs, becomes a toll good (Lesser, 1998; Fulton, 1997). The non-rival nature of toll goods means that they are likely to result in significant market concentration if they are used as key inputs into a production process (e.g. new varieties protected by IPRs, used as inputs in production of seed). Because the toll-good input is non-rival, it only has to be purchased or created once. This fixed cost is incurred only once for each such good — for example, a new variety of soybeans — and the same genetic material can be used again and again without reducing its availability to others and at no additional cost. This means that the average cost of producing the final output (i.e. seed using this genetic material) decreases with the quantity produced because the cost associated with purchasing, or creating, the non-rival input (the new variety) is spread over more units of output. The declining average cost implies that large firms will always have a cost advantage over smaller firms. The lowest industry average cost can be achieved if the good is supplied by a single monopoly. Figure 13.2 shows the cost structure for the production of a product that is produced using a toll good. Toll-good industries for which fixed costs represent a large share of total costs, such as railways, software companies, or electrical distribution networks, are often referred to as natural monopolies.

The toll-good nature of intellectual property (IP) has profound implications for the cost structure of the research industry. Consider the case of breeding new wheat varieties. If one begins with a hypothetical situation where all research is organised in the most cost-effective manner and all the global knowledge generated is shared without transaction cost, this would be the lower bound for the industry average cost curve, where the research costs are minimised. This average cost curve would be downward sloping as the fixed costs of the research that generated the particular innovation are spread over more and more units of output that use that innovation.

Figure 13.2. The cost structure toll-good monopolist



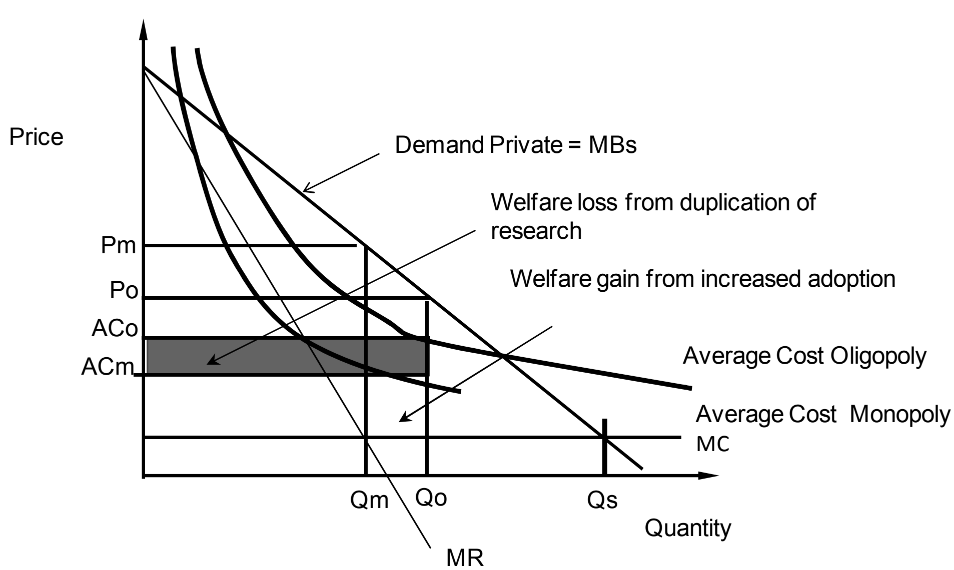
Market power versus research fragmentation

Here is the dilemma. If the wheat breeding industry were made up of one firm, the firm would have the incentive to minimize costs and would operate on this industry minimum average cost curve. However, when a firm is selling to the whole market, the demand for the a new technology, trait, or variety will be price sensitive, (downward sloping) and the single firm will have an incentive behave as a monopolist and maximise its profits by setting the price of the new variety such that the marginal revenue is equal to the marginal cost (Moschini and Lapan, 1997). For example, Monsanto, which has a monopoly on its Roundup Ready™ technology, will not earn rents if the price is set so high that farmers will not adopt the technology or so low that that Monsanto has no margin. The management is paid to find the price where the return to share holders is maximised and this will always be at point where price is greater than the firm's marginal cost. This "monopoly" pricing behaviour reduces economic surplus by deterring adoption. Economic benefits to society are forgone because the price precludes some farmers from adopting, who could benefit and would be willing to pay more for the technology than the zero marginal cost of licensing another acre but are precluded because of the price charged. For example, if Monsanto charges USD 15 per acre for the use of its Roundup Ready™ technology, all farmers who are willing to pay less than USD 15 acre do not adopt the technology even though no resources would be required by

Monsanto on the margin to provide this benefit. As drawn in Figure 13.2, the variety would be sold at price *Pm*, which would create a deadweight loss by inhibiting adoption, compared with a scenario where the technology was free (i.e. the price is zero) or Monsanto could price discriminate perfectly, and charge each farmer his willingness to pay for the technology. In sum, a single firm will operate on the lowest industry marginal cost curve monopoly but will create economic inefficiency by charging a price that is socially too high, (greater than marginal cost), which deters adoption, unless it can act as a perfectly discriminating monopolist.

Competition reduces price but creates another issue. If the industry is profitable it will attract entry by other firms. Typically, research-intensive industries have more than one R&D firm. If two firms were engaged in any form of price competition, this would decrease the price charged for seed and reduce the efficiency loss associated with the over-pricing of the research output. However, this increased competition also comes at a cost. If two identical firms were engaged in research, and each produced effectively identical varieties that were sold to one half of the market, each would incur the fixed cost of research. This duplication of effort would double the research cost, which would shift the industry average cost upward, imposing a loss on society. The net effect on social welfare is difficult to assess. On one hand competition reduces seed prices toward marginal cost, encouraging adoption, on the other hand the duplication of effort increases the cost of the research. This effect is illustrated in Figure 13.3. The entry of additional firms reduces the oligopoly price *Po* below the monopoly price, *Pm*, which encourages more adoption. However, firm entry also increases the average cost of research for a given research outcome, from *ACm* to *ACo* because of the duplication of research effort. While the optimal amount of entry is difficult to assess, the toll-good nature of the research makes this dilemma nearly impossible to avoid in an unregulated private market. As shown in Figure 13.3, the net effect of firm entry will be the gain in surplus from additional adoption minus the additional research costs associated with the duplication of effort.

Figure 13.3. The welfare impact of entry in a toll-good industry



Experience in agricultural biotech crop research industry in North America

In North America, the Plant Variety Protection Act, utility patents and hybrid technologies have allowed strong IP protection, and created powerful economic incentives for private investment in several field crops, most notably in corn, soybeans, canola and cotton. As theory would predict, the toll-good industry is dominated by a small number of firms, each with research programmes large enough to capture some of the economies of scale (Howard, 2009). The impact on research investment in these crops has been substantial. As reported by Wilson and Dahl (2010), the five largest firms have made substantial and growing investments over the past decade, and invest a sum of approximately USD 2 billion per year in crop genetic improvement.

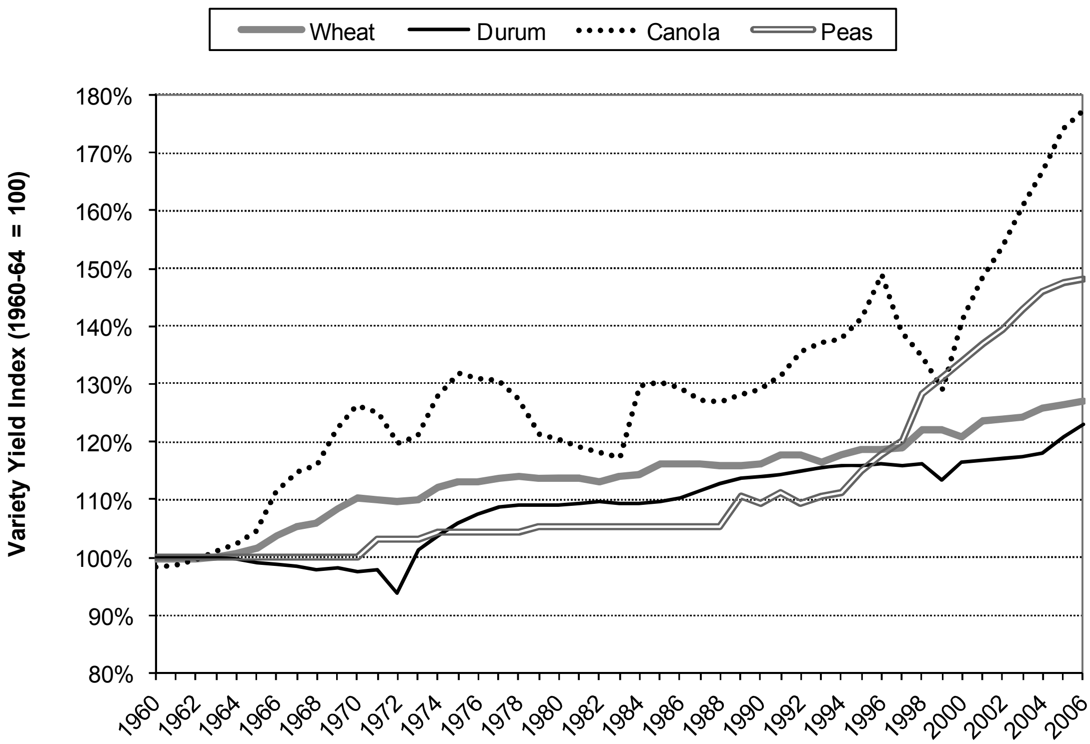
The impact of significant private investment is apparent in a number of ways. First of all, for the large crops in the United States, where IP can be protected by utility patents or hybrid technologies, producers have made the decision to adopt privately-owned varieties. The adoption of private varieties is virtually 100% for corn and well over 90% for soybeans and cotton. Transgenic herbicide tolerance has been especially important for soybeans, allowing the crop area to expand considerably. In corn insect resistance, herbicide tolerance, and other genetics have allowed yield to continue to increase. In cotton, insect resistance has reduced pesticide use. Generally, the gains from the research include increased farm productivity, greater crop production, reduced pesticide use, consumer benefits though lower prices, and a return to share holders (Zilberman *et al.*, 2010; National Research Council, 2010).

In Canada, canola has become the second-largest crop after wheat and is a remarkable success story. Public research and breeding that began in the 1960's created double low rapeseed in Canada, genetics that were trademarked as "Canola". During this embryonic period, the Rapeseed Association of Canada was an important catalyst for industry development (Gray *et al.*, 2001). In the 1980's, with the development of patentable transgenic processes the private sector began to make significant investments in canola genetics. Soon afterward Agriculture and Agri-Food Canada made a decision to withdraw from the commercial seed development and move its research upstream to support the private seed industry. Privately-produced, herbicide-tolerant varieties were introduced in the mid 1990s and reached nearly complete adoption by 2005. In the latter part of this adoption period, hybrid varieties were introduced and now dominate seed sales. This innovative industry recently developed and commercialised high oleic Canola creating a fatty acid profile that reduces trans-fatty acid development during frying. Grown on over a million acres, in value and volume terms, high oleic may be the largest engineered functional food in the world.

Private research has been substantial during the past decade but little information is available publicly about private expenditures levels. A 2007 survey of the industry by the Canadian Seed Trade Association (CSTA, 2008), estimated a total investment of CAD 56 million in private plant breeding investment in 2007. Of the total of CAD 102 million per year of planned investment in 2012, 75% was for canola research (CSTA, 2008). Although, the public institutions no longer produce commercial varieties, public institutions continue to invest up to CAD 20 million per year in pre-breeding research and germplasm development.

Yield potential of canola has grown much faster for canola, for which R&D is primarily privately funded, than wheat, for which R&D is primarily publically funded in Canada. As shown in Figure 13.4, the yield index for adopted canola varieties has grown 75% since 1960 and has shown strong growth in the past decade. In contrast, the yield index for wheat and durum varieties have only increased by roughly 25% during the same period. As a result, canola has increasingly become the crop of choice for many producers, with the expanding seeded area being constrained only by climate suitability and crop rotations for the management of fungal diseases.

Figure 13.4. Adoption weighted variety yield index by crop, Western Canada, 1960-2006



Source: Veeman and Gray (2010, Figure 6.5, p. 132).

The benefits from private investments in canola have been widespread. Producers enjoy higher yields, lower herbicide costs and more flexibility in the timing of herbicide application. The canola processing industry has also expanded and the seed companies enjoy strong seeds sales with high seed prices. Positive human health benefits may have accrued to consumers from lower saturated fats and the higher oleic acid profiles.

Despite the widespread adoption of privately developed varieties, and the apparent gains from the additional research investment, the developments in the North American seed industry have not been without controversy. Issues of market power, seed pricing and knowledge sharing have both come under some scrutiny from economists and regulatory bodies (Stiegert *et al.*, 2010; Wright and Pardey, 2006; Wilson and Dahl, 2010).

The protection of IP afforded by hybrid technologies and patents has had a significant impact on the development of a private seed industry for several important crops. As shown in Table 13.1 the pattern of seed sales and research expenditure for US corn, US soybeans and Canadian Canola, have some striking similarities. Each industry seed sales represent roughly 10% of gross crop income, seed production costs are a small fraction of the seed prices, and each seed industry invests about 10% its gross sales into research (i.e. about 1% of gross crop income).

The approximate rate of 1% of gross farm sales invested in variety development by the private firms for corn, soybeans, and canola is significant. This investment rate is two to three times the total public and private investment rate for wheat breeding in Canada. Thus, IPRs are a policy tool that can be used to address the underfunding issue as identified at the outset of this paper. This funding mechanism may represent a significant improvement over an underfunded public research system, especially considering the scale economies enjoyed by these large multi-national private firms.

Table 13.1. Estimated revenue, rents and research expenditures for IP protected crops, 2010

2010 estimates		US corn	US soybeans	Canadian canola
Farm seed costs per acre	USD	75[a]	52[a]	46[b]
Area sown	Million acres	88[c]	79[c]	17[d]
Total seed expenditure	USD Million	6 593	4 100	773
Gross value of crop at farm	USD Million	66 700[e]	38 280[e]	5 074[f]
Seed cost/ farm gross income	**%**	**10**	**11**	**15**
Seed production costs	USD/bushel	24.0[g]	13.5[h]	56.0[g]
Seed rate	Bushel/acre	0.25[i]	1.20[j]	0.10[k]
Seed production costs	USD/seeded acre	6.0	16.2	5.6
Total seed production costs	USD Million	527	1 280	94
Gross seed margin	USD Million	6 065[l]	2 820[l]	578[l]
Total private research expenditures on all crop improvement research	USD Million	2 000[m]	2 000[m]	87[n]
Specific crop % of total private	%	34[o]	17[p]	75[q]
Estimated crop-specific research expenditures	USD Million	680	340	65
Private research/farm gross	**%**	**1.0**	**0.9**	**1.3**
Private investment/gross seed margin	**%**	**11.2**	**12.7**	**9.6**

a. NASS, USDA Farm Prices Paid 2011, USDA.
b. Author's estimate based on USD 8 per pound paid in 2010 plus a USD 15 Technical Use Agreement fee for Roundup Ready™ Canola on 40% of area.
c. USDA final seeded acre estimate.
d. Statistics Canada 22-007 final estimate.
e. NASS, USDA Crop Values Annual Survey.
f. Statistics Canada 001-0010.
g. Hybrid seed production cost estimated as four times the cost of non-hybrid commercial price of USD 6/bushel.
h. Estimated as 1.5 times the cost of commercial production.
i. Thirty thousand seeds per acre at 2 000 seeds/pound.
j. Seventy-two pounds per acre.
k. Five pounds per acre.
l. Gross value on seed purchases – seed production costs.
m. Wilson and Dahl (2010).
n. Private research expenditure estimate 2007, Canadian Seed Trade Association.
o. Based on corn's share research in 1996 reported in Fernandez-Cornejo (2004).
p. Corn research estimate x soybeans/corn sales.
q. Author's estimate.

A striking feature of these profiles is the 10% share of farm gross income revenue going to seed purchases. This large share of gross income is similar in size to the factor share for land rental. This indicates that producers benefit a great deal from these new varieties and are willing to pay for them, and that with IPRs the seed firms are able to capture a significant portion of the benefits from varietal improvement. It also suggests that these seed prices are high enough to materially affect adoption decisions and that at lower seed prices the adoption of these crops would be even more widespread.[4]

The fact that these seed prices are well above the marginal cost of seed production is consistent with the toll-good nature of the industry (Moschini and Lapan, 1997). The economic significance of seed cost has attracted the attention of economists. Several recent studies by Stiegert, Shi, and Chavas (Stiegert *et al.*, 2010) have found that the pricing of traits is correlated with measures of market concentration. Wilson and Dahl (2010) and Fernandez-Cornejo and Caswell (2006) argue that, on balance, the economies of size realised by concentration more than offset the higher pricing incentives. As recently as 2007 the Anti-Trust Division of the US Department of Justice held an inquiry into Monsanto's pricing behaviour (Wilson and Dahl, 2010). While unresolved, this issue continues to be a concern for policy makers.

As mentioned previously, the non-rival nature of knowledge makes industry cost a function of the degree to which knowledge is shared. Concerns over knowledge sharing and exchange in the crop research industry have been documented in a growing economic literature. A firm might not license its protected IP for several reasons. The first is the management of strategic assets. When firms are in close competition, they may deliberately keep their proprietary knowledge secret rather than license it to a rival. Second, an anti-commons problem (Graff *et al.*, 2003; Heller, 1998; Wright and Pardey, 2006) can exist. If many firms own complementary IP, the *ex post* bargaining behaviour of the individual owners may make it difficult and sometimes impossible to reach an incentive-compatible sharing agreement among all of the requisite owners. The classic case of this is GoldenRice™, which was estimated to contain 40 pieces of IP in the United States that were owned by at least 12 different organisations (Kryder *et al.*, 2000). Finally, the large number of IP claims can give rise to excessive transactions costs. To illustrate the vast number of patents, on 20 March 2011 a simple search of the US patent database revealed 3 054 patents that are related to stress tolerance and wheat. Searching this large database and identifying which patents are potentially useful, determining what patents are enforceable, and what IP can be safely used without violating other patents, is a time-consuming and costly undertaking. The result, often called the «patent» thicket (Wright and Pardey, 2006), adds to the cost of protection and use of IP. For all of the above reasons, firms often have not licensed their IP and have opted to develop their own research platforms, which duplicate effort and drive up the industry cost curve.

Despite the obstacles, some private mechanisms for sharing knowledge can and do evolve. This is important because the lowest industry average cost curve can be achieved with multiple firms in the industry if they can find a way to "share" toll goods. Research consortiums, where the funding partners agree to share the knowledge generated, have been used occasionally by both public and private research institutions. Since 2005, the largely autonomous multinational biotech firms have developed numerous cross-licensing agreements amongst firms (Smyth and Gray, 2011; Galushko *et al.*, 2010; Howard, 2009). These agreements allow for genetic traits and processes owned by separate firms to be combined (or stacked) and marketed as bundles. This is a very important development because it allows the non-rival knowledge to be shared, which lowers the cost of creating superior genetics. However, these agreements can also constrain the nature of competition among firms, by establishing licensing fees, pricing protocols and bundling options.

In summary, the strong IP protection brought about by biotech-related utility patents and hybrid technologies has been successful in simulating substantial private investment, and created significant economic benefits by reducing the underfunding of crop varietal research. In doing so, this strong IPR regime created a concentrated toll-good industry, with extensive economies of size giving rise to concerns over incentive problems related to pricing, versus fragmentation or duplication of effort. As has occurred in other sectors of the economy, the emergence of a toll-good industry may have implications for economic policy, the role of the public research, and the viability of alternative institutional arrangements in AKS. The remainder of this paper will explore some of these alternatives.

Alternative institutional arrangements to manage toll goods

In general, governments have used five main approaches to managing toll goods (Fulton and Gray, 2007).

- Government produces the toll good through a subsidy.
- Government produces the toll good through a non-profit state monopoly that receives limited subsidies.
- Government grants a private firm the monopoly power to provide the good, but then regulates the rate of return (or pricing or other aspects of the firm's economic activities).
- Government allows an oligopoly to produce toll goods with some regulations to enhance entry and competition among firms.
- The government creates or facilitates the development of a non-profit organisation to produce the toll good.

Examples of most of the approaches mentioned above can be found in AKSs. Governments have often created publically funded research institutions that provide knowledge to the sector gratis. Crop breeding undertaken by government has the advantage of solving the over-pricing issue, but typically suffers from public under-funding and other efficiency issues related to market responsiveness and researcher incentives.

In an attempt to improve governance of research, governments have often also created parastatal organisations or state-supported research institutions, which use a corporate reporting structure and operated at arms length from government control. Universities and other non-profit institutions often receive public support for their research, but are given incentives to use property rights to earn revenue from their IP. However, if such institutions evolve to the point of becoming profitable, governments often sell or privatize them for fear of crowding out private investment.

The third option, to sanction a private monopoly with a regulated rate of return, is common in public utilities but very rare, or perhaps even non-existent, in AKSs. If examples do exist they would be interesting to examine.

The fourth option, of regulating an oligopoly, is more common in agricultural research. In the hybrid cotton industry, the Department of Justice required Monsanto to divest itself of a seed company and some cotton seed lines as part of a merger with Delta&Pine Land to prevent over-concentration in the industry (DOJ, 2007). IPR rules have also been designed to enhance competition. In the case of conventional breeding, most of the valuable genetics are embodied in the latest varieties. Sharing of this knowledge among competitors was achieved through a "breeders' exemption" which allowed other breeders to use others' varieties in their breeding programmes (Holman and Galushko, 2007). In effect, this allowed potential competitors to use the knowledge created by other breeders. Other than the sequential aspect, the breeder privilege is not dissimilar to the access regulations for telecom and electrical networks where governments regulated the access to these toll goods in an attempt to enhance the competitiveness of the industry without a costly duplication of effort.

The fifth option, to create a levy-funded, non-profit organisation to undertake research, is common in AKS. Many countries enable industry organisations to levy a tax on production (or collect a tax on behalf of a producer organisation) to generate revenues that can be used for research and/or market development. As mentioned previously these organisations often have the additional advantage of giving voice to the downstream users of the research. In North America, producers can organise, develop plans, and vote to create levy-based research programmes, wherein producers can manage levy-based funds for the purposes of research and development. This approach avoids the over-pricing issue and has the advantage of giving industry voice in research funding and allocation decisions. Many of these organisations however also suffer from collective underfunding because of producer heterogeneity and horizon problems and may not have the economies scale or scope of larger private research organisations.

Of the five policy options used to provide toll goods discussed above, the fifth option is perhaps the most appealing from an incentive compatibility perspective and moreover there are existing examples of success. The use of these types of organisations are used in AKS has direct implications for the role and scope of public institutions involved in research. While we can find many examples of producer levy organisations undertaking research, some are more successful than others. The Saskatchewan Pulse Growers and the Grains Research and Development Corporation in Australia stand out as examples of organisations that have been successful in investing a significant amount of levy-based funding for the benefit of the producers and others they represent.

Levy funded research

Any royalty paid to variety owners does not reflect the marginal cost of using the knowledge but instead is a contribution toward the fixed cost of the R&D used to create the IP. Any royalty charged for new IP will discourage adoption, compared with the theoretical ideal of pricing at the marginal cost or replication, zero. Second, market mechanism exists, other than costly firm entry and duplication of effort, to ensure that the royalty charged by a private industry will approximate the total cost of providing the knowledge.

Levy funded research controlled by downstream users has several advantages over the use of strong IPRs to fund research:

- Because the funding of research comes from a levy on output, royalties can be set at zero to encourage the most rapid adoption of the new technology.

- Downstream users have an incentive to consider any spillovers that they may receive from the research in their funding decisions, so they can fund RD&E even without complete IPRs. For example, growers have an incentive to fund even unprotectable agronomic research.
- The voice given to the downstream industry is important because they have the incentive to determine the appropriate amount of research because the users of research are paying for research.
- At the local industry level these organisations can encourage knowledge sharing and discourage unnecessary duplication of effort without creating pricing and incentive problems.
- As semi-private institutions these organisations may be better able than government to enter agreements with the private firms in the research industry.

The primary obstacle faced by some levy-based organisations is related to collective action and the free-rider problem. Some levy-based programmes are mandatory, with all participants obliged to contribute; others are voluntary, such as some a Canadian schemes that have allowed refunds of levies that are collected in the first instance on all of production. In a voluntary scheme, including programmes with refundable levies, research benefits can accrue as a type of spillover to producers who choose not to pay the levy and instead to free ride on their neighbours' contributions. Voluntary levies tend be maintained at very low rates to mitigate the tendency for some producers to opt out and free ride on the benefits.

Saskatchewan pulse growers

The Saskatchewan Pulse Development Board, also known as Saskatchewan Pulse Growers (SPG) provides an excellent Canadian example of how growers can become actively involved in crop breeding and drive the development of an industry. The SPG is funded through a check-off of 1% of the value of the gross sale of all pulse crops in the province of Saskatchewan. Unlike other commodities, which in Saskatchewan are all established as Commissions, the SPG's levy is mandatory (i.e. non-refundable). In 2003, after twenty years of success, growers voted for an increase in the levy rate from 0.5 to 1%. This levy rate is similar to that of the Australian GRDC and is far higher than the rates that exist for other Canadian crops. For example, the Western Grain Development Fund levy is less than 0.2% current gross revenue.

SPG currently represents over 18 000 pulse crop producers in Saskatchewan and is directed by a board of seven elected pulse farmers, who are each elected for a three-year term. The Pulse Crop Development Plan Regulations, originally written in 1984 and subsequently amended through Board Orders, outline the mandate of the organisation and its legal ability to collect the check-off. Under the Provincial Natural Products Marketing Act (the Agri-food Act), pulse buyers must register with SPG annually, collect the check-off on all purchases (like a sales tax) and make monthly payments to SPG with complete producer information. The Saskatchewan Agri-Food Council, an independent body appointed by the Minister of Agriculture and Food, supervises the activities of all organisations established under the Agri-Food Act.

The revenue base of the SPG has grown with the industry. Between 1985 and 2004, CAD 25 million was collected. With expanded acreage and higher prices, annual revenues have exceeded CAD 12 million in each of the past two years. Governments do not provide matching funds to the pulse levy but do offer research tax credits and have been active in providing research infrastructure and other support for pulse research. SPG has noted the decline of Saskatchewan government funding in recent years.

Saskatchewan Pulse Growers use the revenue from the check-off to fund research projects, extension and communications activities, the variety release programme and general operations of the organisation. It has been used for a number of activities of direct benefit to growers. These include support of the University of Saskatchewan's Crop Development Centre's (CDC) pulse breeding programme, royalty-free seed to select-status seed growers, agronomic research, Pulse Days, the Pulse Production Manual and efforts to increase demand through domestic and international market development programmes. SPG also invested with provincial and federal governments in new facilities at the CDC.

The CDC is the exclusive recipient of funding for breeding through the SPG check-off. All developed varieties are technically owned by the CDC; however, the SPG receives exclusive rights to distribution of all new CDC pulse varieties in exchange for its financial contribution. SPG in turn provides industry access to new pulse varieties through several different release programmes, each designed to maximise grower returns from their investments.

The new varieties bred for large established markets are distributed under the general release programme, which offers seed to all select-status seed growers in Saskatchewan and Alberta on a royalty-free basis. This wide distribution ensures competition in seed propagation and distribution. Under the Niche Variety Release Program, a single firm is given exclusive access to a new class of pulses for a decade, in return for royalties paid to SPG. This gives the private firm the time and incentive to develop these markets. A private firm is also given the rights to foreign distribution of new varieties (after a period of time) in return for royalties, thereby giving the firm the incentive to market and protect these varieties where it is possible to do so. The SPG grants access to BASF for certain lentil varieties so the firm can incorporate the Clearfield™ herbicide tolerant trait. To ensure fair pricing of the Clearfield varieties, SPG releases the same variety without the herbicide tolerant trait at least a year prior to the Clearfield variety. Finally, the SPG has offered financial compensation for some private firms that agree to release independently developed varieties so that they can compete with the royalty-free CDC varieties.

The SPG breeding programme has been a remarkable success. The programme has developed an industry that provides benefits for growers and the industry as whole. Gray *et al.* (2008) estimates that over its first 25 years of its existence producers have earned a 20% annual internal rate of return on their check-off investments. As shown in Figure 13.4, Saskatchewan pea variety yields increased nearly 40% in just two decades. The pulse industry has also helped to diversify the income base of growers, while extending crop rotations, improving soil organic matter, and sequestering carbon from the atmosphere.

The SPG is an example of levy-funded, producer-controlled AKS that has effectively addressed many of the market failures related to knowledge and technology spillovers and the toll-good nature of IP. While the corporate research sector is also involved in pulse research, the SPG has retained control over the germplasm and varieties it has funded. The ability of the SPG to work with governments and the corporate sector, and to have growers recently vote in support a 1% levy is a testament to its success.

The Australian AKS

The Australian AKS has undergone very significant transformation over the past 25 years, moving from a predominantly publicly funded and managed system to one where levy and royalty-based funding play primary roles in applied research, development and extension. The Grains Research and Development Corporation (GRDC) was established in 1989 under Primary Industry and Energy Research and Development Act, which established more than a dozen "Research and Development Corporations" (RDCs) each related to a different sector of the rural economy. The GRDC is funded by a mandatory non-refundable research levy of 1% on the farm sale of 25 field crops, which is matched by the Australian Government up to a maximum of 0.5%.[5]

The GRDC reports to an eight member board of directors appointed by the Commonwealth Department of Agriculture and Fisheries (GRDC, 2011); six of these members are appointed by a national producer organisation. The GRDC has three regional advisory councils and one national advisory council that provide a voice for regional research priorities. In addition to this formal regional representation, the GRDC and its panels hold regular meetings with producer organisations to gather input into research priorities (GRDC, 2011).

While the RDCs collectively play a major role in financing agricultural research in Australia, they only account for one-third of total research funding. Several federal agencies and state governments fund different aspects of agricultural research. As a large pool of resources organised at the national level, the RDCs have been successful in providing a funding and research coordinating mechanism for commodity crops.

A second very important catalyst of change in the Australian AKS was a change in plant breeders' rights (PBR) in 1994 that allowed variety owners to charge end-point royalties (EPRs) for their varieties. With an end-point royalty, any farmer who grows a PBR variety is required to pay a specified royalty to the variety owner on every ton of grain produced and sold, which allows the variety owner to capture a return, even with farm saved seed. With this development, the GRDC saw an opportunity to develop fully commercial wheat-breeding programmes and put out a tender, looking for partners to create three new wheat breeding companies. After a period of transitional support from the GRDC, each firm will eventually be funded entirely from end-point royalties. As outlined in Table 13.2, each company has a minority multinational shareholder, which has been an important source of technology for these fledgling wheat-breeding firms. Meanwhile, the GRDC, which no longer has to fund breeding activities for wheat, can divert its resources to pre-breeding research, further enhancing the stock of knowledge in the Australian AKS.

From the perspective of managing toll goods, the future developments in the fledgling commercial breeding industry will be interesting. With further adoption of existing varieties and increasing EPR rates, this breeding industry can look forward to rapidly growing royalty revenue streams in an industry where market shares will be determined by a few key varieties. It will be interesting to see how these commercial firms — with GRDC, public, and private shareholders — will price their varieties in the future. Will they set price equal to average cost or to maximise the return to shareholders? If they are profitable will they expand research or return dividends to shareholders? If dividends are paid, where will the GRDC and public shareholders reinvest these funds? Given the economies of scale and the potential volatility of revenue, will we see mergers among these firms? While the answers to these questions are still unclear, the presence of the GRDC and public institutions as significant shareholders, can reflect the interests of downstream producers and the public in future decisions as they grapple with toll-good issues.

Table 13.2. Major wheat breeding corporations in Australia 2010

Australian Grain Technologies Pty Ltd
Location and staff: Adelaide, Narrabri, Dubbo, Horsham, Roseworthy, Esperance, Perth: 48 full-time employees.
Shareholders/owners: Vilmorin & Cie (Limagrain), South Australian Research and Development Institute (SARDI), University of Adelaide, Grain Research and Development Corporation (GRDC) (39%).
Breeding programme: Five wheat breeding programmes for varieties adapted to different agronomy/growing conditions and soils including daylight length, temperature, soil type, diseases and specific regional quality needs.
HRZ Wheats Pty Ltd
Location and staff: Canberra and Lincoln (New Zealand): equivalent of five staff under contract with the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and New Zealand Institute for Plant and Food Research (NZPFR).
Shareholders/owners: CSIRO, NZPFR, Landmark Operations Ltd, GRDC (40%).
Commercial partner: All HRZ varieties are marketed through Australian Wheat Board (AWB) Seeds.
Breeding Programme: International and national gene pools; spring wheats and winter wheats; hard milling wheats.
InterGrain Pty Ltd
Location and staff: Perth, Wongan Hills, Melbourne, Horsham: 30 staff.
Shareholders/owners: Western Australia State Government, GRDC (35%), Monsanto.
Commercial Partner: All InterGrain wheat varieties are marketed through Nuseed, www.seedpool.com.au.
Breeding programme: Three regional breeding programmes servicing Western Australia, South Australia, Victoria and New South Wales; a specialist programme provides support in fast tracking disease resistance and elimination of critical defects; and a research and development programme in collaboration with Monsanto to increase the use of genotypic technologies in the core breeding programmes.
Longreach Plant Breeders Pty Ltd
Location and Staff: Narrabri, Clare, Melbourne, York, Adelaide: ten staff.
Shareholders/Owners: Pacific Seeds Pty Ltd, Syngenta.
Breeding Programme: Breeding for four distinct regions, plus breeding alliance for soft wheats.

Source: Grains Research and Development Corporation, GRDC (2011).

Crop research funding in Australia has several attractive features. The introduction of the RDCs has increased the amount of agricultural research being conducted, while committing government expenditures and establishing a national coordinating mechanism. Levy-based funding can still operate where spillovers are large. The establishment of EPRs along with direct investments by the GRDC and State governments has attracted some multinational investment and technology, and established a private seed industry. The combined presence of GRDC and public shareholders as co-owners of the firms changes the incentives and expected behaviour of this toll-good industry, presenting a mechanism for dealing with over-pricing and knowledge-sharing issues that would arise otherwise.

An interesting variant of the Australian and Canadian levy models occurs in France, where farmers pay a uniform levy of EUR 0.5 per tonne of bread wheat marketed. While 15% of the levy is invested in variety testing, the remainder is paid to variety owners in proportion to the tonnage of each variety sold. In effect this is a uniform end-point royalty paid to variety owners. The French levy rate, which is negotiated between the farmer organisations and the seed industry, is too low to support significant amounts of research. If able to operate with a higher levy rate, the French system could create an interesting funding model for the toll-good research industry, by being able manage research spillovers and output pricing, while creating strong incentives for innovation.

Conclusion

Research spillovers and the non-rival nature of knowledge are both sources of market failure. Policy makers have responded to research spillovers firstly with the public provision of crop research. Over time, IP rights have been developed to address some forms of knowledge spillovers, creating incentives for the private provision of crop research.

Well-established IPRs stimulate the development of a private agricultural research industry with economies of size and the cost structure of a toll-good industry. In these industries market power and the costly fragmentation of effort are both significant issues. In crops where hybrid seed and patented traits play a significant role, seed prices have risen significantly over time. Farmer now pay upwards of 10% of gross revenue to access these superior varieties, which limits adoption. Approximately 1% of gross crop revenue is invested in private breeding activities.

Given the persistent economic losses associated with spillovers, market power, and research fragmentation, both public and levy funded research organisations can play an important role in creating efficient agricultural knowledge systems. Industry-directed, levy-funded research can have an advantage over public-funded research by giving voice to downstream knowledge users.

Examples of successful levy-funded industry-directed crop research organisations include the Saskatchewan Pulse Growers and Australia's Grains Research and Development Corporation. The negotiated, uniform end-point royalty system used in the French bread wheat industry also has some interesting attributes for the management of a toll-good industry.

More research is needed to fully understand the economic implications of various institutional options. Toll-good industries will be encumbered by market power and fragmentation issues. A great deal remains to be learned about the operation of levy-based, industry-directed agricultural research funding organisations and the long-term effectiveness of their investments. These organisations have potential advantages from vertical integration, but face challenges related to the provision of collective goods. New partnerships with public and private firms need to be examined. The incentives and outcomes of various institutional structures require additional study, including the study of a variant where levies are used to provide uniform end-point royalties negotiated with downstream producers.

Notes

1. University of Saskatchewan, Canada
2. Alston (2002b) has also pointed out that heterogeneity within producer groups and the nearing retirement age of some producers may result in a systematic under investment by producer groups, which can be addressed by matching funding.
3. For a more in depth discussion of voice, see Picciotto (1995).
4. At these seed prices farmer have an incentive to restrict seeding rates to socially sub-optimal levels, creating another source of inefficiency.
5. The government matching of industry levies serves to offset a number of important incentive problems that may inhibit producer boards from setting high enough levy rates and at the same time it helps make up the difference between the national and industry interest. First, it recognizes that knowledge generated from research inevitably spills over to benefit other industries. Second, it recognizes that differences exist among producers in terms of their owned assets, abilities, ages, farm enterprises, locations, and propensity for adopting innovations arising from research investments, which mean they do not all stand to receive equal benefits from invested levy dollars. Third, it represents a credible commitment of government support, and makes it more difficult for governments to back away from funding research as industry increases its research investment.

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14. The role of business in working with government to develop Agricultural Knowledge Systems for global challenges: The New Zealand experience

Phil O'Reilly[1]

In New Zealand there is a shared analysis and understanding between business and government in the development of agricultural knowledge systems. Primary production underpins the economy. A key driver of New Zealand's international competitiveness is research and technology for agriculture. This section presents case studies to illustrate the private sector's experience in working with government to develop these knowledge systems to meet global challenges at the nexus of food security and climate change. This experience extends from developing near-science to near-market knowledge. The role of the private sector varies in this range to reflect, in part, the different risks, timeframes, competencies and value relevant to business.

Context

An agricultural trading nation

New Zealand's economy has historically had a strong biological focus. Its biological exports were worth NZD 31 billion in the year to May 2011, comprising 65% of total merchandise exports as shown in Table 14.1.

Table 14.1. Biological exports as a share of total merchandise exports

Product	% of total merchandise exports
Wool and textiles	3
Seafood	3
Crops	3
Horticulture and wine	6
Forestry	10
Meat and co-products	14
Dairy	26
Total	65

Source: NZ trade statistics, accessible at: www.stats.govt.nz/browse_for_stats/industry_sectors/imports_and_exports/overseas-merchandise-trade-info-releases.aspx.

This very high biological dependency has implications for New Zealand's agricultural knowledge system, which are amplified by its globally important role as an agricultural trading nation, especially in regard to sheep and game meat, kiwifruit and dairy products, where its share of world production is low, but share of world trade very high for such a small country (see darker cells in Table 14.2).

Table 14.2. Share of New Zealand in world agricultural production and trade, selected commodities

	Production, 2009		Trade, 2008	
	World	New Zealand share	World	New Zealand share
	Million tonnes	%	Million tonnes	%
Beef	62.8	1.0	1.54	1.8
Wool	2.0	8.8	0.56	6.7
Sheep meat	8.2	8.8	1.03	**38.4**
Game meat	1.8	1.5	0.06	**25.5**
Liquid milk	583.4	2.6	Insignificant	None
Cheese			4.44	4.8
Milk powder			3.91	**19.7**
Butter			1.40	**21.5**

Source: Food & Agricultural Organisation statistics, Production figures accessible at: *faostat.fao.org/site/569/DesktopDefault.aspx?PageID=569*.

Four factors that affect agricultural knowledge systems are particularly important for a small trading nation such as New Zealand: global food supply, human population, climate change and research and development.

Food supply

Sustainable and secure food supply is now a national and geopolitical imperative for many countries that are seeking, for three reasons, to secure sources of food protein and carbohydrate. The first reason is a soaring global human population, which is forecast to rise by some 32% from about 6.96 billion today[2] to peak at about 9.22 billion in 2075.[3] The second is increasing demand for higher quality food generally and protein especially amongst people of increasing socio-economic status. The third is climate change. These three factors create significant opportunities for businesses (Section 9).

Human population

Although New Zealand's very high agricultural productivity and high proportion of global dairy and sheep meat export trade suggests that it could have an important role to play in helping to feed the soaring global human population, it is constrained from doing so by its small size, low proportion of cultivable land, and relatively poor soils (that require high fertiliser inputs), as well as its economic need to maximise export revenue.

Consequently, the country has increasingly focused its food production and processing capabilities on higher value products. Doing so requires much greater integration throughout the value chain from behind the farm gate to end market, and the provision of very high quality and nutritious food to consumers whose expenditure is driven by discretionary choice, not hunger. New Zealand businesses must pay close attention to the sustainability and environmental concerns of such people and to those who seek to gain advantage by supplying them, such as large supermarket chains. Businesses must also note that consumer demands are increasingly extending to knowledge of and a desire to influence the system that produces and supplies their food. New Zealand's agricultural production and knowledge systems must be responsive to this trend.

Climate change

Forecasts indicate that a warming global climate will have variable effects in New Zealand because of its mountainous terrain, with parts of the country becoming drier and parts wetter, accompanied by more frequent and severe weather events around the mean.[4] Droughts, for example, are expected to occur more often, while moisture precipitation will be more uneven across the year and include more severe events such as flooding, hail and snow. These trends, which are already evident, are of high significance in a temperate country with pasture-based livestock production outdoors year-round, and will necessitate significant changes to production practices.

Climate change will also bring significant bio-security implications to New Zealand. Because of its geographic isolation and late human settlement, New Zealand has enjoyed a very high level of freedom from weeds, pests and diseases that threaten agricultural productivity in other countries. This advantage will not be easily maintained. Increasing international trade and tourism are greatly expanding the opportunities for the introduction of invasive foreign organisms,[5] while warming conditions will create new and favourable niches for species that were not previously able to survive in New Zealand.

Research and development

Much agricultural research and development in New Zealand, particularly that of a longer-term and strategic nature, is funded by the government because individual farmers are unable to appropriate all the within farm gate benefits, and because of the wider spill-over economic and social benefits to the country. However, the business sector also plays a significant role, both in funding research and development, and in participating in the country's agricultural knowledge system.

Ongoing agricultural production at levels of efficiency and quality will enable New Zealand to continue to play such an important role in global food trade; to meet consumer demands regarding food safety, quality and sustainability; and to respond to the many threats arising from climate warming. These will all require ongoing investment in research and development by New Zealand businesses and government.

A companion paper presented at this conference by Ms Karla Falloon, Counsellor (Science and Technology) in the New Zealand Mission to the European Union, describes the institutional landscape of the New Zealand agricultural knowledge system, including its universities, Crown research institutes, and Centres of Research Excellence.

Business-government interaction

Agriculture has been important in New Zealand since the country was first settled, gaining added importance when regular shipping services enabled the export trade to begin. Business and successive governments have long recognised the challenges and opportunities, and shared their analysis of them. This has led to a clear recognition of their different but complementary roles, and ongoing willingness to work together.

The role of the business sector is to listen to customers and, based on their wants and needs, help to design and invest in agricultural systems that maximise productivity and capture sustainable value. This includes investing both in physical and biological infrastructure and, with government, in developing human capital with the requisite knowledge, capabilities and skills.

The government's role is to foster an innovation-friendly policy framework that provides certainty to businesses, and ensures an educational environment that produces people with the qualities needed by business. With an eye to the future, government must also foster innovation to enable the growth of sustainable new enterprises to help meet global challenges, and provide the policy and regulatory framework that enables business to realise the potential of New Zealand's intellectual assets. In response to climate change, the government works jointly with businesses in the agricultural sector to identify and respond pro-actively to threats such as biosecurity.

Table 14.3 provides a framework in which four types of innovation in New Zealand's agricultural knowledge system are identified. Each is exemplified by a form of collaboration between the key stakeholders involved, a policy instrument that the government uses to enable and facilitate progress, and a case study.

Table 14.3. Examples of innovations and related collaboration

	Type of innovation	Type of collaboration	Government policy instrument	Case study
1	High research intensity Science led Performed by the public sector	Public research, industry and agricultural producers	Biological Industries funding	Gold Kiwifruit
2	High research **and** development intensity Cross sector Performed by public and private sector	Public research with a business firm	University and Crown research institute funding	Precision Irrigation
3	High development intensity Industry led 50/50 public/private collaboration	Public funding with industry consortia	Primary Growth Partnership	Precision Seafood Harvesting
4	Low development intensity Industry led Performed by private sector	New Zealand firm in an international market	International trade linkages	Fonterra in China

A business case study for each type of innovation is identified in Table 13. 3. Each is now discussed below.

Case study 1: Gold kiwifruit

This case study exemplifies research led innovation in New Zealand's agricultural knowledge system, with high research intensity.

Kiwifruit were first introduced to New Zealand in 1904 when seeds of the 'Chinese Gooseberry' (*Arguta deliciosa*) were brought back to the country by a traveller to China. Plantings expanded slowly for the domestic market, and the 'Hayward' cultivar (*Actinidia deliciosa*) was developed in the 1920s. By the early 1950s it became apparent that an export market might be developed. This led to the development of an export-focused industry and the establishment of a grower owned co-operative – Zespri International.

Meanwhile, New Zealand kiwifruit growers had been experimenting with the natural development of a gold coloured kiwifruit since the 1970s. This on-orchard work fed into a much more formalised and intensive government-funded kiwifruit breeding programme that had begun in the 1980s. An excellent relationship between New Zealand and research entities in China led to the importation of further kiwifruit germplasm. More than 600 varieties were in development by 1987 and New Zealand now holds the world's largest kiwifruit germplasm bank outside China. Plants were selected for further development based on quality attributes such as size, colour, storage and shelf life, and then submitted to sensory panels in overseas markets.

A new golden-yellow coloured variety (*Actinidia chinensis*) was found to be sweeter than the Hayward, green coloured variety and emerged as a consumer favourite. However, intense and prolonged research effort was needed to develop the new variety to commercial readiness. Particular challenges were encountered in genetic improvement, the development of appropriate production management systems, and post-harvest technologies that would enable the new gold variety to be exported globally. As these technical challenges were met, intellectual property and brand management strategies were put in place. Plant Variety (intellectual property) Rights were obtained and the variety was licensed to Zespri, later being named Zespri Gold ® Kiwifruit. The new variety was released to growers in 1996 with strong technical support on all aspects of production and harvesting. The first exports began in 1998 followed by a full launch into international markets in 2000. The Hayward variety was rebranded as Zespri Green ® Kiwifruit.

Additional Plant Variety Rights have been applied for in other countries to enable licensed growers there to produce Zespri Gold Kiwifruit, thereby enabling Zespri to provide year-round supply to global markets.

In the year to November 2009, Zespri Gold Kiwifruit amounted to about 14% of New Zealand's total horticultural exports behind Zespri Green Kiwifruit at 32%.[6] However, rapid growth in the production of the Gold variety is being driven by high orchard gate returns. In the 2010/11 season, orchard gate returns for Zespri Gold Kiwifruit grown in New Zealand posted an average of about NZD 84 000 per hectare, compared to an average of about NZD 32 000 for Zespri Green Kiwifruit.[7]

Case study 2: Precision irrigation

This case study exemplifies innovation arising from research and development performed in collaboration between the public and private sector to build a new, research-informed agricultural knowledge system.

While New Zealand is relatively well endowed with water compared to some other countries, precipitation is highly variable both in terms of time of the year and geography. There is increasing competition for water in New Zealand for recreational, environmental, hydro-electric and agricultural purposes, and increasing awareness of its value and the limitations to its use.

New Zealand's total land area is about 27 million hectares, consisting of high mountain ranges and coastal plains. About 60% of the country is farmed. The area under irrigation has been increasing by about 60% every decade since the 1960s,[8] but despite this growth only about 700 000 hectares (4.3% of the land able to be farmed) is currently irrigated. Irrigated land has higher productivity and presently produces about 12% of New Zealand's agricultural GDP at the farm gate.[9]

Spray systems cover about 600 000 of the total 700 000 hectares currently irrigated.[10] Irrigators typically traverse highly variable soil types in New Zealand with marked variation in their water needs. Precision irrigation – applying water in the right place, in the right quantity at the right time – has significant advantages. New Zealand research has shown that precision application saves 9 to 26% in the quantity of water applied, 19 to 55% in drainage and water run-off losses thereby reducing nitrate leaching, and saves energy consumption of 30 to 77 tonnes of CO_2 equivalent per hectare per year.[11] It is estimated that for every mm of water not applied to New Zealand's irrigated area, about 7.5 million cubic metres of water are saved; energy saved is equivalent to about 630 tonnes of CO_2, and pumping costs are reduced by about NZD 1.5 million.[12]

There are additional benefits. The certainty of water provided by irrigation enables high value crops to be grown, and for different crops to be grown in adjacent areas or according to soil type, with water precisely applied to suit soil type, crop type and stage of growth. Exclusion zones such as roads can be kept dry, site-specific application of chemicals and fertiliser in irrigation water is possible, and web-based irrigation reporting and recording is feasible.

Achieving these benefits in New Zealand is being made possible by underpinning research and development by two government funded universities and a Crown research institute, [13] in collaboration with irrigation businesses and leading farmers. Multi-disciplinary research teams, e.g. soil science, agronomy, electronics, GPS and engineering are working together, using data obtained both from the country's national soil database, generated by many years of government funded surveys, and detailed on-farm, site-specific soil mapping.

Case study 3: Precision seafood harvesting

This case study exemplifies industry-led innovation with high development intensity and joint public-private sector collaboration.

A new tool for government - business collaboration, the Primary Growth Partnership (PGP),[14] was established by the New Zealand government in 2009, with committed funding of NZD 190 million over the first four years and NZD 70 million per year thereafter. Government investment must be matched at least 50/50 by industry funding. Government funding is contestable and based on the quality of proposals submitted by businesses. PGP projects must be in the primary sector and can cover the whole of the value chain, including education, research and development, product development, commercialisation, commercial development and technology transfer. They must focus on initiatives that will deliver significant economic growth and sustainability.

New Zealand's 15 000 km coastline borders some 4.4 million square km of fisheries waters ranging from sub-tropical to sub-Antarctic, in which some 16 000 marine species have been identified and 130 species are commercially fished. A strong quota management system allocates fishing rights between some 1 500 quota holders and 1 200 commercial fishing vessels. Seafood exports in 2009 totalled 287 500 tonnes worth NZD 1.42 billion.[15]

Fishing nets catch a wide variety of fish species and sizes, which may include high proportions of unwanted species or undersized fish, which cannot be processed. This is very inefficient and places unnecessary pressure on fish stocks. Fish can also be damaged when nets are brought on board and opened, reducing the quality and value of the resulting product.

A precision seafood harvesting system, funded under the PGP programme, is being developed in New Zealand to enable fish to be targeted by species and size. When implemented, this is expected to lead to an improved quality of catch and to increased sustainability of in-shore and deep water fishing. The research and development is being conducted over six years at a forecast cost of NZD 53 million. The fishing companies involved in the project have between 30% and 60% of the quota for the nine top species fished in New Zealand waters.[16]

It is estimated that, when fully implemented, precision harvesting will improve revenue for the fishing businesses involved by about 20% (NZD 100 million) annually.

Additional benefits are expected to accrue from another aspect of the project which will investigate on-rearing some of the live fish caught, enabling fresh, 'just-caught' fish to be supplied when required by customers. This may also enable new seafood products and product categories to be developed that appeal to consumers in defined market niches.[17]

Both government and the businesses involved in this project know that business viability depends on sustainability, 'green' growth and proactive investment in response to global challenges. In this case, maximising productivity from natural (fish) resources has driven the need for new technology. Development is underpinned by government funding, and by government data on fish stocks and species that is collected to inform the quota management system in New Zealand.

Case study 4: Fonterra in China – dairy farms

This case study exemplifies near market innovation performed wholly by the private sector, but benefitting greatly from New Zealand's agricultural knowledge system.

Fonterra[18] is a farmer-owned cooperative that processes the majority of New Zealand's milk and exports and markets most of its dairy products. It sources about 15 billion litres of milk per year from New Zealand and about 7 billion litres from other countries. It owns global assets worth some NZD 4 billion, has a sales turnover of about NZD 16 billion and is responsible for about one third of international dairy trade (Table 13.2). Fonterra contributes about 2.8% of New Zealand's GDP, this being about one third of the entire primary sector contribution and 26% of New Zealand's export income.[19]

China is the single largest market for Fonterra, although only about 12% of Fonterra's global market. China's dairy industry grew about 20% annually over the ten years to 2009, becoming the world's fourth largest dairy producer. This growth has been driven by a very strong internal market — per capita milk consumption in urban areas rising from about five kg in 1990 to about 18 kg in 2006.[20] The melamine scandal of 2008 caused consumers to pay much greater attention to milk quality and the integrity of the dairy product supply chain.[21]

Fonterra established a pilot dairy farm on leased land in Hebei province, north east of Beijing in 2007. Milking some 3 300 cows the project has a capital value of about NZD 20 million, is 85% owned and wholly managed by Fonterra. A second farm of a similar size is being established now (June 2011), with two further farms to follow in the same region.[22] [23] Each farm has the capacity to supply about 28-30 million litres of fresh milk annually. If these farms are successful, another cluster of farms will be established in a new region.

Fonterra's investments to produce milk in China were essential if it was to play an ongoing role in China, as current milk demand in China of some 27 billion litres is about twice the total volume of milk produced in New Zealand. By establishing dairy farms in China, Fonterra has taken its global experience and scale efficiencies to China and is achieving technology transfer in the know-how of senior staff from New Zealand; in local staff education and training; in the milk processing equipment; and in the dairy heifers exported to China to populate each farm, as these animals carry the benefits of many years of very intensive genetic selection in New Zealand. Fonterra is also fostering technology transfer by funding 100 university scholarships each year in China in food and dairy science. The ingenuity that characterises New Zealand's agricultural knowledge system is also important; for example, milk is snap-chilled to 4°C immediately after milking and the extracted heat is used to heat the dairy parlour in winter, while dung and urine from the cows is used to fertilise surrounding farmland that is used to grow forage for the herd.

Business role in New Zealand's Agricultural Knowledge System

In partnership with the government, business has a unique role in supporting supply to and demand for New Zealand's agricultural knowledge system to address food security and climate change challenges. This role encompasses a number of activities that only business has the knowledge and experience to understand and perform well.

Business is well accustomed to maximising productivity with existing resources. Lacking the ability to raise revenue by impost, business must ensure firstly that any proposed investment, for example in research and development, is likely to succeed and provide a worthwhile return on investment, and secondly that the resources allocated to the investment are fit for purpose and used cost effectively. High accountability means that failure to get these imperatives right is quickly punished.

Business understands that its involvement in the development and use of New Zealand's agricultural knowledge system must be intensely customer-focused. While research has a role in stretching the knowledge of businesses and informing their strategic thinking, leading to them seeing new solutions to problems and new opportunities, business ensures that this is characterised little by technology push and mostly by market pull.

This ability to bring a market and customer lens to New Zealand's agricultural knowledge system enables business to recognise the value of existing and new knowledge in the system. Those active in research activities may see the technological features emerging from their research, but it is business that can best link an appreciation of the technology to its application in markets and ability to deliver benefits desired by consumers,

Although New Zealand is a small country with a very small human population, the much larger scale and export focus of its agricultural sector, and for some products such as sheep meat and dairy, its significant role in world trade, mean that New Zealand businesses in the primary sector can be globally significant. Such businesses have the experience and know-how to be able to partner in multi-disciplinary and multi-national teams to overcome scientific, technical and market challenges, and accordingly are attractive to international entities. An example is provided by the Global Research Alliance on Agricultural Greenhouse Gases where New Zealand is leading livestock-related work.

Businesses are best placed to market the new technologies, products and services that are produced by an agricultural knowledge system. In so doing they create demand and, as revenue and profitability are achieved, raise the value of the agricultural knowledge system.

Businesses also play an important role in technology feedback. As new technologies and products are used by consumers, their experiences can be captured by business and fed back to inform ongoing research and development. An iterative process enabled by business can drive new developments that are very well informed by customers.

In achieving their commercial objectives, businesses also create both private and public sector benefits. These are particularly important in New Zealand where the primary sector plays such an important role and contributes so significantly to export revenue and national GDP.

Boundaries for the role of business

Businesses must assess many factors before making investments. These assume special importance when investing in an agricultural knowledge system, for example because of the risks, timeframes, competencies required and value to business which are described further below.

Risks

Example: Gold Kiwifruit case study

Zespri International, the grower owned co-operative that kiwifruit producers established to market kiwifruit globally, faced a number of significant technical risks with the new gold variety. While it was appealing to consumers, it initially suffered from vine management difficulties, variable fruit shape, and inadequate performance during post-harvest storage and shipping. These challenges were mitigated by an excellent working relationship between Zespri and a New Zealand government owned Crown research institute (HortResearch), and by a long term kiwifruit research and development programme.

There were also high market risks, which were mitigated by considerable in-market testing with consumer taste panels, and intellectual property risks which were mitigated by obtaining Plant Variety Rights initially in New Zealand, followed by applications for rights in other countries.

Kiwifruit are a seasonal fruit and hence there were also supply issues for year-round fruit availability. Zespri overcame these by licensing Zespri Gold ® Kiwifruit for production in other (northern hemisphere) countries. Product supply and quality from those countries was assured by Zespri providing production and harvesting know-how that had been developed in New Zealand.

A new and very serious risk is now posed by the Psa bacterium (*Pseudomonas syringae pv. Actinidiae*) which affects vine health and has recently been found in New Zealand. Zespri and HortResearch in partnership with 14 other research institutions in New Zealand and internationally are conducting very intensive research into means of ameliorating the disease. Developing technical solutions for Psa is now Zespri's highest innovation priority.[24]

While this threat is extremely unwelcome and will be costly to counter, the ability of the New Zealand kiwifruit to do so further exemplifies research-intensive innovation in an agricultural knowledge system.

Timeframes

Example: Fonterra case study

Fonterra faced a significant timing concern in China with considerable implications for its international strategy. There were four inter-related issues. Firstly, the dairy industry in China was expanding at a very rapid pace, driven by burgeoning demand from higher socio-economic consumers in urban centres, such that China was already the world's fourth largest dairy producer. Secondly, although Fonterra supplies customers in many countries, China was its single largest market. Failure to continue building a strong footprint in that market could have adverse supply and market positioning implications. Thirdly, establishing new dairy production capability in any country is difficult and time-consuming, especially one with the climatic conditions of China. Fourthly, the melamine milk contamination issue meant that locally produced and branded milk was under suspicion, with consumer preferences switching to foreign brands.

Aligning these four time-bound issues created opportunities for Fonterra and it accordingly moved to establish its first pilot dairy facility, quickly followed by more. In doing so it identified new technologies that were pertinent to a key market and implemented them simultaneously with its development of that market.

Competencies

Example: Precision irrigation case study

Being favoured by generally high rainfall, New Zealand was a late-comer to the irrigation of rural land compared to many other countries. Its agricultural sector therefore had the benefit of being able to take advantage of know-how and technologies developed and proven elsewhere. However, precision irrigation posed new challenges and required the research, development and integration of new technologies which were required to work in the soils, landforms, hydrology, climate and farming practices distinct to New Zealand.

At one level this necessitated that tools such as electromagnetic induction survey of soils could be used quickly and efficiently over fields to map soil variability, then be ground-truthed to check survey, establish soil water holding capacity and assess capillary rise from any high water tables. At a second level, pasture or crop agronomic data at varying stages of growth had to be matched to the chemical and physical attributes of highly variable soil types within any one irrigation run. At a third level, actual soil moisture at varying root depths had to be monitored in real-time and matched to soil moisture loss and pasture or crop evapotranspiration rates, dependent on forecast weather. At a fourth level, GPS data had to be acquired and rendered seamlessly into software to drive travelling irrigators and pulse nozzles on and off with the precision needed to apply the exact volumes of water required.

None of these many factors are normally within the domain of business competency, but all are needed to ensure precision irrigation success on the land. Business success then demands an additional suite of well-integrated commercial competencies ranging from entrepreneurship to sales and marketing; manufacture, distribution, technical support and after-sales service – all shaped to meet the demands of a new technology in a new business market.

Value to business

Example: Precision seafood harvesting case

Two New Zealand businesses have committed to jointly investing NZD 53 million over six years to develop the precision fish harvesting technology sought. While the businesses concerned between them hold a high level of catch quota for desirable fish species, giving them some assurance of potential harvest yield, making such a commitment necessitated belief that the business value obtained from investment would be high, after allowance for the technical uncertainties and many other sources of project risk.

An important factor determining business value in any wild-harvesting operation is sustainability — of the species sought, but therefore also of the ecosystem that supports those species in the wild. In determining this value, the investing businesses had the advantage of multi-year New Zealand government data on fish stocks. However, they had to gauge the biological variability and sampling error, if any, in this, while also calculating the value to their business of consumer concerns about the sustainability of marine species subject to ongoing harvesting, and the added value that might be realised if consumers knew that unwanted species and other by-catch were not being caught, while their fish were being caught using new, precision technology.

Such value appraisals can only be made by businesses and not by governments. Governments set the boundaries for business investment and, once made, become embedded into agricultural knowledge systems.

Challenges for businesses

While governments are responsible for predictable economic policy and are important with respect to matters such as education; policy, regulatory and innovation frameworks, business and intellectual property law, businesses must assess and manage many challenges in order to obtain tangible benefits from their investment in agricultural knowledge systems. A number of these have been variously mentioned above and include issues such as:

- new and/or disruptive technologies and their use to obtain and maintain competitive advantage;
- capturing intellectual freedom to operate and defending intellectual property against genuine or vexatious legal challenges;
- predicting and responding to competitive action by other businesses and determining when it is better to cooperate, compete or practice “coopertition”;
- overcoming suspicion and inertia that resists change and investment in new technologies;
- governance and management capability appropriate to what the business aspires to become;
- scientific and technical skills and know-how appropriate for the business now and in the future;
- financial capabilities, both cash-flow and capital, that are adequate for proposed investments and resilient to set-backs and change; and
- having very clear knowledge of technology and business direction and where the value-build opportunities are; and accomplishing all of this in a strategic and tactically astute fashion.

Such challenges are familiar to businesses. However, they have a special dimension when investing in agricultural knowledge systems because of the biological and environmental variabilities that are difficult to predict and largely unable to be controlled, particularly in a country such as New Zealand.

Conclusions

- Businesses in the private sector have an important role to support agricultural knowledge systems in ways that are consistent with business objectives.
- Government policies in New Zealand are complementary with private sector support for agricultural knowledge systems.
- A fundamental principle in agricultural knowledge systems that is consistent with business objectives and with sustainable food production and climate change is to maximise productivity within natural resource limitations.
- Business investment is constrained by boundaries common to all firms, but which take on special meaning in the case of investment in agricultural knowledge systems.
- Business must overcome challenges regarding the benefits and risks of agricultural knowledge systems that are influenced by their uptake and acceptance by government, the public and the business sector itself.
- Research and development and innovation are thriving in the New Zealand business sector as the four case studies presented here show.

Notes

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5. For example, the Psa bacterium (*Pseudomonas syringae pv. Actinidiae*) which impacts on vine health has recently been identified in New Zealand and is posing a serious threat to the kiwifruit industry.
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15. Partnerships in agricultural innovation: Who puts them together and are they enough?

Andy Hall[1]

Successful cases of innovation invariably demonstrate a range of partnerships, alliances and network-like arrangements that connect together knowledge users, knowledge producers and others involved in enabling innovation in the market, policy and civil society arenas. With this comes the realisation that public agricultural research needs to strengthen links to a wider set of players from the private and civil society sectors and, of course, farmers themselves. Public agricultural extension services have traditionally played the role of linking farmers to technology. However, recent studies that view this role as one of innovation brokering point to the fact that it involves a range of innovation management tasks that go beyond simply linking to sources of research-based knowledge and include: linking to input and output markets, network development, conflict resolution, and helping negotiate changes in the policy environment, working practices, standards and regulations and financing arrangements. But who should perform this linking task and what forms of brokering really matter?

Studies in the Netherlands point to the emergence of specialist brokering organisations, which include privatised public agencies and civil society organisations that rely on a mixture of public and private funding. This section presents the findings from an agricultural research-into-use support programme operating in Asia and Africa, which has focused on finding ways to embed research into the wider set of networks involved in innovation. This has included the establishment of pilot specialist agencies to broker linkages for innovation. The main findings of this work suggest that in the case of the specialist agencies, rather than there being a fixed type of brokering activity that needs to be performed and a preferred organisational format, these agencies have adapted to the conditions in the countries they are located in.

Successful cases of agricultural innovation invariably demonstrate a range of partnerships, alliances and network-like arrangements that connect together knowledge users, knowledge producers and others involved in enabling innovation in the market, policy and civil society arenas. Over the last 20 years policy frameworks have gradually come to acknowledge that agricultural innovation takes place in this way. This is reflected in the widely accepted convention of conceiving agricultural research not as a stand-alone intervention but as part of an agricultural knowledge system (FAO) or, more recently, as part of an agricultural innovation system (World Bank, 2006).

A key implication of taking this systems view of innovation is the realisation that the success of public agricultural research is dependent on how effectively it builds links and partnerships with a wider set of players from the private and civil society sectors and, of course, farmers themselves. Yet if linkages are so important in making agricultural research an effective player in innovation processes, how should these linkages be created?

Public agricultural extension or advisory services have traditionally played the role of linking farmers to technology. But the role of these agencies does not seem to address the wider set of partnerships that are now recognised to be involved in innovation. Recent studies point to the importance of a more broadly conceived role referred to as innovation brokering (Klerkx *et al.*, 2009). This involves a range of innovation management tasks that go beyond simply linking to sources of research-based knowledge and include: linking to input and output markets, network development, conflict resolution, and helping negotiate changes in the policy environment, in working practices, in standards and regulations and in financing arrangements. But who should perform this linking task and what forms of brokering really matter?

This is a topic that has particular relevance for developmental countries where agriculture is a key economic sector and is viewed as key instrument in reducing poverty. It is also in these countries that the performance of agricultural research has fallen short of expectations and where new and more effective ways of using agricultural research are most needed. This section presents the findings from an agricultural research-into-use support programme operating in Asia and Africa, which has focused on finding ways to embed research into the wider set of networks involved in innovation. This has included the establishment of pilot specialist agencies to broker linkages for innovation. It has also involved supporting entrepreneurial activity around promising new technologies as a way of marshalling resources and partners.

The main findings of this work suggest that there is a strong case for using public money to support both specialist innovation brokering services as well as entrepreneurial activity as both can enable innovation. Their key value is that in addition to building partnerships around research, these approaches stimulate a wider range changes implied by the idea of innovation brokering — an umbrella term that encompasses a range of intermediation tasks that bring about adaptation at the technological level at the farm, adaptation at the organisational level and adaptation at the policy and institutional level of an innovation system. In other words, partnerships and partnership building are important, but as part of a wider suite of changes that enable innovation. The paper concludes by stressing that a wider implication of this view of agricultural development is the need to switch from measuring the economic value of research to measuring the value and behaviour of the innovation system in which research is used for economic, social and environmental purposes.

The section starts by explaining why policy frameworks have shifted from an interest in agricultural research to an interest in innovation and why this places an emphasis on partnership, linkages and institutional and policy change. The section then introduces key insights from an innovation systems perspective and explains how these are taking shape in policy frameworks. The main sub-section presents a case study of innovation brokering in a Research into Use (RIU) programme, mentioned above.

From research to innovation

The interest in partnerships and linkages between agricultural research and other players in the sector needs to be understood in terms of the factors that are driving policy attention from research to innovation as the chief organising principle for interventions. Six key changes lie behind this:

- ***Shelves of technology, poor uptake, weak demand orientation.*** As a public policy tool agriculture — particularly in developing countries — has had mixed results. Globally, economic studies of agricultural research investments show good, although highly variable, rates of return (Pardey *et al.*, 2001). However, evaluations of agricultural research programmes in the developing world tell a different story (see, for example, Spencer *et al.*, 2005). It has been recognised that research has developed many potentially useful technologies. However, the uptake and adoption of these has often been weak and technologies have often not responded to the demands of farmers. The result is that the social and economic impacts of research have been disappointing. At a time of contracting public spending, this poor performance of agricultural research has come under increasing scrutiny, with widespread calls to move a away from a “business as usual” approach and start to make research matter in efforts to improve the prosperity and well-being of societies.

- ***Increasing outcome orientation in the policy narrative.*** The nature of the policy narrative is also changing. Increasingly countries are articulating their ambitions in broad social, economic and environmental terms of prosperity, well-being and sustainability. This outcome-oriented narrative is drawing attention away from inputs such as research and education and focusing efforts on processes that best make use of these inputs within chosen development pathways. Therefore, innovation as a process of change is seen as central to achieving societies’ ambitions.

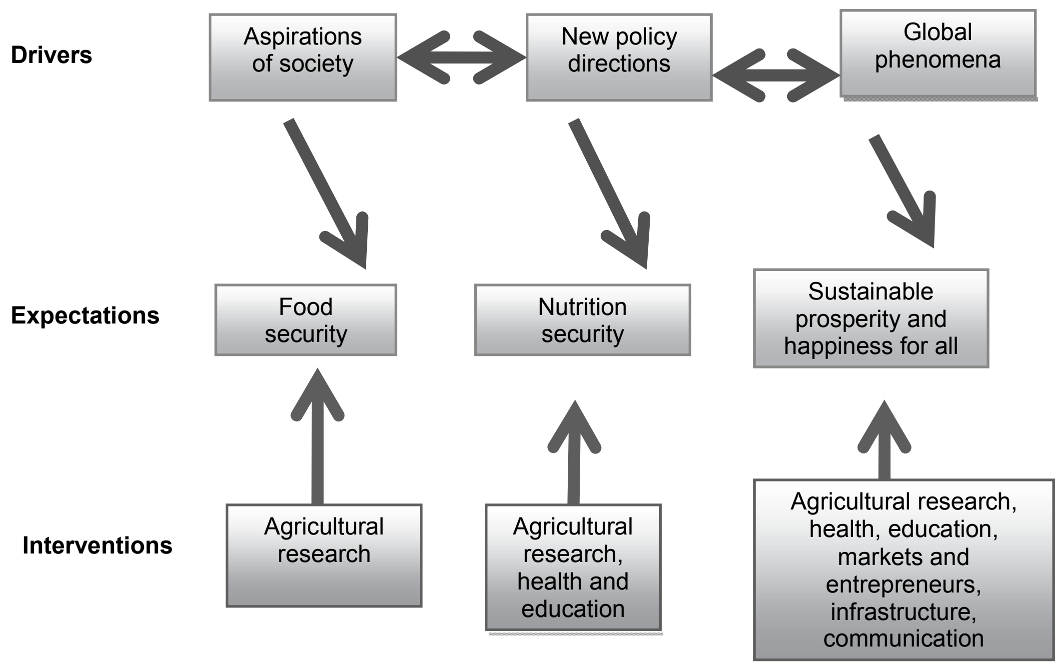
- ***New players and more prominence for the private sector.*** The agricultural landscape has also become more diverse. No longer is it just the domain of farmers and public support services. Instead, in most developing countries the sector has become more market-oriented, with the private sector becoming a much more prominent player. Also, civil society organisations with social development and increasingly environmental agendas have also become much more pervasive. This presents opportunities for the public sector to partner with these organisations in its pursuit of development goals.

- ***Multifunctional agriculture.*** Agriculture is not what is once was; the nature of the sector and the expectations of society are changing. It is no longer a sector with the uni-dimensional role of producing food or primary commodities for industry and export. Increasingly agriculture is multifunctional. The sector has critical social functions, particularly in countries that have large rural populations dependent on agriculture and with few other employment opportunities. It has a range of economic functions: as a source of national economic growth, international competitiveness and a route to social and economic empowerment in rural areas. It is no longer just concerned with food production, but also as sources of sustainable energy, environmental services (carbon, water, biodiversity) and a way of tackling climate change. Through the sector's role in nutrition, agriculture has close links with human health. In some countries the rural sector has important recreational roles (Figure 15.1).

- ***A dynamic and unpredictable sector.*** Another thing that has become more pronounced is that agriculture is an increasingly dynamic sector and needs to constantly respond to changing conditions. Driving this are factors that include: urbanisation; the globalisation of trade rules and markets; rapidly shifting patterns of demand and competitiveness; climate change, and trans-boundary pest and disease outbreaks. This has the effect that shocks and new opportunities emerge frequently and unexpectedly.

- ***The search for new ways of framing research.*** Taken together, multifunctionality and unpredictable patterns of change mean that disciplinary research goals are no longer an appropriate way of framing research planning. Instead broader organising principles are needed to account for the more widely-defined goals and expectations of the sector (mentioned above) and the fact that these goals are themselves moving. This is not to deny the importance of disciplinary research as one tool in achieving these goals. Rather it is about recognising that this is no longer the only planning framework to organise action and intervention. For research planning this is important for two reasons. Firstly, it anchors research to outcome areas couched in social and economic terms and allows research to work backwards from these outcomes to determine how it can best contribute. Secondly these outcome areas help reveal and map out the other organisations, processes and policies that research needs to connect with if it is to help achieve these higher order objectives. So, for example, an objective of improving rural household nutrition needs to link together plant breeding research on the development of vitamin enhanced crops in a wider array of efforts related to education, health, and women's empowerment and social organisation. This is where the value of partnerships between research and other activities becomes so important and it is where contemporary notions of innovation are becoming more useful as a way of rethinking the architecture in which agricultural research sits.

Figure 15.1. Agriculture isn't what it used to be: Multifunctionality



Innovation revisited

There is now a very large conceptual and empirical literature that reveals agricultural innovation not as process of invention driven by research, but as a process of making novel use of ideas (old and new) with the specific intention of adding social, economic and/or environmental value (a comprehensive recent review is provided by Juma, 2010). This literature makes six key points that are important for understanding the whys and hows of partnerships in agricultural innovation.

- Innovation seems to emerge from a network involving formal and informal alliances.
- Research is part of a wider process and assumes greater importance at different times — creating novelty, problem solving, upgrading production processes, responding to changing market demands, etc.
- Context matters in the way innovation is organised and a diversity of innovation configurations exist — some are research-driven, some are market-led, some are participatory and involve many players, etc.
- Alliances between agricultural research and the private sector are important, but this usually involves local firms in value chains rather than multinational life science companies with research capabilities.
- Huge institutional inertia holds back partnerships and network development even where market incentives would be expected to stimulate collaboration.
- Innovation includes technical adaptation, organisational adaptation and adaptation of the policy and institutional elements that make up the framework conditions for the enabling environment for innovation.

Innovation systems as a planning tool and its relevance

The picture that we can now see reveals change and innovation emerging from a system of different players constantly using and reusing ideas and technology to adapt, compete and cope to achieve the different objectives that motivate them. This view of innovation is now commonly referred to as an innovation system (Figure 15.2). As a policy analysis and planning tool it recognises four main dimensions to be investigated and strengthened (World Bank, 2006).

- The range of organisations and players involved around a particular theme or objective of innovation and the skills and resources that these organisations have.
- The patterns of linkage and interaction between these different organisations.
- The routines and ways of working in these organisations and the way these affect the way information, ideas and technologies are accessed, shared and adopted and the way learning takes place.
- The wider enabling policy environment and the way its shapes the behaviour of the system as a whole.

Analysis of these four dimensions also accounts for the global context in which innovation is taking place and the way innovation processes are able to respond to changes.

The power of the innovation systems idea is that it helps us see beyond innovation as a single point intervention and focus on multiple entry points — research, education, business, infrastructure, institutional arrangements and the policy environment. Most importantly it points to the interconnected nature of the change and innovation process — interconnected in the sense of the links between different organisations associated with a particular focal area, but also interconnected in the sense that technological innovation, organisational innovation, and institutional and policy innovations work hand in hand and need to be tackled as a whole rather than piecemeal.

Figure 15.2 provides a stylised illustration of an innovation system. Box 15.1 gives details of the organisations found in an agricultural innovation system.

Box 15.1. Organisations in an Agricultural System of Innovation

Support organisations

- Banking and financial system
- Transport and marketing infrastructure
- Professional networks including trade and farmer associations
- Education system

Research organisations

Mainly producing codified knowledge

- National and international agricultural research organisations
- Universities and technical collages
- Private research foundations

Sometimes producing codified knowledge

- Private companies
- NGOs
- Enterprise organisations

Users of codified knowledge, producers of mainly tacit knowledge

- Farmers
- Commodity traders
- Input supply agents
- Companies and industries related to agriculture, particularly agro-processing
- Transporters

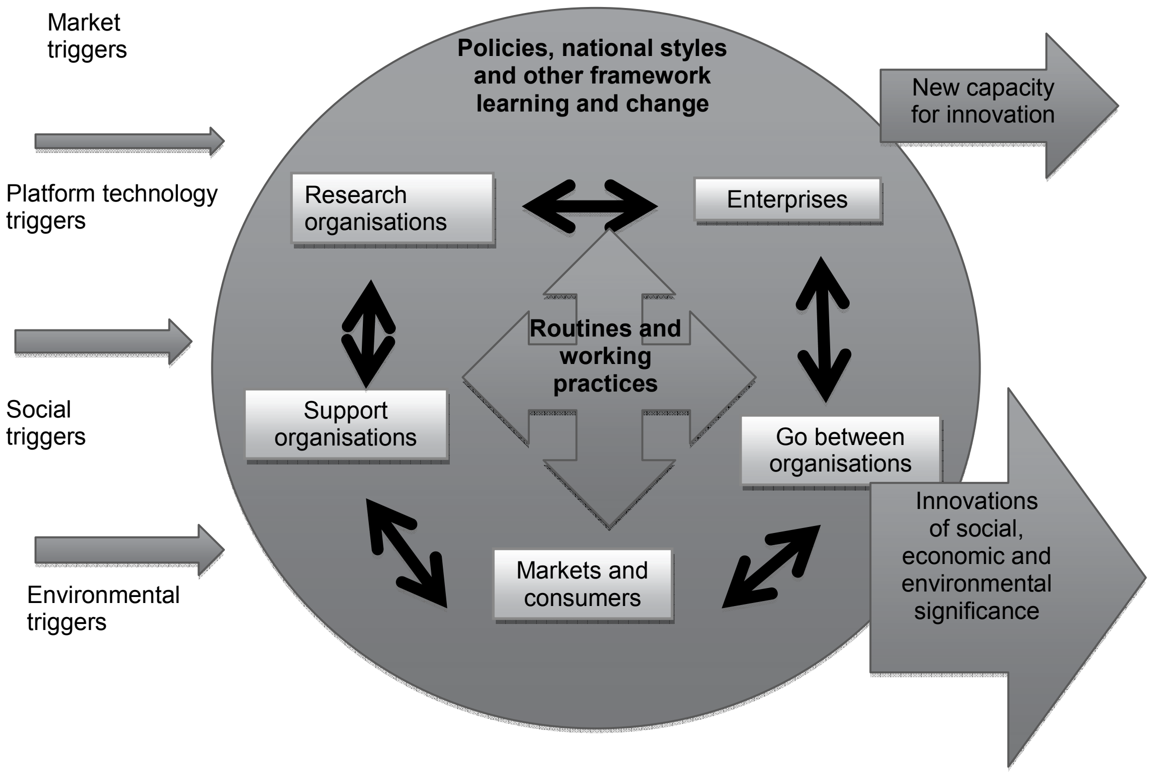
Demand organisations

- Consumers of food and food products in rural and urban areas
- Consumers of industrial raw materials
- International commodity markets
- Policy-making process and agencies

Go between organisations

- NGOs
- Extension services
- Consultants
- Private companies and other entrepreneurs
- Farmer and trade associations
- Donors

Figure 15.2. Elements of a dynamic working system



Crafting agricultural innovation systems: The role of innovation brokers

While the ideas about innovation systems have been embraced with considerable enthusiasm as a way of rethinking the organisation of agricultural research, a persistent critique has been about who puts these systems together. In other sectors there has for some time been recognition of the importance of a "go between" or intermediary organisation, whose role is one of "wiring up" innovation systems. These intermediary organisations can be in the form of advisory services, consulting companies or even civil society organisations. Increasingly these organisations are referred to as innovation brokers. Studies by Klerkx and Leeuwis (2008a, 2008b) on the Netherlands were the first to point to the emergence of specialist brokering organisations in the agricultural sector. Emerging from the historical development of the agricultural innovation system in the country, these organisations include privatised public agencies and civil society organisations that rely on a mixture of public and private funding. Klerkx and Leeuwis describe innovation brokering as:

> *"a role that is neither involved in the creation of knowledge nor in its use in innovation, but one that binds together the various elements of an innovation system and ensures that demands are articulated to suppliers, that partners connect, and that information flows and learning occurs."*

Klerkx and Leeuwis (2008b) argue that innovation brokers play different sorts of roles: Some deal with articulating farmers' demand for research and helping them access technology. Some deal with adapting the policy environment for agriculture on behalf of farmers. Others are more associated with creating linkages in value chains. Sometimes these are private organisations and at other times civil society organisations. But while the roles played by these organisations are valued, it is rarely sufficiently tangible for clients to be willing to pay for it. Like many institutional developments, the emergence of different forms of innovation brokering is heavily shaped by the historical context in which it emerges.

But what do these roles look like in practice and what can we learn from recent experiences? To explore this further we shall now look at the use and forms of innovation brokering in a donor-supported agricultural development programme — the Research Into Use (RIU) programme.

Innovation brokering in practice: The case of Research Into Use

Commissioned by the UK's Department for International Development (DFID) in 2006, the Research Into Use (RIU) programme was an ambitious experiment of sorts — conceived as a departure from the more conventional donor-funded development or research programmes. Launched with a budget of USD 50 million, the programme was originally intended as a successor to DFID's previous ten-year (1995-2005), USD 300-million investment in agricultural research through the Renewable Natural Resources Research Strategy (RNRRS). A terminal review of the RNRRS programme (Spencer *et al.*, 2005) came to the conclusion that while the research itself was excellent, its impact was limited because it was rarely if ever applied in practice.

The intention behind RIU was that the programme could extract long-term impact in Asia and Africa from DFID's underused agricultural research, while at the same time drawing lessons on the process of putting that research into use. However, what became apparent very quickly was that the process of putting research into use wasn't as easy as dusting off finished research products lying unused on shelves and getting them to end-users. Out of a total of 1 600 RNRRS projects and 280 research products, DFID's own assumption was that the RNRRS legacy contained at least 30 high-performing research products that had yet to reach their full potential and which, with "one more push", could achieve large-scale impact. This was the original premise that was, however, soon abandoned when the programme discovered that these 30 "waiting to be put into use" technologies did not exist, or at least not in the way initially conceived by the donor.

The RIU interventions took on three distinct forms

- ***A competitive grant scheme.*** RIU established an Asia challenge fund — primarily targeting India, Bangladesh and Nepal — to select 13 modest-scale projects as a stop-gap approach when no obvious blockbuster technologies were found in the RNRRS legacy. The logic behind the approach was that of scaling-out and scaling-up existing research-derived knowledge by expanding partnerships around existing RNRRS-era research groups and themes.
- ***Specialist innovation brokering services***. RIU established six African country programmes — Sierra Leone, Nigeria, Rwanda, Tanzania, Malawi and Zambia. The rationale here was that the country teams would focus on building the architecture and capacities that would allow innovation to happen, by incubating clusters of organisations that could respond to development opportunities and challenges. There was also an assumption that the country programmes would also stimulate wider

institutional and policy changes in their countries of operation that would help enable innovation more generally. A key strategy adopted by the country programmes was the use of innovation platforms as a way to bring together the different organisations involved in innovation (Box 15.2 describes the concept of an innovation platform). These were set up as usually informal, interactive, multi-actor arrangements, often focused on specific commodities, with RIU providing innovation brokering support. Rather than rigid rules on "getting RNRRS research products into use", the focus here shifted to building systems that connected research organisations with development and enterprise activity.

- ***Enterprise-driven innovation***. RIU launched a Best Bets initiative, which involved a quasi-venture capitalist selection process of business models that combined innovation and development relevance. The logic here was that RIU would support entrepreneurial activity around promising new technology and help incubate business models and private-public sector partnerships focused on delivering research products to large markets of poor people.

Box 15.2. What is an innovation platform?

The Innovation Platform was a mechanism adopted by the Research Into Use (RIU) Programme as a multi-stakeholder arena within which most brokering activities could occur. There has been much scholarship in recent years on the concept of an innovation platform, which imagines it to involve a set of stakeholders bound together by their individual interests in a shared issue, challenge or opportunity, dealing with it together in order to improve livelihoods, enterprises and/or other interests. These stakeholders cooperate, communicate and share tasks to carry out activities needed for innovation to take place (FARA, 2007). The platform thus provides a physical space for a forum of loosely-defined group of actors with shared interests around a common theme, coming together— despite often competing interests — in order to explore opportunities to address those common themes and investigating and implementing joint solutions Stakeholders have a shared objective for coming together, which needs to be clear to all participating and translate into commitment to cooperate (Nederlof *et al*., 2011). This objective has to be "tangible, realistic and achievable".

The RIU programme envisioned a platform as a group of partners driven by a mutual interest to further development, by generating, modifying and using research-derived knowledge in new ways. While initial strategy teams made recommendations about which platforms might be put in place, they emphasised that the full development of the platforms would have to be led by committed individuals or groups of individuals in each sub-sector or area of focus. During the programme development phase and beyond, the types of platforms RIU would support evolved significantly. The bulk of them formed around specific commodity sectors (legumes and cotton, for instance), while others were envisioned to tackle thematic issues (such as input-output supply). In addition, platforms were planned for more homogeneous sets of stakeholders (including farmers and process facilitators) as peer-to-peer learning mechanisms. All of these were expected to operate on a national level. District- and area-based platforms, in turn, would build momentum on a more grassroots level. Platform membership was often free entry and free exit, which also implied that certain platform members came into prominence at certain points of time depending on the overarching task at hand, and faded to the background at other points.

Before looking at how innovation brokering played out in these different types of interventions it is important to clarify the role of research products and expertise in the different RIU activities. Reflecting on the experience of RIU Hall (2011) points out that new technology was just one of a number of different starting points for making better use of research. Quite early on in the programme RIU tacitly acknowledged that better use of research would only be achieved by addressing bottlenecks in the innovation process. Some of these bottlenecks were indeed technological — for example, the promotion of new control techniques for the African migratory pest Army worm or improved varieties of fish fingerling in Malawi. However, the programme recognised that there were other bottlenecks and that these were also valid starting points for interventions that want to make better use of research. As RIU matured it selected input supply systems, value chains, innovation capacity development (in the Africa country programmes), new problem-solving research and policy and institutional arrangements as entry points to oil the wheels of the innovation process. It is important to make this point here before looking at brokering as RIU activities were not research and technology brokering as the name “research into use” might imply — although programmes and projects did perform these tasks as part of a wider function. Rather, they were innovation brokers shepherding the innovation process in the hope that this would create the conditions under which better use would be made of research.

Only the Africa country programmes were explicitly established to provide the types of specialist innovation brokering services anticipated by analysts such as Klerkx and Leeuwis (2008a, b). However, all three RIU interventions demonstrated the critical importance of agencies that by design or default play a role in creating links and negotiating change in innovation processes. We focus first on the Africa country programmes, illustrating it with the way brokering efforts played out in different countries.

Brokering in the Africa country programmes

- ***Tanzania: Brokering enterprises and value chain development.*** The Tanzania country programme was managed by a private consulting company. In its initial stages it brokered a number of commodity and thematic innovation platforms. However, its most notable success was its brokering efforts to establish a supply chain for local breeds of chicken for urban markets. This involved supporting the development of a decentralised production base of small-scale women entrepreneurs. Once established RIU then brokered access to hatcheries equipment and poultry disease control expertise, as well as negotiating import tax changes on equipment with the government. The Tanzania country programme coordinator described her role as continuous “troubleshooting”, tackling a series of unexpected bottlenecks that arose in the process of business incubation.
- ***Sierra Leone: Brokering change in the innovation enabling environment.*** The RIU country programme in Sierra Leone was located in the Ministry of agriculture. It began its activities like the other Africa programmes by trying to establish innovation platforms around different commodity chains and developing a computer-based agricultural information system. However, it soon found that the main bottlenecks to research use and innovation in Sierra Leone were policy issues in the enabling environment for innovation — a situation complicated by the fact that the country was just beginning to emerge from the effects of a decades-long civil war that had debilitated public infrastructure and crippled the private and financial sectors. The RIU programme shifted its attention to developing a platform of policy-makers, researchers and entrepreneurs to push through key changes, such as changing interest rates and revising import duties in order to kick-start entrepreneurial activity. This group, PAID, registered itself as a company. The location of the Sierra Leone country programme in the Ministry of Agriculture was key in helping negotiate these sorts of changes and facilitating the role of PAID.

- ***Nigeria: Brokering new innovation practice and policy.*** The RIU country programme in Nigeria was established as a partnership with the Agricultural Research Council of Nigeria (ARCN), locating its office within the council. The Nigeria programme established a series of commodity-based innovation platforms to link research with entrepreneurial and developmental activities. These platforms showed considerable success in both the soybean sector and in the commercialisation of improved packaging for cow peas. Given the strong links with Nigeria's apex agricultural research body, the country programme was then able to leverage the RIU experience of commodity-based innovation platforms in discussions about the on-going reform of the NARS. The relationship with ARCN acted as an unofficial sanction of RIU activities, helping broker links between research organisations and farmers and the private sector.

- ***Malawi: Facilitating technology supply chains.*** The RIU Malawi programme began by debating whether to locate within a government ministry — an idea that was rejected as it was felt that in this case it would divert time and resources from programme activities. A partnership with a civil society organisation — the African Institute for Corporate Citizenship (AICC) — gave RIU Malawi a home with legal standing as well as a long record in project management. In contrast to Nigeria and Sierra Leone, the country programme here felt the need to focus on building up technology supply chains, for example around fish farming, as it felt there was a gap in knowledge supply. While the technology supply chain was the entry point the Malawi programme found that it needed to develop a much wider network that included commercial hatcheries to supply fish fingerling, but also included university researchers and civil society organisations working with farmers (Box 15.3).

Box 15.3. Innovation platform in practice: The Malawi fisheries platform

The RIU Malawi country programme decided early on to establish an innovation platform on fisheries, given the momentum in the country's policy environment to focus on the sector as a way to improve livelihoods and increase economic returns. Research organisations, including the international World Fish Center, were the first eager members of the platform, invited because a gap between technical research and knowledge and its ultimate use was perceived as the main bottleneck to developing the sector. Other actors invited to join the platform included government extension agencies, civil society organisations with some experience in fisheries and fish farmer organisations themselves, representing numbers of small and medium-sized farmers producing fingerlings and table fish. Some private hatcheries also expressed an interest in signing on.

The platform slowly expanded to include other actors as when gaps were perceived. For instance, farmers from distant areas of the country brought to the attention of the platform a problem they faced in accessing improved varieties of fish seed — available at the time only at a research institute located in the centre of Malawi. The platform then brought in other private sector hatcheries in order to multiply improved varieties of fish seed and brood stock and distribute these to farmers. RIU created a revolving fund that made loans to hatcheries in order to help them expand their activities to regions beyond their normal purview.

As platform activities expanded further, the absence of one of the country's largest private sector actors in fisheries, Maldeco, became increasingly glaring. The company was invited to join the platform to share its marketing expertise. However, membership for the company became attractive only when it discovered that it could use it to leverage change at the government regulatory level. Maldeco had been struggling for years to convince government to approve sex reversal technology, which could accelerate the growth rate of table fish. The RIU fisheries platform convinced the company that a collective lobbying effort might yield results, and this proved, ultimately, to be the case. RIU was thus able to broker policy change by first using the innovation platform to broker links between the private sector and research organisations, with the latter providing technical data to support the advocacy efforts of the former.

Source: Hiroven (2011); Madzudzo (2011).

Brokering in the best bets

- ***Policy brokering for regulatory change***: RIU supported Real IPM as one of its Best Bets. It is a private company in Kenya that produces and sells bio-control agents to smallholder farmers to control the parasitic weed striga and also promotes seed priming. The company encountered numerous regulatory hurdles in registering its products for commercial application — legislation made provision for licensing chemical pesticides but not bio-control agents. Real IPM was forced to engage in policy brokering activities that included engaging with government officials and scientists, presenting scientific evidence from field trials and building relationships with a range of interested stakeholders in the regulatory process. This brought about a review of import regulations and the consequent drafting of Kenya's regulations for biological inputs, although the bio-control agent is yet to be licensed for sale.
- ***Consortium management.*** This Best Bet involved a public-private sector consortium promoting migratory pest prediction and bio-control. The consortium — operating both in Kenya and Tanzania — comprised a mix of researchers, NGOs and government ministries and departments that came together to find ways of controlling the migratory African armyworm pest. The aim was to oversee the implementation of community-based armyworm prediction or forecasting, and ultimately production and marketing of a simple low-cost and environmentally-safe biopesticide. The consortium was led by a not-for-profit science-based development and information organisation, CAB international (CABI), whose primary activities involved not only various policy brokering roles to enhance a speedy registration process, but also, significantly, the primary task of managing the entire consortium. CABI had to persuade various government departments, civil society actors, research organisations and other key actors in the armyworm value chain to support the initiative, while also negotiating through competing interests within the consortium and ensuring a commitment to the overarching goal.
- ***Linking farmers to private companies and research organisations***. The Best Bets initiative Farm Input Promotion Services (FIPS) is a non-profit company promoting small seed and fertiliser packs among smallholder farmers in Kenya. Adoption of fertiliser and improved seed in parts of rural Kenya is low due to the high cost of large packs of inputs. With limited demand many rural areas are poorly served by private input suppliers. FIPS has tried to address this by kickstarting demand by negotiating with input companies to provide small low cost seed and fertiliser packs. FIPS then provides technical advice to farmers to encourage them to use these inputs. To achieve this FIPS brokers networks between farmers and local input stockists, public research institutes and input manufacturers. Providing farmers access to technology has been a starting point, but FIPS is now playing a role in brokering linkages with local supply systems and research.

The RIU Asia portfolio contained quite a diverse set of projects with a rather diffused logic about using partnerships to scale up technologies. However, like the Best Bet projects, brokering was observed as a pragmatic tactic by project implementers to achieve their goals. Many of the projects were successful in piloting ways of developing value chains that made better use of existing technologies. For example in Bangladesh, the establishment of micro-entrepreneurs to sell improved fish fingerling made successful use of previous research by the WorldFish Center and other research conducted under DFID's RNRRS research programme. A review of these projects by Sulaiman *et al.* (2010)

discusses the wide set of brokering functions observed as innovation management and identifies six key tasks. These tasks are presented in Table 15.1 along with the actions involved in these tasks and examples of the operational tools observed in the RIU Asia projects to perform these tasks.

Table 15.1. Innovation management tasks observed in RIU projects in Asia

Tasks	Actions	Tools used in RIU to perform tasks
Networking and partnership building	Convening	Grain cash seed bank
		Community-based seed producer groups
	Brokering	Community based user groups
Setting up/strengthening user groups		Producer companies
	Facilitating	NGO led private companies
Training		Market chain analysis
	Coaching	Market planning committees
		Community germplasm orchards
Advocacy for institutional and policy change	Advocating	Village crop fairs
		Food processing parks
	Information	Use of lead entrepreneurs
Enhance access to technology, expertise, markets, credit and inputs	Dissemination	Participatory action plan development
		Community resource centres
	Negotiating	Policy working groups
Reflective Learning		Thematic committees
	Mediating	Cluster-level sharing workshops
		Forest policy seminar series

Sulaiman *et al.* (2010) argue that there are a number of important points arising from this observation.

- Putting research into use involves a range of tasks beyond ensuring access to technology and information
- These tasks do not work independently and innovation is usually only enabled when a cluster of these tasks are performed together
- There is no set formula for which tasks need to be deployed together — sometimes network development will be more important, sometimes advocacy for policy change. The history and context of the innovation will largely determine this
- This view of how research is put into use does not deny that there is a role for the traditional extension task of improving access to new technology. What the RIU experience highlights is that this works best when it is bundled together with other supportive tasks (access to markets, convening consortia, etc.)

Are partnerships and brokering enough?

The evidence from across the RIU programme suggests that there is a role for innovation brokering in helping put research into use. In some cases it might be useful to establish specialist innovation support services to play this role. This is probably true in situations where entrepreneurial and civil society is not well-developed or where the prevailing policy and institutional environment restricts their ability to undertake intermediation and brokerage functions. In other situations it might be possible to use existing pragmatic brokerage that is taking place in development programmes, enterprises and advocacy networks. RIU support of such types of activity through its Best Bets projects provides an operational alternative that could exploit the brokering skills inherent in entrepreneurship to help put research into use.

A wider analysis of the RIU experiences, however, raises a number of cautionary points (Hall, 2011). The most notable is that while RIU piloted a number of promising innovation processes that helped integrate research into the wider change process, little headway was made in tackling the wider policy and institutional dimension of the environment that enables innovation. Take the Malawi case. This was certainly a good development project that made use of existing technology to develop a strong supply chain that serves poor farming households. However, it did little to fundamentally change the relationship between agricultural research in the country and private sector and civil society activities. Nor did it tackle agriculture sector policies and the incentives these could provide to support an innovation-driven smallholder development paradigm. The lesson that emerges from this observation is that while developing partnerships between agricultural research and other organisation is an important ingredient in the innovation process, efforts are needed to simultaneously address policy and institutional change.

The intelligent use of brokering can be used to address this need to tackle different elements of innovation capacity — that is to say both linkages and supporting institutional arrangements and policies. In the case of RIU while all country programmes started out trying to broker relationships around commodities, the focus of the programmes adapted to fill vacuums or priority bottlenecks.

For example in Sierra Leone, where there was a policy vacuum, it was best for the agency to locate within government and engage mainly in brokering policy change to enable innovation. In Tanzania, where there was an entrepreneurial vacuum, it was best to locate the agency in a private company and focus on enterprise incubation, brokering relationships and tackling bottlenecks to get the enterprises off the ground. In Malawi, where there was a technology supply chain vacuum for aquaculture inputs to small-scale farmers, a civil society organisation was best placed to broker the participation of companies to develop a supply chain.

In all these cases new brokering needs are likely to emerge as these developments progress. Recognising that tackling partnerships, or the institutional and policy environment is only the starting point of efforts to strengthen innovation capacity and being aware that sustained support on a number of fronts is going to be necessary, should be the guiding principle making better use of agricultural research.

Wider implications

This paper has argued that understanding research as part of a more widely conceived agricultural knowledge or innovation system has fundamentally changed the nature of capacities and policies needed to support the agricultural sector. The example of the RIU programme illustrates that while brokering partnerships with research is an important element of this new capacity building agenda, much more is needed. The idea of an innovation broker encompasses this wider task and involves a range of intermediation tasks that bring about adaptation at the technological level at the farm, adaptation at the organisational level and adaptation at the policy and institutional level of an innovation system.

None of these observations and new ways of thinking about agricultural development diminishes the importance of agricultural research. On the contrary, these provide insights into ways that the power of science can be magnified. What it does mean, however, is that the key metric by which countries can track and improve the performance of agricultural sector policies is not by measuring the economic value of research. Rather it is by measuring the value and behaviour of the innovation systems in which research is used for economic, social and environmental purposes. This is old news for the industrial sector policy analysts, but still relatively novel in the agricultural sector.

Note

1. Director LINK Ltd and visiting professor, Open University, United Kingdom.

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16. The role of innovation brokers in the agricultural innovation system

Laurens Klerkx[1]

This section discusses the role of innovation brokers in bridging communication gaps between various actors of innovation systems. On the basis of recent experience in the Netherlands, it outlines the success of brokers in finding solutions adapted to the needs of farmers and industry, and thus their positive impact on innovation adoption. This section also examines some issues on how brokers function, particularly with regard to balancing interests, funding their activities, and the role of government.

Introduction

Innovation is regarded as key to survival in the current agricultural sector (Hall *et al.*, 2006). Support of innovation in the agricultural sector has undergone large-scale transformation over the last two decades, which in turn has affected the agricultural knowledge infrastructure in many countries. This has three important consequences: first, multifunctionality of agriculture entails a more heterogeneous knowledge demand. Tailor-made knowledge is needed. However, current research and extension systems still do not fully address these multiple demands (Laurent *et al.*, 2006); second, privatisation and other reforms of public agricultural knowledge infrastructures has entailed a switch from supply-driven to demand-driven knowledge provision. However, this has also increased strategic behaviour and closure of the knowledge system (Leeuwis, 2000; Garforth *et al.*, 2003); third, it is now recognised that the agricultural knowledge infrastructure is part of an agricultural innovation system, but not necessarily the principal driver. The innovation systems concept emphasises the need for broad network building amongst public and private actors, and focuses on the enabling and constraining factors for innovation other than knowledge. These included the physical "hard" infrastructure and the social "soft" infrastructure, for example informal norms, values, attitudes and practices, and formal rules embedded in legislation and policy (Hall *et al.*, 2006).

Challenges emerging due to this new context

The change to a heterogeneous market for research and extension, and the adoption of an innovation systems perspective requires institutional changes and capacity building in research and extension (Garforth *et al.*, 2003). This has implications for several actors preoccupied with agricultural innovation. For farmers and other agri-chain actors it implies that they need to articulate innovative ideas and visions into which they will integrate productive, economic and societal needs, and corresponding demands with regard to knowledge and other innovation enabling factors. All these actors must find suitable research and extension providers and other co-operation partners and interact with them during the subsequent innovation process. Many farmers experience an "information overload", however, and find it difficult to perform successfully in the market for research and extension; they also sometimes lack the necessary skills to manage innovation (Garforth *et al.*, 2003; Laurent *et al.*, 2006). Research and extension providers must place greater effort into procurement in a market that is increasingly pluralistic and served by non-traditional, non-agricultural research and extension providers (Phillipson *et al.*, 2004); they must also become responsive to the needs of their clients. The paradigm of demand-driven research and extension service delivery implies a shift away from mere technology transfer to the provision of a broader range of communication functions and advisory services (Leeuwis and van den Ban, 2004). As a result, there are several "gaps" from a market and innovation system interaction perspective. With regard to the nature of these gaps, one can identify cognitive/cultural gaps (actors from different institutional backgrounds have too much cognitive distance to adequately learn together, or have different norms, values and incentive systems which hinder effective communication), information gaps (actors are imperfectly informed about possible cooperation partners), and managerial gaps (actors are unable to acquire and successfully implement new knowledge), and a "system gap," which is related to issues such as the system lock-in, i.e. resistance of the present agri-food systems to accommodate innovations and deficient innovation system linkages.

The emergence of innovation brokers

As a response to suboptimal linkages in agricultural innovation systems, several authors have argued that, in the context of a pluralistic (market-based) research and extension system and from an innovation system perspective, "systemic intermediaries" are needed (Aflakpui, 2007; Spielman *et al.*, 2008). These should connect demand and supply for agricultural research and extension services, and fulfil other bridging functions with the broader innovation system (i.e. between farmers, education establishments, government, agri-industry (both suppliers and processors) and advocacy organisations). Howells (2006) introduced the broad term "innovation intermediary" for such a systemic intermediary; he defines this term as *an organisation or body that acts as an agent or broker in any aspect of the innovation process between two or more parties.* Basic functions include problem/challenge diagnosis (demand articulation), partner search, selection, and matchmaking (network composition) and facilitating the multi-stakeholder learning process (innovation process management) (Klerkx and Leeuwis, 2008; 2009a). To distinguish these intermediaries from extension and research providers who may also provide such innovation brokerage tasks as a side-activity (Howells, 2006), we adopt the specific term "innovation broker" (Winch and Courtney, 2007) for this type of organisation. Although some studies have been undertaken to describe and analyse such specialised independent innovation brokers or "free actors" in the agricultural sector (e.g. Phillipson *et al.*, 2004; Spielman and Von Grebmer, 2006; Hartwich *et al.*, 2007; Wielinga and Vrolijk, 2008), relatively little analysis has focused on providing an overview of the different types, their effects, and describe how they become embedded within the privatised agricultural knowledge infrastructure.

Innovation brokers in the Netherlands

On basis of the integration of several separate analyses (see Klerkx and Leeuwis, 2008; Klerkx and Leeuwis, 2009a; Klerkx and Leeuwis, 2009b, for more detailed information), seven different types of innovation brokers (Table 16.1) in the Dutch agricultural sector have been identified at different levels of system aggregation. These brokers address different levels of innovations (incremental, radical, system innovation, societal transitions) and connect the different kinds of actors, such as farmers, input suppliers, processing industries, research and extension providers, government, and civic advocacy organisations, and enhance their interactions by acting as a neutral facilitator. Most of these organisations receive direct basic funding from government or collective funds, or receive indirect public funding through subsidised innovation projects. Only a few work with private funds.

Table 16.1. Different types of innovation brokers

Type	Examples
1) and 2) Innovation consultants aimed at individual farmers (1) and collectives of farmers (2) and aimed at incremental innovations	Agricultural Knowledge Centre Noord Holland*#/Agricultural Knowledge Centre Flevoland*#, Agricultural Knowledge Centre Zuid-Nederland*#/Agricultural Knowledge Centre Zuid Holland*#/Innovation Support Centre Wageningen*#/Syntens Agro/Stimuland,/LaMi,/ Agro&Co/Food Valley Innovation Link/Horti Solutions*/Poultry Centre/Cropeye/ Innovation Support Point Zuid Limburg*#/ KnowHouse/ Agri-chain Knowledge*#/ Grower's Service Technology Department#/ Platform Agrilogistics/Support Point Care Farming#/ Knowledge Alliance#
3) Peer network brokers forging farmer networks for horizontal learning (comparable to e.g. farmer fields schools)	Dairy Farming Academy#/Horticultural Cluster Academy#/Pignet#/Program Networks In Animal Husbandry#/ Versatile Countryside Academy#
4) Systemic instruments for forging public-private multi-actor alliances for radical innovations	Courage/ Greenhouse Horticulture Innovation Foundation#/Innovation Network Rural Areas and Agricultural Systems#/ Transforum/ Eggnovation/ Germination Power#
5) Portal sites that offer an overview of relevant goods and services and enable virtual interaction	Ziezo.Biz/Knowledge on the Field #/ExperienceBox/Bioknowledge#/Knowledgefield #/AgriHolland
6) Research councils with innovation agency that programme and facilitate demand-driven participatory research	Bioconnect* / Transforum*
7) Practice-education brokers that provide education establishments with the latest insights from practice	Green Knowledge Cooperative#/Content broker#/Flower Bulb Academy#/Knowledge Counters Brabant#

Names have been translated from Dutch where appropriate.
* These organisations have ceased to exist.
Source: Derived from Klerkx and Leeuwis (2009a).

Positive contributions

Innovation brokers are valued because they operate from an independent and neutral "third party" position as regards the problems and challenges they address, the partners to involved, and their interests during the innovation process. In the sphere of demand articulation, innovation brokers helped farmers and other agri-food stakeholders to think about new possibilities to sustain their businesses. Because of their unbiased position, innovation brokers offer a fresh look at diagnosing the constraints and opportunities of farmers or, at a higher level, production chains, regions, or sub-sectors. Due to their critical approach, brokers tend to force their clients to look for possibilities beyond their current situation and constraints.

In the sphere of network building, there are numerous examples where innovation brokers have helped farmers and others that want to initiate innovation projects to get in touch and negotiate with project partners and other relevant stakeholders. These partners can come from the policy, market, and civil society domain, as well as suitable knowledge providers who can assist in orienting farmers towards new activities. The variety of sources available is essential for developing new combinations that are central to innovation. At the system level, brokers have contributed to the development of innovation agendas, and radical and/or system innovations to meet future challenges by performing foresight exercises and initiating innovation projects that bear a high risk of failure. This has resulted in several new concepts, some of which were initially regarded with suspicion and disbelief, but now have become viable new development strategies.

Finally, it is evident today that innovation process management is an important function that can be performed by innovation brokers. Innovation processes tend to involve different groups of actors, with different expectations and interests determined by their institutional background. For example, farmers often want instant access to applicable knowledge and quick results; research providers have an interest in undertaking (publishable) research; and policy makers want to realise their policy goals and see the results of public investments. The interested parties thus differ with regard to the time horizons of projects and the desired output. Innovation brokers have clearly facilitated co-operation and managed to synchronize expectations of different actor groups for a number of innovation processes. They have made different project partners aware of their institutional backgrounds and expectations, and of the role they can fruitfully play in the innovation process. Moreover, they have been successful in making transparent the risks and benefits attached to engagement in the innovation process. This is especially useful because by doing so they contribute to reducing uncertainty in the early stages of the innovation process when the risk of failure is high. In addition, brokers act as a "translator" between the different cultural worlds and perform mediating roles in the event of conflict about, for example, the attribution of intellectual property rights, strongly diverging goals and visions, or the division of funds. The involvement of innovation brokers in innovation processes hence accelerates the innovation process by helping members to maintain their focus and energy during this process. Beyond the level of a single project, innovation brokers fulfil the roles of acting as a catalyst (to bring about change and stimulate co-operation), as a liaison (e.g. to inform policy) within the agricultural innovation system, and in the area of innovation capacity building.

Tensions with respect to how brokers function

Although brokers are seen to have a positive effect as a knowledge infrastructure and innovation system catalysts, there are tensions with regard to their status which have important policy implications. First, there is a "neutrality paradox:" innovation brokers often need existing parties and networks for referral and matchmaking purposes, but may also need to destroy existing networks to make new combinations and which threatens their credibility as neutral brokers. Furthermore, they have to balance the interests of different parties in their role of brokers (e.g. clients, financiers) to maintain their social and financial resources, and hence future brokering flexibility. However, resource dependencies on certain financiers, such as government or research institutes, may force them to allow those parties to influence their work and which thus affects their perceived neutrality in the eyes of others, such as farmers and other research and extension providers.

Second, there is ”function ambiguity”: some functions, especially those that go beyond demand articulation and network formation and deal with the facilitation of established networks, are seen to be similar to those that existing research and extension providers offer. Also, innovation brokers have to balance the dilemma that they need sufficient topical knowledge to be credible for network participants, but too much knowledge on the subject makes them a threat to experts and may be conducive to too narrow a focus (lock-in). In view of the lack of a clear understanding as to what constitutes the actual role of an innovation broker, innovation brokerage having an autonomous role has not yet been fully accepted by the Dutch agricultural knowledge infrastructure.

Third, there is a “funding paradox”, wherein innovation brokers who wish to tackle various market and system failures in the agricultural knowledge infrastructure, suffer themselves from the same systems and market failures. This includes the difficulty of clients and financiers to understand their activities, which seem invisible and intangible, and to assess the effect of their activities on innovation. Related to this, there is “funding impatience” due to funding being withdrawn too soon. This causes innovation brokers to collapse, or become “traditional” extension providers and hence lose their systemic function.

Conclusion

In many countries network building and facilitation for agricultural innovation is seen as a principal challenge and thus innovation brokers may be a valuable new type of actor in the agricultural knowledge infrastructure and the agricultural innovation system (Klerkx *et al.*, 2009c). This calls for policy with regard to innovation brokers as an agricultural innovation policy instrument. The tensions mentioned above prompt a critical evaluation of the role that government must play as an *innovation system facilitator* by supporting innovation brokers. Arguments in favour of government support include the difficulty to make the basic functions of demand articulation and network formation self-sufficient. In addition, the contribution to innovation system interaction and the role as catalysts of innovation, and the fact that innovation brokers can more neutrally fulfil the role of facilitator than parties that have a substantive stake in the subsequent research or innovation process also call for a government role. Nevertheless, there are also some dilemmas, which include 1) the justification for public spending on innovation brokers, as impact evaluation appears to be difficult; 2) the proper demarcation of the mandate of publicly financed innovation brokers, as activities that go beyond demand articulation and network formation are sometimes perceived as competition by traditional research and extension providers; and 3) the risk that due to resource dependencies, innovation brokers may become a more or less “hidden messenger” for government or another party, which would be detrimental to their credibility as a neutral facilitator and “free actor.”

Note

1. Wageningen University, Communication and Innovation Studies Group. Address: PO Box 8130, 6700 EW, Wageningen, The Netherlands. Tel.: + 31-317-484694 Fax: +31-317-486094. Email: Laurens.Klerkx@wur.nl.

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Part IV.

Regulatory framework conducive to innovation

17. The European Union system for health and consumer protection

Niall Gerlitz[1]

This section provides a general overview of the EU system for health and consumer protection, and examines some of the initiatives that the European Commission is currently undertaking to encourage innovation in this area. The first part of the chapter presents a background on some of the challenges we are currently facing including — increasing global food demand, and aging population, hunger, food waste, increasing prices and competitiveness in the food supply chain. The second part identifies some of the initiatives designed to spur innovation through smarter legislative processes and other strategies, launched under the Europe 2020 programme. Finally, there is brief examination of challenges in three areas: Genetically Modified Organisms (GMO), pesticides, and nanotechnology.

Introduction

The Bovine Spongiform Encephalopathy (BSE) outbreak and other food crises of the 1990s led to a complete review of the regulatory framework within the European Union. This led to the adoption of a new general food law which led to the construction of a comprehensive legal framework covering all aspects of food, feed and veterinary control. This framework is founded on three general principles:

- protection of public health;
- consumer protection; and
- effective functioning of the internal market.

This regulatory framework introduced several important elements. It established the principles of risk analysis as a fundamental element of food chain assessment and, most notably, involved stakeholders at all stages of food law development. Indeed, legislative transparency and effective public consultation are considered essential to building greater confidence.

Key facts

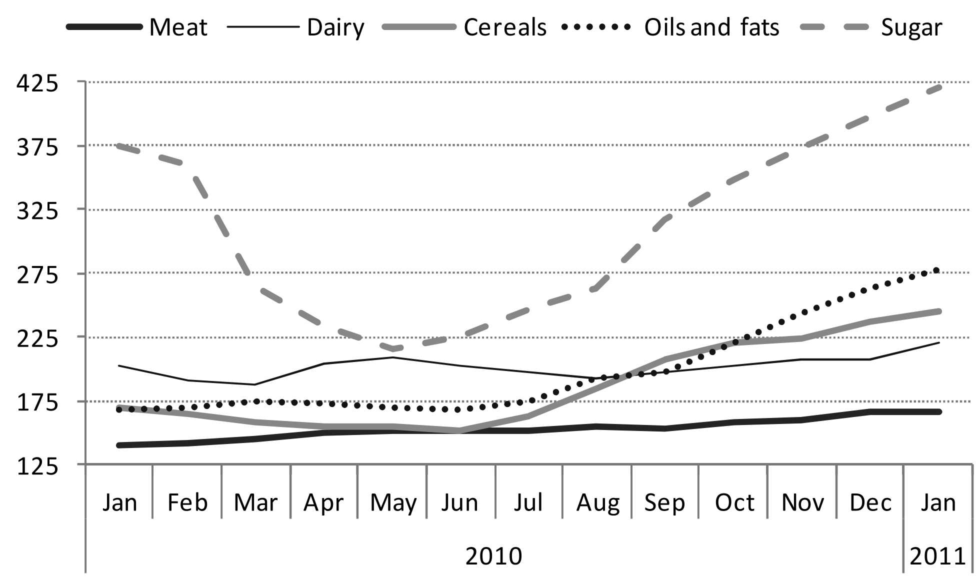
Today, this regulatory system faces a number of challenges. First, global demand is increasing due to a surging population level that is projected to reach 9 billion by 2050. This, in turn, has raised new sustainability issues since we must meet food needs with a finite supply of land and resources. At present, it is estimated that 1 billion people are in need of food.

We have also seen a notable spike in demand from emerging countries for animal products, coupled with an increase in global greenhouse gas emissions, of which the European Union emits up to 12%. In addition, the European Union produces approximately 90 million tonnes of food waste per year — an estimated 60% of which is considered avoidable. Surveys indicate that almost half of this amount is attributable to household waste. These issues have given rise to new challenges pertaining to long-term sustainability.

Food prices, meanwhile, have become more volatile in recent years. The current food price index is 40% higher today than it was in April 2010. Not surprisingly, this rise is having an impact on the world's food supply chain, which has become much more complex in order to meet growing demand. Recent trends in commodity prices and household food consumption can be seen in Figures 17.1 and 17.2.

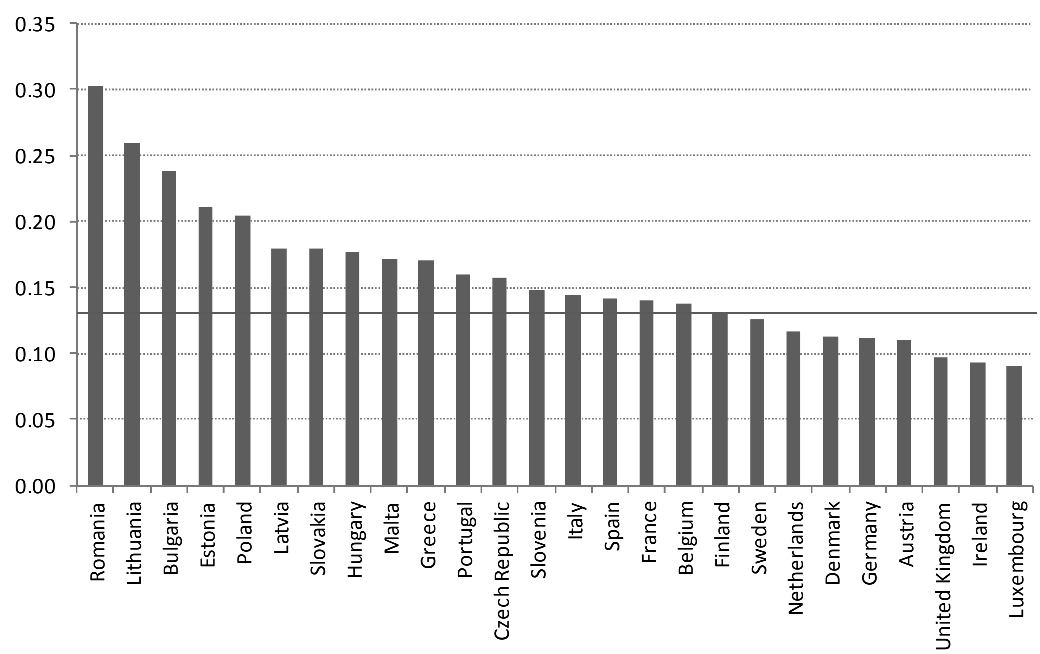
Figure 17.1. Food commodity prices

Food Commodity Price Indices, 2002-04=100



Source: FAO World Food Situation, Food Price Index available at: *www.fao.org/worldfoodsituation/wfs-home/foodpricesindex/en*.

Figure 17.2. Household food consumption (% of total), 2009



Notes: Food and non-alcoholic beverages; 2008 figures for Ireland and the Slovak Republic; 2007 for Portugal, 2005 for Bulgaria.
Source: EUROSTAT National accounts.

The agro-industry sector, in particular, is the largest manufacturing sector in the European Union. In 2009, its turnover exceeded EUR 920 billion, comprising 13% of global turnover. The sector is comprised of approximately 290 000 companies and employs more than 4 million people, making it the leading employer in the European Union.

Clearly, the agro-industry is a very important sector which is faced today with several important challenges. It is widely recognised that, barring any changes in technology or adaptation, the food system as we know it today is unsustainable. The World Bank estimates that this recent wave of food price volatility has already relegated 44 million people to extreme poverty.

Strategies

In light of these challenges, it is fair to say that many of today's production systems compromise our capacity to increase future food supplies. We need to explore solutions that will reduce food waste, overconsumption and overproduction, while responding to a host of societal and ethical concerns, including those related to animal welfare, and new technologies such as biotechnology and cloning. There is also a need for better governance and smarter regulation, especially since globalisation and climate change could increase the risk of future price volatility.

Moreover, we must undertake efforts to improve the availability and accessibility of safe food, while improving the nutritional adequacy of food. Calorie intake may be adequate for many consumers, but the profile and nutritional value of the foods they consume may be inadequate — particularly for those in lower socio-economic groups.

The Commission has already begun addressing these challenges. Last year, it launched Europe 2020 — the European Union's growth strategy for the next 20 years. This initiative is based on the principles of a smart, sustainable and inclusive economy. Upon these three pillars, a number of flagship initiatives have been developed as outlined below.

Innovation Europe

Innovation Europe is an initiative intended to refocus Research and Development (R&D) policy on the major challenges addressed during this conference. Specifically, it is designed to make Europe a world-class science performer, while removing obstacles to innovation and improving the mechanisms through which public and private sectors work together. There are many different instruments that will be used to implement this strategy, including innovation partnerships, the European Research Area, the Seventh Framework Programme, and other research networks and initiatives.

Flagship initiative for a resource-efficient Europe

The flagship initiative for a resource-efficient Europe under the Europe 2020 strategy supports the shift towards a resource-efficient, low-carbon economy to achieve sustainable growth.

Natural resources underpin our economy and our quality of life. Continuing our current patterns of resource use is not an option. Increasing resource efficiency is key to securing growth and jobs for Europe. It will bring major economic opportunities, improve productivity, drive down costs, and boost competitiveness.

The flagship initiative for a resource-efficient Europe provides a long-term framework for actions in many policy areas, supporting policy agendas for climate change, energy, transport, industry, raw materials, agriculture, fisheries, biodiversity, and regional development. This is to increase certainty for investment and innovation and to ensure that all relevant policies factor in resource efficiency in a balanced manner

European Innovation Partnership on Active and Healthy Ageing

As the baby-boom generation retires, the population of over 60 is increasing twice as fast as before 2007, i.e. by some two million people a year. By 2050, the number of people over 50 will have increased by 35% and that over 85 will have tripled. If the current level of diseases in these age groups continues, many millions more Europeans would suffer from disorders such as neurodegenerative diseases (Alzheimer/Parkinson), cancer and cardiovascular diseases which are prevalent at an older age. This calls for increasing the discovery and deployment of screening, detection and (non-invasive) diagnosis, of medicines and treatments to prevent and address these diseases. To help address this, a pilot European Innovation Partnership on Active and Healthy Ageing has been launched which aims to increase the average healthy lifespan in the European Union by two years by 2020. It also aims to improve the sustainability and efficiency of our social and healthcare systems, and to create an EU and global market for innovative products and services with new opportunities for EU business. Active and healthy ageing is a societal challenge common to all European countries — an area in which Europe has the potential to lead in providing innovative responses.

European Innovation partnership on agricultural productivity and sustainability

With world food demand expected to increase massively over the next two decades, the Commission has also launched an innovation partnership in activities tied to agricultural productivity and sustainability. The aim of this partnership is to promote a resource-efficient, productive and low-emission agricultural sector which works in harmony with the essential natural resources on which farming depends, such as soil and water. The objective is to deliver a safe and steady supply of food, feed and biomaterials — both existing products and new ones. There is a need to improve processes to preserve our environment, adapt to climate change and mitigate it. The partnerships would build a bridge between cutting-edge research and technology and the farmers, businesses and advisory services which need them.

Better functioning of the food supply chain

A high level working group for a better functioning of the food supply chain comprising different stakeholders operating in food production, processing and distribution, and those from professional associations or Non-Governmental Organisations (NGOs) has been set up to examine issues affecting this chain. The mandate of the High Level Forum is to examine business-to-business contractual practices within the food supply chain to unearth any unfair commercial practices, while improving market transparency. Its mandate also encompasses issues related to food price monitoring, competitiveness in the agro-food industry and agro-logistics.

Smarter regulation

Smarter regulations, and a process of simplification which has been ongoing for several years, aim to simplify existing EU legislation in order to spur innovation and reduce the administrative burden for operators. We are currently commissioning independent evaluations of several legislative areas including Genetically Modified Organisms (GMO), animal health, plant health, and seeds.

Before considering any proposals put forth by the Commission, an impact assessment is now a required. The aim of the impact assessment process is to improve the quality of proposals, ensure consistency between Community policies, and contribute to sustainable development by assessing all economic, social and environmental impacts of the proposal at hand. In terms of innovation, more specifically, the impact assessment will take the following questions into consideration:

- Does the option stimulate or hinder R&D?
- Does it facilitate the introduction and dissemination of new production methods?
- Does it affect intellectual property rights, including patents, trademarks, copyright and other "know-how" rights?
- Does it promote or limit academic or industrial research?
- Does it promote greater productivity or resource efficiency?

Genetic Modification (GM), pesticides, nanotechnology

The Commission put in place a legislative framework on GM eight years ago. To date, we have more than 45 GMOs authorised within the European Union. In fact, the European Union is highly dependent upon imports of GM material, with more than 35 million tonnes imported annually (mainly soya), comprising a crucial element for feed supplies. At the same time, however, there is strong resistance from many stakeholders, particularly with respect to cultivation.

To address this, the Commission has adopted a full package of initiatives to address key areas such as the low level presence problem, the transformation of the risk assessment guidelines into legal documents with Member States' endorsement, the proposal on GMO cultivation giving room for member states to decide on grounds other than science, and the reinforcement of monitoring activities

In addition, we have launched an evaluation of GMOs. This may lead to new initiatives toward the end of 2012, creating efficiencies which will better streamline the current authorisation process.

Regulation (EC) 1107/2009 is a relatively new framework for the marketing of pesticides, which is intended to steer development of new substances that could result in safer products, with more environmentally favourable properties. It also establishes rules for SMEs to access certain studies which should facilitate the application process and provides for mutual recognition of authorisations that have been granted in different member states. Furthermore, it acknowledges the important role that plant production products play in producing quality food, while considering the myriad impacts on the environment and biodiversity.

There is currently a regulatory framework on nanotechnology included under the food additives and plastic food contact material legislation in the European Union. However, there remains a need for further development of scientific knowledge and for broader consumer acceptance of this technology. Of course, health, safety and environmental aspects remain crucial to the successful development of nanotechnology.

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18. The United States approach for fostering new biological technologies and ensuring their safety

Dr. Michael Schechtman[1]

This section addresses the regulation of genetically engineered (GE) products and biotechnology as exemplary of a system for delivering innovative new products and assuring safety with public involvement. Biotechnology has been integral to the record productivity the US Department of Agriculture (USDA) has seen in major crops. In the United States, the regulation of GE and biotechnology products involves three agencies: APHIS, the FDA and the EPA. Each agency has different responsibilities, though their regulatory domains often overlap. As a result, there is a high level of collaboration and cooperation across agencies, with each decision based on scientific fact and experimental data. GE crops, in particular, have had significant impact upon sustainability within the United States. These crops have had measurable beneficial economic and environmental effects on GE and non-GE producers alike. Going forward, we need to facilitate the transfer of scientific knowledge and innovation between the public and private sectors, through Intellectual Property (IP) protection and public-private partnerships.

This section addresses the regulation of genetically engineered (GE) products and biotechnology as exemplary of a system for delivering innovative new products and assuring safety with public involvement. It also discusses the complexities of this regulation, as well as the mechanisms through which biotechnology contributes to sustainability within the United States. Finally, the section addresses the intellectual property issues within the context of technology transfer between public and private sectors.

Background

Agriculture is a priority for the US economy. Rural prosperity is essential for a healthy agricultural sector, and a healthy agricultural sector, in turn, is essential for rural prosperity. Given the fact that different forms of agriculture have different rural footprints, the USDA supports all forms, including not only biotechnology, but organic and non-GE production, as well. Keeping people on farms and maintaining the health of rural communities is very important to the department. Nevertheless, biotechnology and GE-based agriculture comprise a vital component of our agricultural system.

Increasing population, wealth and energy use have recently spurred a global surge in consumption of food commodities. In response, the USDA has focused its future research on several high priority thematic areas, including climate change, bio-energy, food safety and global food security, along with nutrition and childhood obesity. Several of our objectives directly relate to the use of biotechnology, which will be essential to addressing these issues.

Within the US context, biotechnology has been integral to the record productivity we have seen in some of our major crops, including maize, cotton and soybeans. Biotechnology has been rapidly adopted by farmers, its safety record has been exemplary, and it has helped raise awareness of the importance of environmental stewardship in agriculture.

Indeed, it will likely be impossible to achieve our goals for production of bio-fuels without the most advanced technologies, including biotechnology. These technologies will also be critical to addressing climate change and reducing greenhouse emissions.

Regulation of biotechnology in the United States

The US regulatory system on biotechnology was introduced in 1986, with the Coordinated Framework for Regulation of Biotechnology. This system was developed under a process that was led by the White House, and involved discussions among various government agencies, as well. Its development was underpinned by the work of the US National Academy of Sciences, which found that the types of risks associated with crops produced using GE are not different from those associated with other products. As a consequence, the National Academy of Sciences determined that US regulation should be based on the end use of products, and that it should be conducted on a case-by-case basis. This work also revealed that adequate regulation of biotechnology-based products could be facilitated through existing US laws.

Three agencies are involved in this regulation: The USDA's Animal and Plant Health Inspection Service (APHIS), the Environmental Protection Agency (EPA) and the Food and Drug Administration (FDA). APHIS is responsible for protecting agriculture against pests and diseases, the EPA is charged with ensuring the safe use of pesticides, and the FDA is responsible for food and drug safety. In several areas, the regulatory domains of each agency overlap. Indeed, products are frequently regulated by more than one agency.

Extensive coordination and collaboration among regulatory officials and agencies are crucial to this process. Within the United States, regulations have been updated numerous times to keep pace with scientific advancement. All product decisions are based on scientific evidence. It is also worth noting that as time has gone on, we have adopted new market tools to deal with ancillary issues not covered under our regulatory framework. For example, parts of the USDA have developed the capacity to evaluate test methods used to detect the presence of GE products, and to verify that laboratories are proficient in using them.

The USDA conducts oversight of nearly all field trials concerning GE plants. All field trials must receive USDA approval, and must be designed in a manner that guarantees biological confinement. This ensures that tested organisms will not persist in the environment, and that there will be no impact on non-target organisms outside of the test. When an applicant has enough information to demonstrate that a given organism will not pose danger to agricultural and human environments, and that it will not pose any plant-pest risks, he or she can petition the agency for "deregulated status." The agency will then conduct an environmental analysis process based on the supplied data, though it may request additional information, if needed. The public also has the opportunity to provide input during this process. Depending upon the conclusions drawn from this initial analysis, more complex and elaborate analyses may be required, as outlined under federal law.

This process demands information on a broad range of topics. Applicants must supply all relevant experimental data, including any data that may be unfavourable, as mandated by law. These data must also include comparisons to conventional crops. If a petition is approved and a product is deregulated, that product can be grown and marketed without further GE-specific oversight from APHIS. Deregulation, however, does not guarantee that the product will not undergo concurrent EPA or FDA review.

The EPA is responsible for the regulation of pesticidal microorganisms and any plant-produced pesticidal substances. If a plant were to produce the insecticidal toxin BT, for example, the EPA would regulate that substance as a pesticide. The agency also sets tolerance levels for the safe use of various conventional pesticides. If any herbicide is used in coordination with an herbicide-tolerant plant, the EPA will regulate the use of the herbicide in conjunction with that plant.

Regardless of whether a pesticidal substance is applied to, or produced by a plant, there is a wide range of information that must first be examined. Each product needs to be characterised, and its effects on human health, ecological impacts and environmental consequences must be evaluated. For certain insecticidal substances produce by a plant (e.g. BT proteins), the EPA also requires plans for resistance management, in the event that insects develop resistance to that insecticide. In addition, the EPA's responsibility with respect to these substances covers not only environmental effects, but impacts on food and feed safety, as well.

The FDA is responsible for ensuring that foods produced through GE are as safe as conventional foods. The types of issues addressed for GE products are the same as those addressed for conventional foods, including toxicity and allergens, food composition, nutritional value, and intended use. The FDA also conducts consultations with product developers. Formally, these consultations are considered voluntary, though it is very unlikely that a company would bring a product to market without first consulting the FDA. These consultations typically include significant dialogue between regulators and developers.

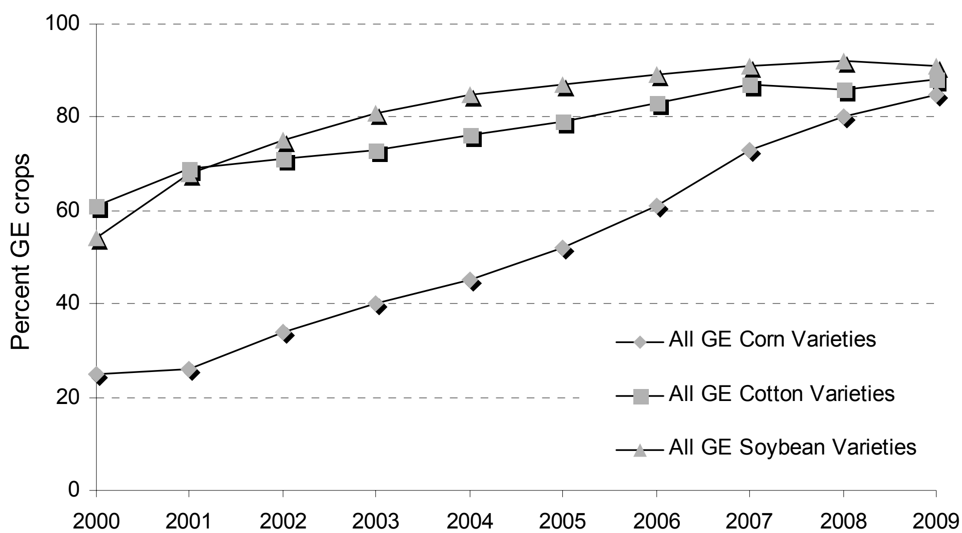
In short, all foods must meet same safety standard under the Food, Drug and Cosmetic Act, regardless of whether or not they are derived from GE organisms.

Impact of GE crops on farm sustainability in the United States

Last year, the National Academy of Sciences published an important report examining the ways in which biotechnology has contributed to sustainability in the United States. These effects encompass environmental and economic impacts, on both GE and non-GE producers, alike.

Adopters of biotechnology have benefited from improved weed control, reduced losses from insect pests, reduced expenditures on pesticides and fuel, increased worker safety, greater flexibility in farm management and lower risk of yield variability. As a result, these products have been rapidly adopted over the course of the last decade, as demonstrated in Figure 18.1

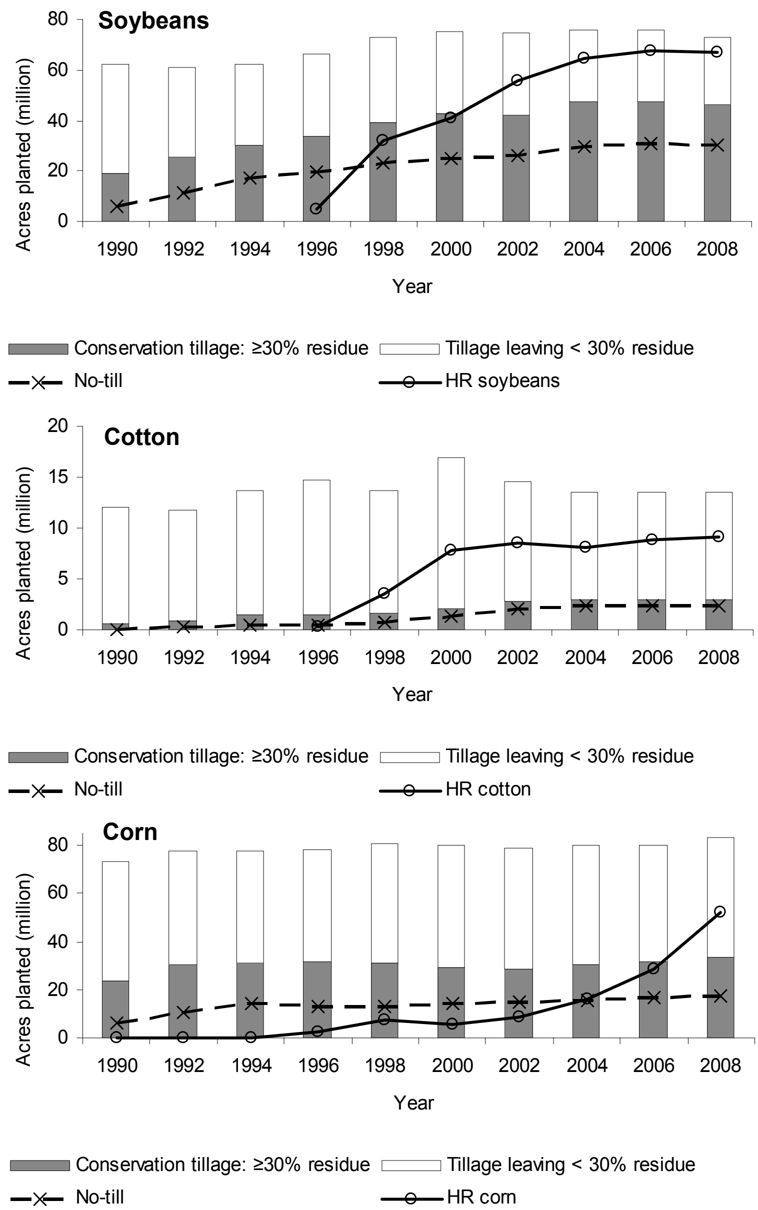
Figure 18.1. Nationwide acreage of GE soybean, corn and cotton crops as a percentage of total acreage of these crops



Source: USDA-NASS (2001, 2003, 2005, 2007, 2009b).

Herbicide-resistant crops have been associated with the complementary use of conservation tillage practices (Figure 18.2). These practices have improved soil retention and have also led to conjecture that surface water quality has improved. Data on water quality, however, remain incomplete.

Figure 18.2. Trends in conservation tillage practices



Source: CTIC, 2009; USDA-FRS, 2009.

Economic effects on non-GE producers are generally more complicated and poorly understood. It is clear, however, that purchasing decisions of GE producers have an effect on those of non-GE producers. To date, there is no quantitative estimate of the economic impact on livestock producers, though it should be noted that we have observed landscape-level effects on pests, with the growth of pest-resistant biotech crops reducing pest pressures on non-GE crops grown nearby. At one point before the commercialisation of GE papayas, for example, non-GE papayas in Hawaii could not be grown, due to viral loads in the region. Now, however, it is possible to grow both. In addition, segregated markets for non-GE products have arisen, in part, due to increased demand from a segment of the population that wishes to avoid GE products altogether.

Recently, the United States has deregulated three products that have received more public scrutiny: an herbicide-tolerant alfalfa, high amylase corn and an herbicide-tolerant sugar beet, which has received partial deregulation. APHIS is currently reviewing petitions for additional products, including some that will address climate change and may introduce nutritional improvements.

Some of these products approvals (including the herbicide-tolerant alfalfa and herbicide-tolerant sugar beet mentioned above) have come in face of legal challenges. The decisions made with regard to these products are based on a thorough scientific review as described above through the Coordinated Framework, but these legal challenges have indeed slowed down the approval process, while increasing costs for both government regulators and developers. None of these legal challenges, however, has questioned the findings of safety regarding these products; rather, they have focused on details of the process under which the decisions were reached. The upshot is that the approval process continues, and legal challenges will undoubtedly continue, as well.

The Secretary of Agriculture has identified a need for increased dialogue among stakeholders with a range of differing interests, in order to discuss approaches to future technological advances. In particular, the Secretary has revived the Advisory Committee on Biotechnology and 21st Century Agriculture, which is charged with providing practical recommendations for bolstering coexistence in US agriculture. The President of the United States, meanwhile, has recently issued executive orders calling for improved regulation across government, greater reliance upon scientific experience, and increased collaboration and coordination among agencies.

Facilitating innovation

United States law allows for a variety of forms of Intellectual Property (IP) protection for GE agricultural products, including patent and plant variety protections. There are a variety of mechanisms to facilitate the transformation of public sector technologies into products commercialised by private sector. Congress has passed laws to facilitate the process of transferring technology from the public to the private sector.

Public-private partnerships (PPPs) have also helped facilitate this process, and, going forward, will become increasingly important in the development of new technology. Because many important developments come from groundbreaking public sector research, strengthening the pathway for product development through the public sector will be critical. Additionally, the first patents on biotechnology-based products are about to expire within the next few years. The transition to a marketplace with generic products will likely raise new IP, economic and stewardship issues.

Note

1. Agricultural Research Service, US Department of Agriculture, United States.

19. Breeding business: Plant breeder's rights and patent rights in the plant breeding business

Hans Dons and Niels Louwaars[1]

This section discusses differences in the strength of Intellectual Property protection between plant breeders' rights (a form of intellectual property right developed specifically for new plant varieties) and patent rights. It presents the main findings of a report, "Breeding Business", issued in the Netherlands and which examined trends in technological developments, socio/economic developments, intellectual property protection, and policy and use of genetic resources. The analysis contained in this report suggests that access to genetic variation is so crucial for further innovation in breeding that a form of breeder's exemption within patents rights seems both justified and necessary. Options to achieve this objective can be found at three levels: via amendments to current legislation and regulations; via the improvement of the quality of patent; and via improvement of the handling of intellectual property in the industrial sector.

Introduction

Plant breeding seeks to create new varieties (cultivars) of crop plants that have a novel genetic make-up. This results in plants with novel traits selected in such a way that they are better adapted to the needs of growers, transporters, retailers and consumers. Plant breeding research and the development of new cultivars is a creative and innovative type of work, and is the basis for an innovation chain that goes from fundamental research to the production and commercialisation of plant seeds and planting material.

Plant breeding is at the basis of the world food supply and, as such, makes an important contribution to food security. It becomes even more important if one takes into account the world's growing population (expected to reach over 9 billion in 2050) and the extended range of uses of biomass in a bio-based economy. Adaptation of plants to poor growing conditions, to novel crop production systems, and even to climate change is essential for the creation of a productive and sustainable agriculture. The basis for plant breeding is the use of genetic variations that exists in nature to make new gene combinations via a process of crossing and selection, and the recombination processes that takes place during meiosis. This highly innovative process leads to cultivars of crops that did not previously exist.

Plant breeding companies develop new varieties with new properties (traits) which enables it to sell new varieties on the market (e.g. in the form of seeds) in order to obtain or expand its market share. The development of a new variety requires much time, effort and high investments that can only be recouped if the company can commercialise the variety. To protect the rights of the breeder, the legislator has developed systems that protect the breeder/inventor against others who could copy, imitate and commercialise the product. A successful system has been developed specifically for the plant breeding sector, called the Plant Breeder's Rights (PBR) or Plant Variety Protection (PVP).

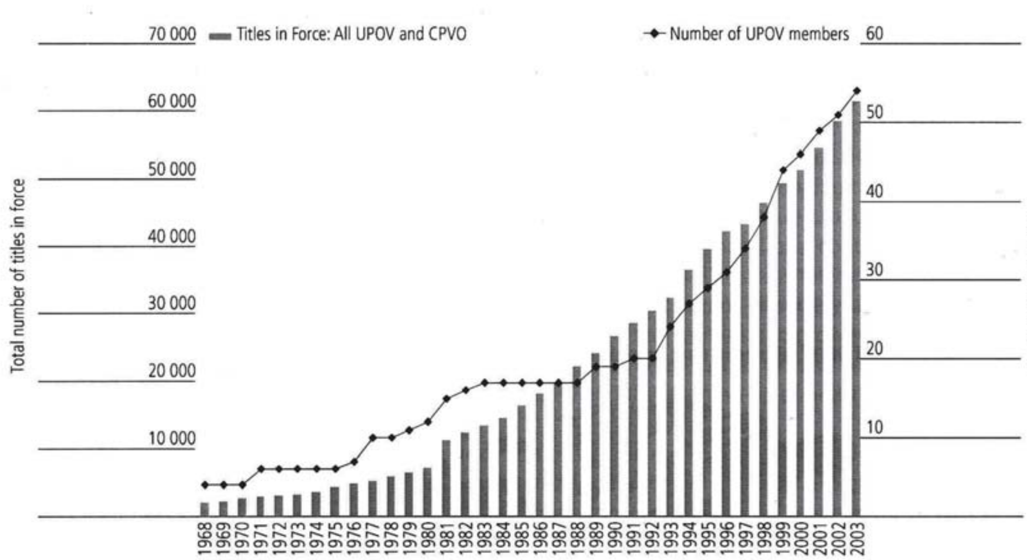
In the 1970s, a number of breakthrough technologies were developed within research organisation that revolutionised plant breeding. This so-called plant biotechnology not only led to a novel type of plant breeding (from conventional to molecular breeding), it also introduced other Intellectual Property Rights (IPRs), the patents system, into this business. Due to differences in the strength of protection, a conflict has arisen between Plant Breeder's Rights and Patent Rights. It is this conflict that is analysed in this section.

Plant breeder's rights

Plant Breeder's Rights is a form of Intellectual Property Protection designed to protect the breeding of new plant varieties. In the first half of the 20th century interest in commercial plant breeding and seed business developed and was stimulated by the rediscovery of Mendel's laws of heredity and technological innovations in the breeding process, e.g. hybrid seed production.

This professionalisation of the commercial seed business soon led to questions about the protection of intellectual property in this area. It is interesting to note that the patent systems already been in place for other industries were not regarded as suitable for plant breeding for ethical, legal and technical reasons. Therefore other ways to protect the breeder and create opportunities for a good return of investment had to be created. The Netherlands was the first European country to implement a special legal protection system in1941. Most PVP systems are presently based on the International Convention for the Protection of New Varieties of plants (UPOV Convention), which in turn is based on the results of diplomatic conferences of 1957 and 1961 that involved several European countries. The UPOV system has been improved over time (last time in 1991) and has gradually strengthened the rights of the breeders. The number of UPOV members has increased gradually over the years and today has over 60 member countries (Figure 19.1).

Figure 19.1. Titles in force: All UPOV and CPVO



UPOV: International Union for the Protection of New Varieties of Plants; CPVO: Community Plant Variety Office.
Source: UPOV Report on the Impact of Plant Variety Protection, 2005.

The UPOV clarifies that its mission concerning a PVP system is "to provide and promote an effective system of plant variety protection, with the aim of encouraging the development of new varieties of plants for the benefit of society" (UPOV, 2005).

Since PVP systems have been developed with the specific purpose to protect newly developed plant varieties, specific criteria have been developed for the recognition of new cultivars. New cultivars have to be examined for their distinctness, uniformity and stability (what is called the DUS testing). If a new application fulfils these three requirements, the breeder is granted breeder's rights that give him a protection restricted to this specific cultivar. This clearly is different from the patent system where the granted claims determine the width of protection. Other differences with the patent system relate to exemptions from rights.

First, farmers have the right to re-use seed produced on their own farm. There are strict regulations concerning the crops used and the amount of re-used seeds in order to reflect the legitimate interest of the holder of the breeder's rights.

Secondly, and most prominent in the current debate on plant breeder's rights and patents is the Breeder's exemption. This gives the opportunity to other breeders, or indeed to anyone, to use the protected variety for further breeding and commercialisation.

The breeder's exemption is generally regarded as a cornerstone of plant breeding practice and has been very important in stimulating innovation, in the continuous creation of new cultivars and upgrading of the germplasm of the world's most important crops.

Patents in plants

The patent system for the protection of intellectual property is much older than the system just described for Plant Breeder's Rights. The Paris Convention of 1883 laid the foundation for internationally agreed standards for patents. For about one century the system was not relevant for plant breeding, and protection was fully based on PVP systems. This has changed dramatically with the introduction of biotechnology in the breeding business.

Patents are an important business tools for several industries, e.g. pharmaceutical, automotive, electronics, etc, by giving the patent holder the legal right to prevent others to produce, use, offer for sale or sell the patented product without the permission, via a license, of the patent holder.

A patent is granted by one of the official granting agencies if the invention meets three requirements: it is new, inventive, and industrially applicable.

- ***Novelty.*** An invention is considered as novel if it is not part of the state-of-the-art. A state–of-the-art is formed by everything already made publicly available through a written or verbal description, through application, or by any other means before the date of submission of a patent application.
- ***Inventiveness.*** An invention is the result of the activities of the inventor if the invention is not obvious for someone skilled in the art.
- ***Industrial applicability.*** An invention is considered suitable for application in an industry if its design can be produced or applied in any sector of that industry, including agriculture.

Different countries may interpret the above requirements slightly differently. For example, the United States refers to "non-obviousness" instead of inventiveness. A patent application has to include a description that enables someone "skilled in the art" to reproduce it. Patents are only valid in the countries in which they are granted at one of three levels: national, European (EPO), or international (PCT).

Assessment on IPR systems in plant breeding

The debate on the interaction between the two IPR systems in plant breeding began as soon as biotechnology was introduced in plant breeding. In 1984, for example, The Netherlands Agricultural Research Council discussed this relationship and came to a far-reaching conclusion (translated from Dutch): "Such a patent right on one gene would then form an absolute barrier for the use of certain varieties by farmers and breeders. The commission assumes that the legislators have not intended such an unrestricted monopoly in either of the legal systems."

In early 2009, the relation between the two protection systems was placed on the agenda of the Dutch Parliament and was discussed at several meetings of the Lower House of Parliament. The Minister of Agriculture, Nature and Food Quality, in consultation with the Minister of Economic Affairs, decided to ask Wageningen University and Research Center to study the relationship between patent rights and plant breeder's rights, as well as the impact of these systems on the structure of the plant breeding sector in the Netherlands and abroad. This study resulted in the report "Breeding Business, the future of plant breeding in the light of developments in patent rights and plant breeder's rights", that was presented in December 2009 and forms the basis of this section.

The breeding business

The above-mentioned report was the result of research, consultation and interviews. Most of the work consisted of technical, socio/economic and legal research into the current trends in plant breeding and the impact of these trends on industry. The body of the research was formed by several trend analyses.

- Trends in technological developments.
- Trends in socio/economic developments.
- Trends in Intellectual property protection.
- Trends regarding policy and the use of genetic resources.
- Trends in developing countries.

Technological developments

Major changes have taken place in plant breeding research as a result of the application of modern biotechnology. Up to 1980s, commercial breeding had been based on classical breeding methods and plant biotechnology was limited to rapid in vitro multiplication of propagation material, the production of haploid plants for the rapid development of homozygous lines, etc. Several scientific breakthroughs in fundamental biology had taken place in the 1970s, however, including the discovery of restriction enzymes for the fragmentation of long stretches of DNA, technologies for determining the base sequence of DNA, and the development of high/throughput sequencing later on. Unravelling the role of a DNA plasmid of the soil bacterium *Agrobacterium tumefaciens* formed the basis for the development of genetically modified – transgenic - plants.

Since the 1980s, these new molecular technologies continued to be improved and extended and are now part of the plant breeder´s tool box. The knowledge of molecular genetics is developing at a high speed and it is just a matter of time before access to all genetic information of all major crops is obtained. Application of these technologies is called molecular breeding; it uses enormous amounts of genetic data (bioinformatics) and enables the combination of genetic information on gene expression (transcriptomics and proteomics), physiological data (metabolomics) and phenotypic data.

The application of molecular breeding has revolutionised plant breeding but at the same time has increased the costs of this type of breeding. Implementation of new technologies is one of the drivers for the consolidation in the seed market (Schenkelaars *et al.*, 2011) and has increased the demand for a good return of investment. The application of biotechnologies in plant breeding has led to the introduction of the patent system in this business.

Socio-economic developments

Since 1970, major changes have also occurred in the organisation of the international seed business with the number of seed companies in Europe and North America decreasing sharply as a result of mergers and acquisitions. The seed business has become increasingly professionalised in a rapidly growing marketplace; from an estimated USD 18 billion in 1985 to USD 34 billion in 2006 (Table 19.1). Several factors were responsible for this growth in turnover: first because an increasing number of countries and continents opened up the market for commercial seed due to globalisation; second, more farmers started to buy commercial seeds and recognised its value; and, third, due to the high quality of seed, prices went up.

Table 19.1 also shows the effect of the consolidation that took place. At the global level, the top four seed companies have developed from a market share of 8% in 1985 to close to 30% in 2006. The market is dominated by the large life sciences companies that have important other business in other sectors, such as agrochemicals and pharmaceuticals. In the vegetable seed sector, a comparable consolidation took place which resulted in a market dominated by a few companies only; the top ten companies control over 85% of the professional seed business.

Table 19.1. Changes in seed company turnover 1985 – 2006

1985		1996		2006	
Company	**Million USD**	**Company**	**Million USD**	**Company**	**Million USD**
Pioneer	735	Pioneer	1 500	Monsanto	4 028
Sandoz	290	Novartis	900	DuPont-Pioneer	2 781
Dekalb	201	Limagrain	650	Syngenta	1 743
Upjohn-Asgrow	200	Advanta	460	Limagrain	1 475
Limagrain	180	Seminis	375	KWS Saat	615
Shell Nickerson	175	Takii	320	Land O'Lakes	550
Takii	175	Sakata	300	Bayer BioScience	465
Ciba Geigy	152	KWS	255	Delta PineLand	417
VanderHave	150	Dekalb	250	Sakata	410
CACBA	130	Cargill	250	DLF Trifolium	365
Global seed market	18 000		30 000		34 000
Top 4 (%)	8		12		30

Note: Adapted from Le Buanec (2007).

Source: Louwaars *et al.* (2009).

Although the consolidation of the international seed business is evident, the driving forces behind this are complex. A recent study by Schenkelaars *et al.* (2011) revealed that these forces include the professionalisation of the sector, the globalisation of the seed market, and the technological developments. Another important factor is the implementation of genetically modified (GM) technology in the seed business, the development and application of which require economies of scale not only because of the investments needed for research and development, but also because of the high costs related to legal constraints, registration, and liability, including stewardship responsibilities. Within these developments, the use of patents as protection for intellectual property plays a very important role. Patents on technologies and traits are not restricted to one variety, but can be applied to a number of varieties or even to a number of plant crops. This can give a company control over different markets and other breeding companies that wish to use the technologies or traits for their own breeding programs. The potential market power is best exerted by companies that combine global presence with a large legal capacity.

Trends in IPR

As shown in Figure 19.1, the number of countries that have become members of UPOV has increased considerably in the past 40 years and this has given rise to the number of granted PVPs (the titles in force). The application for plant variety protection was facilitated by the establishment of the Community Plan Variety Office, which allowed breeders to make a single application for all countries of the European Union.

The number of PVP certificates granted to various companies is shown in Table 19.2. This table is based on UPOV data about the allocation of plant breeder's rights by CPVO for the main crop groups. The names of the companies have been adjusted manually on the basis of available information on acquisitions. This can result in a slight overestimation of the diversity of applicants. The table shows that for some crop groups (e.g. cereals and vegetables), the number of applications for European plant breeder's rights has decreased, resulting in an increase in the share of the top five companies. Ornamental crops and fruit, however, show the opposite trend: more applicants and a smaller share for the top five companies. For these crops, many companies or individuals have applied for one or two varieties in both periods. Finally, the table shows that the largest companies at the global level (Monsanto, Pioneer, Syngenta, Limagrain/Vilmorin) are all present in Europe.

As discussed above, the rise of biotechnology in plant breeding and the introduction of genetic modification have resulted in increasing interest in the application of patent rights as IP protection system. In Europe, the Biotechnology Directive was enacted only in 1998. In 2008, the European Patent Office (EPO) handled over 150 000 applications in biotechnology. Only a minor part of this deals with plant breeding, more specifically with genetic modification. Between 1980 and 2006, a total of 4 048 patent applications for plant biotechnology processes and GM were submitted.

Table 19.3 shows the top ten companies that account for most of the GM patent applications. This concerns applications to EPO and USPTO between 2003 and 2007. The share of the top ten companies in the United States is no less than 75.1%. The level of concentration in Europe remains lower, with 42.5% of all patent applications. The results of this analysis point towards a substantial decrease in the number of companies that can use biotechnology to develop new plant varieties and that patent positions are concentrated on a smaller number of companies.

Table 19.2. Spreading of PVP applications to the CPVO

	Number of applicants		Top five applicants (%)		Number of varieties	Top five companies (number of varieties)
	1996/2000	2001/2005	1996/2000	2001/2005	1996/2005	
Cereals	96	63	43	60	2563	SW-Seed (40) Ragt (126) KWS (153) Pioneer (265) Limagrain (279)
Oil seeds	26	29	56	66	592	Limagrain (21) Syngenta (21) SaatenUnion (Raps gbr) (27) Pioneer (58 Monsanto (67)
Fruit	85	139	32	19	639	CIRAD (10 Driscoll (12) CRPV (14) INRA (20) Darnaud (22)
Vegetables	152	112	40	52	2031	Bejo Zaden (68) Nunhems (Bayer) (68) Syngenta (76) Monsanto (143) Rijk Zwaan (152)
Ornament crops	559	759	19	12	9365	Anthura (122) Ball (128) Poulter Russell (144) Yoder Brs (150) Vletter & den Haan beheer (155)

Note: UPOV database.
Source: Louwaars *et al.* (2009).

Table 19.3. Top ten companies applying for GM-plant patents between 2003 and 2007

USPTO patent applications (total 2 992)			EPO patent applications (total 1 220)		
Company	**Number**	**Share**	**Company**	**Number**	**Share**
Pioneer Hi-Bred	843	28.5%	Pioneer Hi-Bred	107	8.8%
Monsanto	728	24.6%	BASF	105	8.6%
Syngenta	167	5.6%	Monsanto	101	8.3%
BASF	128	4.3%	Bayer CropScience	57	4.7%
Bayer CropScience	89	3.0%	Crop Design	36	3.0%
CERES INC.	74	2.5%	Syngenta	28	2.3%
Mertec LLC	58	2.0%	Unilever	23	1.9%
Anix Corporation	49	1.7%	Icon Genetics	22	1.8%
Dow AgroScience LLC	48	1.6%	Novartis	21	1.7%
Delta and Pine Land	39	1.3%	Mendel Biotechnology	18	1.5%
Total	2 223	75.1%		518	42.5%

Note: Ownership of a company is allocated in the year of acquisition. Crop Design was acquired by BASF in 2006, Icon Genetics was acquired by Bayer in 2006, Delta and Pine Land was taken over by Monsanto in 2006.
Source: Louwaars *et al.* (2009).

Trends in policies and use of genetic resources

Access to genetic variation is the basis for the success of plant breeding. Since the 1980s, there has been increasing awareness of the value of genetic resources for mankind. International policy with regard to genetic resources began in 1983 with the adoption of the "International Undertaking on Plant Genetic Resources for Food and Agriculture" by the FAO Council (UN Food and Agricultural Organisation). This agreement treated such genetic resources as a "heritage of mankind" that should be freely available to all. However, the countries where such resources originated obtained sovereignty over their genetic resources via the Convention on Biological Diversity (CBD) in 1993 which led to restricted access to genetic resources for plant breeding. Since then, countries can limit accessibility and make access subject to mutually agreed terms. To solve the problems of accessibility, in 2001 the International Treaty for Plant Genetic Resources for Food and Agriculture came up with a system of multilateral access and sharing of benefits originating from the use of the genetic resources. A single Standard Material Transfer Agreement was put in place, and includes mandatory payments.

There is concern about the access to genetic resources, that would restrict the basic genetic variation that can be used today and in the future for plant breeding and the development of new varieties. On the other hand, we are dealing with genetic erosion due to the fact that the plant breeding business has made selections of uniform varieties out of a wide genetic diversity. To make sure that genetic variation will be conserved for the future, international, national and corporate gene banks have been established. In a recent study by Van de Wouw *et al.* (2011), it was shown that access by breeders to gene banks increases the use of exotic material, and thus increases the genetic diversity.

Trends in developing countries

In the discussions on PVP and patents in plants, developing countries play a specific role. IPR systems are still underdeveloped, there is a lack of effective protection, and there is a high dependence on IPR protection that is much more developed in the western world and not adapted to specific situations in developing countries. Breeding in developing countries is strongly dependent on public investment, such as the centres belonging to the Consultative Group on International Agricultural Research (CGIAR).

The WTO Trade-Related Aspects of Intellectual Property Rights (TRIPS) Agreement of 1994 stimulated the upgrading of patent systems, as well as the introduction of Plant Breeder's Rights systems in many countries. Most Latin American countries joined UPOV under the 1978 Act. Several countries in Asia developed their own systems, many of which resemble UPOV. In Africa, only a small number of countries are members of UPOV and the level of implementation of PVP differs widely. A major concern in developing countries is the farmer's privilege, which under UPOV acts becomes restrictive. Farmers are not allowed to exchange seeds of protected varieties and the re-use of their own seeds is restricted to certain crops. This is in opposition to traditional seed handling by farmers and explains the hesitation of governments to implement UPOV rules.

With regard to patent rights, developing countries are adopting the requirements of TRIPS. Patents in plants do not allow for any reproduction of seeds by farmers, except in Europe where an explicit exemption has been included in the Biotechnology Directive.

IPR in plant breeding

IPR plays an important role in the plant breeding business. The way in which IPR is used should have a positive impact on the development of the breeding sector and, at a more abstract level, should benefit society. A critical evaluation of current practices in IPR protection in the breeding business should be done with a number of normative points of departure.

- Plant Breeding should continue to be the main tool towards food security and sustainable agriculture.
- Access to genetic resources remains the cornerstone for creating better varieties in the future.
- The innovative strength of the sector should be preserved and even increased.
- Diversity of companies is key for healthy competition and increased innovation.
- A decent and profitable market share should be safeguarded.
- A good Intellectual Property Rights systems should be supportive for the whole business.

We will use these basic principles in a critical assessment of the use of PVP and patents in the plant breeding business. Despite the significant differences between IPR systems, plant breeder's rights and patent rights have two fundamental and identical objectives. On the one hand, both systems ensure that the developer/inventor is recognised for his/her creation/invention by granting an exclusive right. For the owner of the rights, this serves in practice a business-economic purpose that may provide the basis for a good return on investment (ROI). On the other hand, plant breeder's rights as well as patent rights include an important socio-economic objective by disclosing information on the patentable invention and by making a plant variety under PBR available for further breeding (the "breeder's exemption"). This offers possibilities to build on such inventions and may stimulate further innovation by others, including competitors, which serves the public objective of economic development. Assessment on how plant breeder's rights and patent rights are applied in plant breeding needs evaluation as to their true contribution to both objectives.

The plant breeding industry is recognised as a very innovative industrial sector in which new breeding technologies in combination with genetic resources ensure a continuous supply of new plant varieties. Of course, large differences exist in the development of the sector between countries and continents, between various subsectors, and between companies. The Netherlands, for example, is a country that has a very strong knowledge structure (Dons and Bino, 2008; Laane and Besteman, 2009) with a major influence on the quality of the commercial R&D sector, the development of varieties and the production of high quality seeds or other planting material. Commercial R&D realises high investment levels in R&D, 15% to over 25% of turnover.

The drive to innovate in new breeding methods and the development of new varieties is based on the breeder's motivation to find creative solutions for problems in the culture of crops and in the value chain that can capture a market segment. Protection of IPR is not the primary driver to develop new, innovative varieties. It is, however, an adequate tool to protect such varieties against illegal reproduction and sales.

The proposition that obtaining plant breeder's rights is not the prime driver of innovation is illustrated by the fact that plant breeder's rights for many new varieties are not applied for, but that nevertheless a good market share can be acquired with good profit margins.

The breeder's exemption is regarded by many breeders as the cornerstone for successful innovation in the breeding sector. In fact it is a sort of "open innovation" *avant la lettre* because all breeders are allowed to use the latest varieties with the best properties' (or traits) whether the varieties are protected or not. In the ornamental breeding sector especially, the breeder's exemption is of direct significance for survival in this sector and it even stimulates the entrance of new companies.

It is also noteworthy to recognise that plant breeding is a cumulative type of innovation. From the start of agriculture on, breeders were building on earlier breeding work. The breeder's exemption is in fact the formalisation of an innovation mechanism that has existed over a very long time.

The large number of new varieties, the increasing number of varieties for which PVP is requested, and the positive way in which stakeholders speak about the breeder's exemption allow to conclude that the breeder's exemption plays an essential role in innovation in plant breeding. The combination of protection and breeder's exemption makes that plant breeder's rights perfectly satisfy the two objectives concerning the balance between the benefits for the breeder/inventor and society in general.

Since the introduction of modern plant biotechnology, many new molecular technologies have been developed that are important for breeding. As shown, these technological breakthroughs have led to major changes in plant breeding and for the development of molecular breeding. If these new techniques meet the criteria of novelty, inventiveness and industrial applicability, they qualify for a patent. The inventor has the option to use the patented technology himself or to let it be used by others under license. And because the patented technology is published it contributes to public knowledge and stimulates further innovations in breeding. Such use of patents in plant breeding is in full accordance with the objectives of patent rights.

However, patents are not only granted for new technologies but also for genetic properties of plant (the so-called trait patents). The strong increase in knowledge about plant genetics has led to patenting of an increasing number of genes that code interesting properties. This gives the patent holder an exclusive right to commercialise those plants. Similar to plant breeder's rights, such patent rights on plant properties can also lead to a return on investment. But plants with these new properties are not available for further breeding and products further down in the chain may also fall under the scope of the patent.

Our research has revealed some concerns about the way in which patents are granted, the scope of the claims, and the way in which patented findings are handled.

- There is much debate about the question whether the discovery of new traits based on existing genetic information meets the criterion of inventiveness. Especially because certain new technologies become state of the art.
- There is debate on the acquisition of licenses, the costs of licenses, and the licensing conditions. Due to the high licensing costs, companies depending on licenses on important traits will lose part or all of their profit margin on seeds. This endangers their own R&D and further increases their dependence.

- Since the plant breeding industry builds on work undertaken over many years of breeding and selection and new varieties created by using the total genetic information (the gene pool), access to that genetic information is required for further improvement.
- If the claims in a patent on a certain genetic trait stretch into a broad variety of plant species or further on in the innovation and production chain ("reach-through" claims), this can restrict further innovation if insufficient licenses are granted.
- Acquiring a patent on a new trait is often seen as a bonus on the high investments over time and R&D costs, so it becomes a method to obtain a good return on investment. However, this disregards completely the fact that investments and duration are no criteria for acquiring a patent.
- If patenting in plant breeding becomes the normal way to protect intellectual property, we have to be aware of "ever-greening." This is a system under which *de facto* a prolongation of the patent protection is obtained by patenting a new variation on essentially the same invention.
- Other forms of strategic use of patents are used by companies to protect their own IP position and to restrict the room for others. Such as "patent thickets" by creating a multitude of patents around the same theme, leading to uncertainty about the precise description and the boundaries of claims.

Referring to the original objectives of patent rights (mentioned above), it is clear that several of the observations concerning the use of the patent system in plant breeding might be in line with the business-economic objectives of a company, but are not in line with the socio-economic objective of patent rights.

Towards improvement of IPR in plant breeding

This study has shown that the granting of patent rights for genetic properties is increasingly used in plant breeding, conflicts with plant breeder's rights, and the breeder's exemption in particular. The analysis has shown that access to genetic variation is so crucial for further innovation in breeding that a form of breeder's exemption within patents rights seem justified and required.

Options to achieve this objective can be found at three levels: via amendments to current legislation and regulations; via the improvement of the quality of patent; and via improvement of the handling of intellectual property in the industrial sector. These options are described briefly.

- Amendments to existing legislation and regulations. This implies the introduction of a sort of breeder's exemption within patent law. Options are:
  - Exemption of patentability of plants (as mentioned in TRIPS) or plant traits.
  - Full breeder's exemption in patent legislation.
  - Restricted breeder's exemption in patent legislation.
  - Only allow the use of the genetic background and not the patented trait.

- Improvement of the quality of patents.
    - A more critical analysis of novelty.
    - Stricter criteria for the inventiveness of the invention (the "inventive step").
    - A wider interpretation of the concept "processes of essentially biological nature,", as confirmed in part by the ruling on the broccoli case before the enlarged board of appeal of EPO.
    - Restriction in the number and scope of claims.
    - Restriction of the possibility to *de facto* prolong patent validity via "ever-greening" strategies.
- Improvement of handling with IP.
    - Stimulate discussions at the international level in the seed business.
    - Evaluate alternative models for the exertion of patent right, e.g. "patent pools" or licensing in a Fair, Reasonable And Non-Discriminatory (FRAND) way.
    - Establish a novel code of conduct via international organisations, e.g. European Seeds Association (ESA) and International Seed Federation (ISF).
    - Investigate the patent and licensing policy of public research organisation.

It is clear that some of these options have far-reaching consequences and need careful consideration of the legal consequences at the national (e.g. the Netherlands Patent Act), European (Biotechnology Directive and the upcoming European Patent system) and international (TRIPS Agreement) levels. Moreover, the issue of IPR in plant breeding is relevant for the international community to the extent that a number of adjacent policy areas must be taken into account; changes in IPR legislation relate to completion of laws, innovation and development policies, etc., and to genetic resources policies in the context of the Convention on Biological Diversity (CBD) and the International Treaty on Plant Genetic Resources for Food and Agriculture (IT PGRFA)

Current status of the debate

Although discussions on the role of patents in plant breeding and the co-existence of plant breeder's rights and patent rights has been taking place for several years, the debate really started in 2009 and was initiated by the Dutch parliament where the subject was raised in relation to the socio-economic aspects of genetically modified organisms where patent rights play an important role. On basis of all the questions raised by members of Parliament, the minister decided to initiate research performed under the lead of Wageningen University and Research Centre. The report, *Breeding Business*, was issued at the end of 2009.

PlantumNL, the Dutch association for the plant reproduction material sector, also adopted at this time the position that there should be a full breeder's exemption, including the free use for further breeding and exploitation of new cultivars, for biological material protected by patent rights.

On basis of the Wageningen report, the minister's opinion on this matter that was tabled in Dutch Parliament can be summarised as follows.

The main conclusion was that the minister confirmed the lack of balance between the use of plant breeder's right and patent rights in the plant breeding sector and that access to genetic resources needed to be supported. It was proposed to implement a restricted breeder's exemption in the existing patent law, in the same way that is done by Germany and France. However, this is not enough. An evaluation was announced to investigate whether a full breeder's exemption could be achieved. The minister confirmed in 2011 that this exemption should be done in consultation with other European countries.

The Dutch government also supports the European Patent Office in improving the quality of patents granted by this office. This is in line with internal activities to improve the quality within EPO, otherwise known as "raising the bar".

It is the opinion of the Dutch government that part of the problems must be resolved by the seed business itself. The companies are invited to discuss these issues and to look for opportunities to come to a code of conduct on the use of IPR in their business and to develop license agreements under FRAND conditions.

In addition to these activities in the Netherlands, also the international organisations of the seed industry have also actively taken up this issue. The German and French Seed Associations have formulated strong positions that focus on significantly reducing the number of trait patents. The German Government aims to abolish patents on living organisms altogether. Both the European (ESA) and the International Seed Organisation (ISF) have put IPR in plant breeding high on their agendas. Since the topic is complex and extremely important for the future of the international seed business, the process will take some time. It is expected that both organisations will make their position public at the end of 2011 or in 2012.

Note

1. Hans J.M. Dons, Bioseeds BV, and Niels P. Louwaars, Centre for Genetic Resources, The Netherlands and Law and Governance Group of Wageningen University.

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20. Public-private partnerships: The role of the private sector

Dominic Muyldermans[1]

This section addresses the role of the private sector in agricultural Public-Private Partnerships (PPPs), and its capacity to drive innovation and Research and Development (R&D) — elements that are crucial to fuelling growth in the agricultural sector. The private sector plays a particularly critical role in spurring agricultural R&D, especially when combined with public sector initiatives within mature markets with strong Intellectual Property Rights (IPR) to protect returns on investment. The key to a successful PPP lies in combining the different objectives and aims of the public and private sectors in order to bring about a synergy effect – a co-operative mechanism whereby both public and private sectors share the financial burdens of R&D. This synergy effect enables returns on investment by taking advantage of the private sector's technical expertise, and the public sector's knowledge of local needs and networks. This section also discusses the issues that may arise when implementing PPPs, including increased liability exposure and the potential erosion of IPR. As we demonstrate, effective PPP strategies must recognise the differences in objectives and capabilities across the public and private sectors, while acknowledging that returns on investment are essential to creating and fostering innovation. PPPs must also promote enabling, science-based frameworks in favour of prohibitive regulatory frameworks. Finally, we recommend an increase in public spending in order to foster innovation and make new technologies more widely available.

This section discusses the role of the private sector in Public-Private Partnerships (PPPs) within the agricultural sector. It examines the ways in which the private sector fuels Research and Development (R&D) in both mature and non-mature markets, and highlights the importance of strong Intellectual Property Rights (IPRs) as a means of protecting returns on investment. We then examine the synergy effect underpinning successful PPPs, and its benefits for both private and public actors. Finally, we introduce some issues that may arise during the implementation of a PPP, including increased liability exposure and the potential for IPR erosion.

Private sector innovation

R&D is key to fuelling growth in the agricultural sector. Strong R&D improves crop productivity, strengthens sustainable agricultural practices and empowers farmers to adopt best practices. Robust R&D also results in higher farming incomes, thereby helping to reduce poverty and improve health and welfare.

The private sector plays a particularly crucial role in spurring agricultural R&D. In fact, the world's top ten plant science companies employ a total of approximately 15 000 scientists, and collectively spend USD 5 billion each year on R&D.

It is important to note that the private sector's primary objectives differ from those of the public sector. Whereas the private sector aims to make profits, national governments are typically concerned with providing solutions for larger public needs through non-profit research, and with generating profits to fund such research. It should be noted, however, that the private sector's focus on profits does not exclude corporate social responsibility.

IPRs play a major role in fuelling innovation, as well. IPRs create a return on investment in a particular technology, thereby generating incentives to invest in the same or similar technologies. A return on investment in one market or one field can also trigger a similar innovation in other markets, fields, or countries. Furthermore, strong IPRs avoid the pitfalls of free-riding behaviour, which could create disincentives to invest.

Once technologies have been commercialised in a mature and competitive market, they generate returns on investment, since farmers are willing to pay a higher premium in exchange for higher profits. These returns in mature markets can then drive R&D within developing country or non-mature economic markets. Without returns on investment, however, the costs of publicly-funded R&D would increase substantially.

Public-private partnerships: the synergy effect

The key to a successful PPP, then, is to combine the objectives and abilities of both public and private sectors. The following are examples of PPPs that have done so successfully within developing country markets:

- Developing Agriculture Project (South Africa);
- Integrated Pest Management (Latin America, Southeast Asia and Africa);
- HarvestPlus Challenge Program (Asia and Africa);
- Water Efficient Maize for Africa (Tanzania);

- Vitamin A Consortium with the International Rice Research Institute, IRRI (Philippines);
- Donation of Biotech eggplant technology (India, Bangladesh, Philippines);
- BioCassava Plus Project (Sub-Saharan Africa); and
- Biofortified Sorghum Project (Africa).

Underpinning each of these PPPs is a synergy effect, whereby both public and private sectors share the financial burdens of R&D. This cost-sharing enables returns on investment, while focusing on facilitated access in non-mature markets. It achieves this by making existing technology available for local needs, or by developing new technologies. It is important to keep in mind that within this context, the term "technology" encompasses the creation of regulatory skills and stewardship, in addition to the innovation itself.

This synergy also creates expert resources for capacity building, and combines complimentary capacities across both public and private sectors. More specifically, it allows the private sector to contribute its technical expertise, while taking advantage of the public sector's knowledge of local needs and close ties with local authorities and stakeholders.

As a result, the synergy effect increases the leverage of a public-private knowledge base, while sharing costs of infrastructure and increasing the effectiveness of technology. It also enhances the quality and quantity of sectoral knowledge, and promotes the effective and responsible use of new technology through the cultivation of sustainable stewardship practices. Public and private sectors clearly play different roles and have different abilities in the continuous cycle of innovation needed to ensure food security. Combining these roles and abilities in strong PPPs can result in products and technologies capable of meeting consumer demands with greater efficiency and effectiveness.

Potential issues

When implementing PPPs, there are two primary issues that may arise: increased liability exposure and erosion of IPRs.

Liability exposure

PPPs may increase liability exposure by decreasing control through a broader dissemination of regulated technologies. Liability exposure may also be increased through very stringent regulatory systems, which can be even prohibitive in some cases, especially with regard to Genetically Modified Organisms (GMOs). Very specific regulations can engender a rather significant liability exposure, due to the manner in which regulations are executed and enforced in many countries. Such a highly regulated environment can often result in a lack of legal certainty, a need for specific skills or expertise, and substantial costs relating to regulatory risk management. Trade losses, meanwhile, may arise, while a lack of expertise in laboratory or field trial practices may give rise to further risks.

Erosion of IPRs

The dissemination of technology in countries where Intellectual Property (IP) protection is either weak or unavailable can contribute to the erosion of IPRs. This, in turn, may lower the value of IP by introducing disincentives to further investment not only for the private sector, but for the public sector, as well. Indeed, this devaluation could lead to a substantial increase of public sector funding and diminished returns on investment opportunities, therefore resulting in less efficient and less effective innovation.

Conclusion

Effective PPP strategies must therefore recognise the differences in objectives and capabilities across the public and private sectors. They must also acknowledge that return on investment is essential to creating and fostering innovation. This return on investment should be combined with policies that make technology available in broader sense, while supporting IPR as a key incentive for innovation.

In addition, PPPs must promote enabling, science-based frameworks in favour of prohibitive regulatory frameworks. Science-based frameworks, it should be noted, do not exclude socioeconomic elements, but remain centrally focused on technology. Effectively implementing these frameworks is a challenge for both developed and developing countries, alike. Finally, rather than decreasing government spending, we would recommend an increase in public investment in agricultural R&D, considering its ability to foster innovation and to make technology more widely available.

Note

1. Senior Legal Consultant to CropLife International.

Part V.

Facilitating adoption of innovations and technology transfers

21. A rainbow revolution and participatory plant breeding: Combining traditional knowledge and modern science

Masa Iwanaga[1]

The adoption of new crop varieties by local farmers has been a key technological innovation for improving productivity and profitability. Plant breeding, carried out either by farmers or professional breeders, has been the main tool for the development and dissemination of these new varieties. Its role will continue to increase in importance over the coming decades in a time of major challenges for sustainable plant production due to factors such as global climate change, food insecurity and the degradation of natural resources. A successful example of an Agricultural Knowledge System (AKS) is participatory plant breeding which combines the local knowledge of traditional farmers and the scientific knowledge of modern scientists applied at a global level, thus allowing for efficient local innovation in the context of global challenges. The lessons learned and the future prospects of this participatory approach are analysed.

Introduction

Cultivation of new plant varieties has played a crucial role in efforts to increase productivity and profitability of farming activities. Humans have successfully transformed wild ancestral species into cultivated species that were amenable to changes and preferred for human uses as food, fodder and fibre. Three key skills are often mentioned as being decisive in marking the differences between humans and other species: effective communication skills, and the skilful use of fire and tools. I would add one more skill that distinguishes humans from the rest: the skill to manipulate genetic composition of other species for their own benefit which has enabled the development of agriculture, which in turn has changed the evolution of human society.

The skill to modify the genetic composition of other species is called breeding. This breeding skill has been used by farmers to develop new varieties that are better suited for their needs for the last 10 000 years. Traditional farmers and farming communities have practiced breeding and have created a vast genetic diversity to meet their needs, e.g. to increase productivity and to adapt to climate change. For example, more than 100 000 different rice varieties known to exist were developed by traditional farmers before professional breeders came into activity about 100-120 years ago. Mendel's discovery of the laws of inheritance in the late 19th century established the foundations for scientific breeding. Current agricultural production mostly depends on the plant varieties developed by professional breeders (with formal training), rather than on varieties developed by traditional farmers.

The Green Revolution

The enormous power of plant breeding was highlighted by the success of the Green Revolution in the late 1960s. High-yielding wheat and rice varieties were developed at this time through the crop improvement programmes by the International Maize and Wheat Improvement Center (CIMMYT) and the International Rice Research Institute (IRRI), respectively. These new varieties with high-yield potential responded well to external inputs (i.e. irrigation and fertiliser) resulting in the doubling of yields in many developing countries of Latin America and Asia. These new varieties, often called "miracle rice" or "miracle wheat" varieties, were characterised as having 1) drastically improved harvest index (short stature and lodging tolerance) and 2) responsiveness to external inputs when accompanied by improved agronomical practices. This success contributed to dramatic productivity increases and to the easing of food scarcity in many countries. This remarkable innovation that contributed to rural development is called the Green Revolution. Dr. Norman Borlaug, then Head of CIMMYT Wheat Improvement Program, was awarded the Nobel Peace Prize in 1970, the first ever given to an agricultural scientist. The Green Revolution was said to have saved millions of people from starvation. It eased global food prices (Evenson and Gollin, 2003) and saved vast forest areas from being converted to agricultural land (Borlaug, 1983) which otherwise could have resulted in increased CO_2 emission and loss of biodiversity (Burney *et al.,* 2010). Morris and Bellon (2004) analysed the reasons behind the successful crop improvement and articulated the value of "global" crop improvement programmes relative to breeding programmes at the national and local levels in its scope of operation.

The limits of the Green Revolution

The positive impact of the plant breeding approach lasted beyond the 1960s and 1970s, and included many more crop species beyond wheat and maize (Evenson and Gollin, 2003). It has become, however, increasingly clear that there are certain areas where major productivity increase did not take place, mostly in rain-fed areas. Whether irrigation is available or not presents a major factor that influences yield potential and use of farmlands. Agricultural areas are therefore classified into two major categories, namely irrigated and rain-fed. The Green Revolution benefitted most of the irrigated areas in the world, but the rain-fed areas did not get much benefit. The rain-fed region is characterised as being marginal in terms of farm productivity potential, as well as being heterogeneous (or diverse) in terms of biophysical and social conditions. In Africa, 96% of crop land is rain-fed, leaving only 4% that is irrigated. Moreover, Africa has diverse, heterogeneous agro-ecosystems with no single agro-ecosystem dominating its continental landscape (InterAcademy Council, 2004), which contrasts with Asia where the rice-based cropping system dominates.

The global crop improvement system is based on an innovative technology package with wide application (e.g. wide adaptation of a new variety), and thus it is not as effective in addressing the situations of rain-fed areas. We need to have a cost–effective technological innovation system that is complementary to the global system to enable it to address the high-location specificity of the majority of the poorer regions in the world where poverty and food insecurity problems persist.

The needs and difficulties of addressing location-specific problems

The current plant improvement system, which is operated by professional breeders, is described as a centralised, sequential, and linear process (Sperling *et al.,* 2001). The main objective of breeding programmes is usually to develop new varieties that are suitable for a broad range of environments, and thus can be widely distributed. Varieties with wide adaptability can be grown in large areas and enjoy the economy of scale. Thus, development of such varieties measured by their occupied acreage gives breeders economic incentives and professional pride. There is an enormous driving force to develop varieties with wide adaptability and for what breeders should do to achieve it.

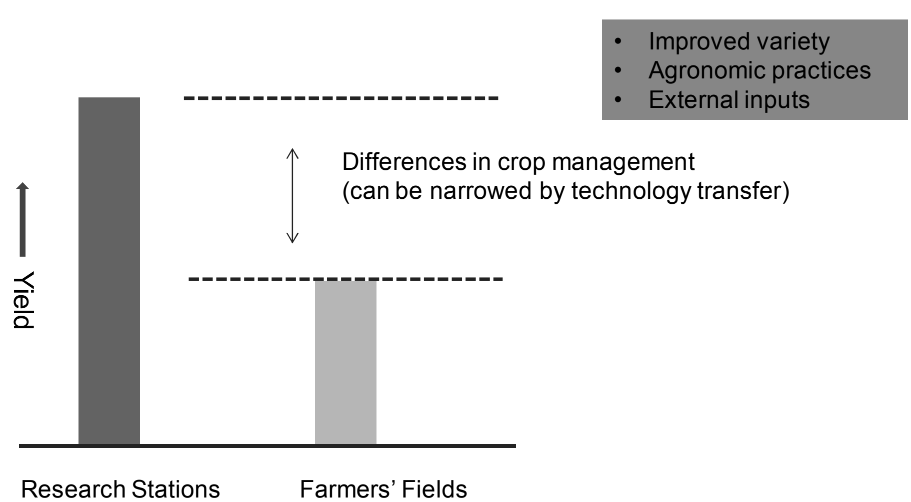
The need for wide adaptation inevitably leads to efforts to minimise the environmental effects on the expression of genotype (variety) developed by breeders. This means, genetically speaking, a minimisation of Genotype (G) x Environment (E) interactions. Breeders want to ensure that genotype dominate the phenotypic value of a new variety, regardless of the environmental conditions of the area where it is grown. The main pathway to such minimisation within the realm of modern agriculture practices has been the standardisation of production conditions so as to render each environment (E) as uniform as possible. In practical terms, this minimisation is carried out by standardizing field conditions by providing inputs such as fertiliser (that reduce soil fertility heterogeneity). Furthermore, most of the evaluations are carried out in research stations where breeders can have as much control over the environments as possible. Then, in order to increase predictability of performance of new genotype(s) in distant places, breeders classify environments. They have done so chiefly by clustering environments on the basis of available agro-ecology data and by observations of genotypes in these environments.

Environment (E) includes not only biophysical but also social heterogeneity such as cultural preferences for eating quality. However, modern plant breeding tends to simply ignore such heterogeneity. On the other hand, in low-input environments, a different breeding logic is required. A limited margin of manoeuvre does not allow adequate crop management (e.g. fertiliser application) to compensate for the factors that limit biophysical conditions; and the wide range of uses prevents the emergence of a uniform, universal logic for the genotype. Ideally speaking, the aim of plant breeding should no longer be limited to the modification of the environment to suit the genotype, but the reverse; to try to adapt genotype to a wide range of environments in marginal areas. The current breeding system dominated by breeders' quest for wide adaptation is ill-suited to deal with location-specificity problems, especially in low-input environments. This unfortunate for the modern plant improvement system and this change to address location specificity is potentially disruptive to established plant breeding. The effort required partially explains the difficulty to rethink breeding systems for new environments. Desclaux *et al.* (2008) made a powerful argument for a paradigm shift in thinking of G x E interaction.

Yield gaps and technology transfer

Yield gaps are estimated by taking the difference between yield potential and average farmers' yields over some specified spatial and temporal scale of interest (Lobell *et al*., 2009). In practice, the gaps between yields reported by scientists in their research stations and actual farmer yields obtained in a particular location and season are therefore used as indicators of yield gaps. Using this yield gap concept, we tend to make the simple argument that small-scale farmers could potentially achieve yields as high as those obtained by scientists in the research stations if they would use improved varieties accompanied by improved crop husbandry practices and necessary inputs. This is the typical technology transfer model that has been used for decades to support developing countries (Figure 21.1). We could have a different model if we would accept the reality of traditional farmers who live in marginal areas with highly-diverse environments and who often lack access to external inputs.

Figure 21.1. Yield gaps model



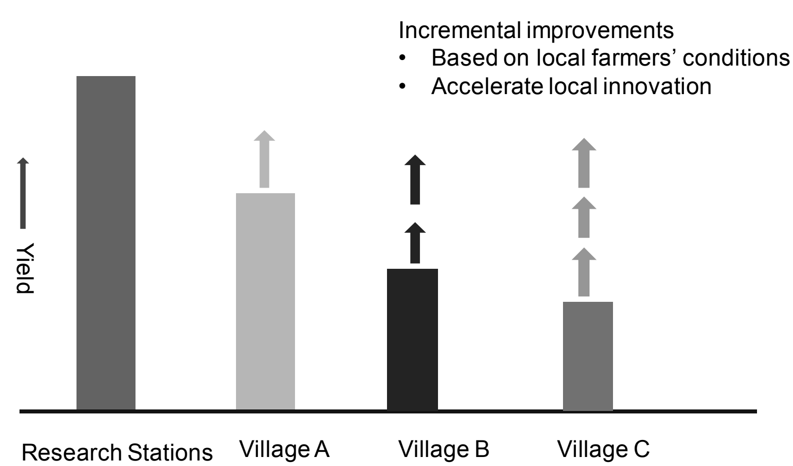
Source: Modified from Lobell *et al.* (2009).

Conventional plant breeding in which professional breeders play a central and dominant role in most countries has been and still remains largely centralised. Key research decisions including breeding objectives are made by technology suppliers such as professional breeders. Variety release requires approval from a central body and seed regulations are defined centrally. This practice is characterised by top-down decision-making and supply-driven approach. Farmers or others interested in genetic diversity and variety improvements have little or no meaningful say in the process. The research process is very inward-oriented and is often disconnected from farmers' experiences of the diverse and often rapidly changing environment(s) on which their livelihood depend.

A new innovation system benefiting from location diversity: A call for a "rainbow revolution"

If one is to solve all problems by using a single innovation (e.g. super-variety), the impossible task of addressing location diversity concerns would be encountered. This problem could be avoided by homogenizing soil conditions by applying a large supply of external inputs (irrigation and fertiliser) and by ignoring the diverse preferences of farmers. Attempts to attain a simple repeat of the Asian Green Revolution in Africa using this approach have met with only partial success in the last 40 years However, we should celebrate diversity instead of considering it as a hindrance, and instead of solving all problems with only one technological innovation (e.g. new super-variety), we should have many innovations that contribute, to productivity and profitability increase in each defined location, even if the impact of each is small. This new innovation approach could be called the "Rainbow Revolution" as major productivity improvements would come from many innovations rather than from a single major "green" innovation (Figure 21.2). Plant breeding has been a remarkable example of technology innovation that can change the lives of millions of people. If we can develop a new innovation model for plant breeding, it can set an exemplary case for technology innovation and adoption for food security and climate change in the 21st century.

Figure 21.2. Rainbow revolution model for technology innovation



Is there an innovation system that can address cost effectiveness, and location specificity and diversity?

Participatory plant breeding (PPB) is one of the answers. PPB involves scientists, farmers, and other stakeholders, such as consumers, extensionists, vendors, industries, and rural cooperatives in plant breeding research. It is termed "participatory" because users can play an active role at all major stages of the breeding process, as well as in the selection process. Such "users" become co-researchers as they can help set overall goals, determine specific breeding priorities, make crosses, screen germplasm entries in the pre-adaptive phases of research, take charge of adaptive testing, and lead the subsequent seed multiplication and diffusion process (Sperling and Ashby, 1999). The fundamental rationale for PPB programmes is that joint efforts can deliver more than when each actor works alone. They have different characteristics (Table 21.1) and by combining their strengths in a complementary way (Table 21.2), one can expect a formidable breeding team and an innovation system that is cost effective in addressing location-specificity problems through the development of a variety with desirable traits needed by farmers and for appropriate uses in a much shorter time period.

Table 21.1. Characteristics of farmers and breeders for plant breeding

Farmers	Breeders
• Main actors for 10 000 years. • Custodian of local (tacit) knowledge and diversity • Users of variety. • Beneficiaries. • Interest limited to own farm and village.	• 100 years as profession. • Front runner of modern science (genetics: universal language of life). • Seek wide adaptation for bigger market/impact. • Technology supply-driven (linear model of technology development).

Table 21.2. Contribution from farmers and breeders

Farmers	Breeders
• Clarify local needs. • Local knowledge. • Local genetic diversity. • Testing on their fields under their management. • Local adaptation. • Local institutions/system.	• New (exotic) genetic resources. • Difficult crosses. • Long-term view (e.g. climate change). • Key traits (e.g. heat tolerance) • Scientific evaluation, interpretation. • Cross-regional activity. • Scale-up opportunity.

Two examples give a quick view on value of PPB. One is the New Rice for Africa (NERICA), developed from the progenies of inter-specific hybrid between African rice and Asian rice (Jones *et al.,* 1997). NERICA has complementary traits derived from its parents, namely local adaptation and high preference from its African rice parent, and high-yielding potential and earliness from its Asian rice parent. Adoption of this new type of rice by farmers in many African countries has been successful, partly due to the use of the participatory approach involving active selection by traditional farmers. Kanbar and Shashidhar (2011) combined the DNA markers analysis in research laboratory and the phenotypic evaluation in farmers' fields to identify drought-tolerant rice lines with acceptance by local farmers. These successes can be achieved only when local farmers and modern scientists actively work together.

From a practical point of view, this implies working towards a new division of labour between the formal sector (e.g. professional breeders) and the informal sector (e.g. traditional farmers), new partnerships, and new forms of decision-making and learning. PPB approaches developed in the last decade have made significant inroads into giving concrete shape to these new roles and responsibilities. One of the goals of PPB is to involve farmers in the research in ways that are meaningful and useful to them, and to improve the quality of their participation as a means of empowerment. Farmers are no longer the passive (end-of-the-line) recipients of technologies, seeds and information. In participatory approaches, they are encouraged to take on active roles, help set the direction, and take part in decision-making. Women farmers in particular are given priority because they often have intimate knowledge of crop production and reproduction. They often also have particular needs and interests in food security, and play a leading role in households, extended families and social networks.

The active participation of farmers in PPB is characterised at the following three stages (Weltzein *et al.,* 2003) as follows:

- ***Design***. Breeding goals are set and variabilities are generated. Decisions are made on the basic parameters of variety type(s), preferences, and user needs. In most programmes, this stage involves designing and making crosses between diverse parents with complementary trait combinations. It may involve building base populations for cross-pollinating crops or the generation of new progenies for testing.

- ***Testing.*** In plant breeding, decisions are made about how to narrow down the new variability achieved in the design stage from several thousand to a few hundred progenies or clones (in the case of vegetatively propagated crops), and includes selection in segregating generations in self-pollinated crops. In population improvement schemes, this is referred to as the progeny testing stage. In plant breeding this stage includes the testing of experimental materials on-station and, increasingly, on-farm. This testing looks for desired productivity traits, adaptation and acceptability, usually in replicated plots over a range of locations with increasing plot sizes. Testing continues until the desired varieties are proposed for release.

- ***Diffusion***. This stage includes varietal release, on-farm demonstrations conducted by farmers, and the identification of a seed production and distribution system. Although this stage goes beyond the purely technical breeding process, it can create a bottleneck in the seed system, especially in poor countries, and this needs to be taken into consideration early in the design stage.

Perceived merits of PPB

Key merits of PPB include being able to produce plant varieties that are well-tailored to poor producers' needs, to shorten the amount of time plant breeding programmes need to get appropriate materials into farmers' fields and to accelerate adoption and seed dissemination. There is also an impact on research efficiency related to improving the overall rate of innovation and diffusion. In some situations, PPB helps to maintain or increase plant genetic diversity in farmers' fields and improves agricultural sustainability.

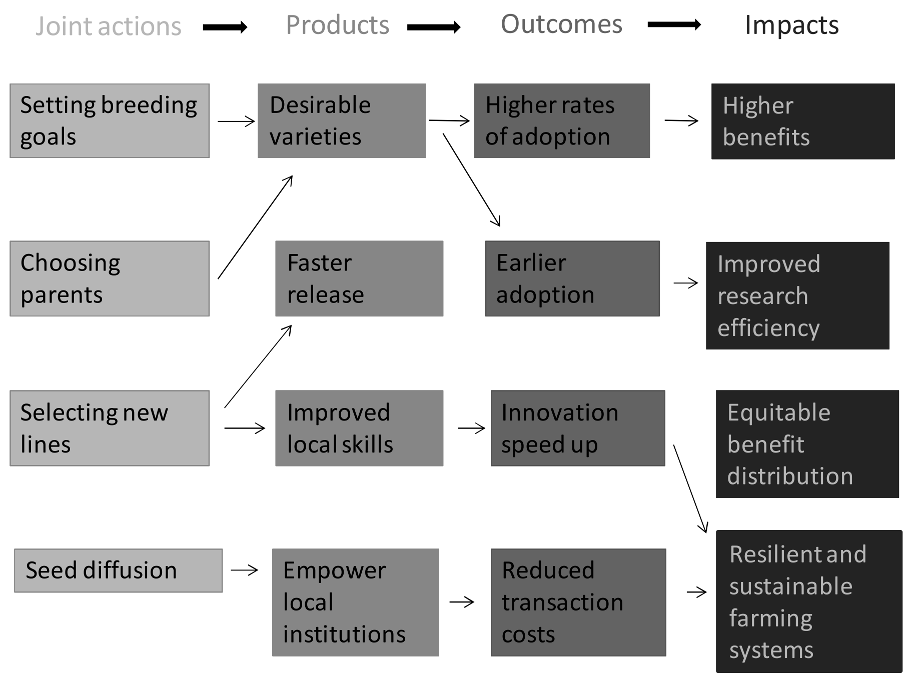
PPB carried out with farmer groups improves farmers' organisational and social capital, as well as individual farmers' knowledge and skills, and capacity to learn and experiment: all contribute to more resilient and sustainable farming systems. In addition, PPB is expected to have welfare impacts by increasing poor farmers' access to improved varieties, their productivity, nutrition, marketing and incomes. Given the important role played by women in managing plant genetic resources in many farming communities, PPB can also affect gender equity. Widely seen as having advantages for use in low-yield potential, high-stress environments, PPB is most often applied when specific adaptation is sought. PPB tends to promote crop diversification taking advantage of environmental and crop species diversity in any given location. Therefore, PPB is particularly relevant to addressing plant breeding constraints in areas unaffected by the Green Revolution. In other words, PPB could be one of the key weapons for the Rainbow Revolution.

Its impact pathway

Ashby (2009) presented a clear impact pathway for PPB. Impact pathways provide a framework for systematically mapping the cause-effect relationships (in the form of a flow chart), whereby a given intervention leads to a set of impacts, either expected or observed. The impact pathway is a tool that a breeding programme can use to clarify its expected or actual outcomes and impacts. Figure 21.3 shows a modified impact pathway based on the one presented by Ashby. Products in an impact pathway refer to results over which programmes have a high degree of control and a high probability of achieving. Outcomes in an impact pathway refer to the effects of using the products in a short-term period (usually about two or three years). Impacts refer to effects that take more time to achieve. The impact pathway for PPB illustrates how impacts change as participation occurs at earlier stages in the breeding process. A product of PPB is information about farmers' varietal preferences. However, in PPB, this exchange takes place early enough for breeding objectives to be defined jointly. In some PPB programmes, parents are also identified and crosses jointly planned. Thus, PPB involves reciprocal learning by farmers of key information about breeding strategies and some basic procedures. Farmers help manage early selection in the breeding programme, and this activity harnesses a lot of energy and resources that farmers otherwise expend on trying new varieties on their own.

In addition to more desirable varieties, PPB characteristically produces varietal releases more quickly, reducing the time from the first crosses to release by as much as 30%. Two other impacts of PPB are, first, the increased skills and knowledge of both farmers and breeders about "how to" collaborate to co-produce improved crop varieties — this results from a collaborative participation early in the breeding process. Second, norms of trust and reciprocity (social capital) developed between breeders and farmers who collaborate, as well as among groups of farmers, lead to observable increases in farmers' self-confidence and leadership (empowerment). One outcome is to reduce the transaction costs for numerous actors involved in developing, releasing and disseminating new varieties, which has a positive effect on the overall speed of diffusion of innovation in the agricultural research and development system. Increasing the speed not only for making a given variety available to growers but also for the whole process of introducing new varieties by dramatically increasing the benefit stream.

Figure 21.3. Impact pathway of participatory plant breeding



Source: Modified from Ashby (2009).

Evidence of impact

The availability of published studies on the impact of PPB has increased notably in the last decade. Ashby (2009) and Walker (2006) have made extensive studies and have compiled cases of the production of positive outcomes and impacts. The usual caution is required when using many of the available studies of PPB to make inferences about its impacts due to the lengthy process involved from output generation to impact pathway. Some PPB impacts are relatively easy to measure using established impact-assessment methodology. Agronomic and economic outcomes can be assessed at the farm level by measuring yield changes, net income over time, and externalities such as changes in pest pressure or soil loss. Increases or decreases in costs are also straightforward. Generally speaking, positive results have been reported in many cases for the following six points:

- higher rates of adoption of varieties with desirable traits;
- faster varietal release;
- faster varietal release leading to earlier adoption increases the stream of benefits to farmers;
- desired varieties and higher adoption rates improve research efficiency;
- fostering of new skills, knowledge and social capital that speed up innovation; and
- inclusion of the poor and disadvantaged, especially women, in R&D that leads to a more equitable distribution of benefits.

Perceived disadvantages of PPB

Some consider that PPB has two inherent disadvantages. One is related to the cost efficiency of an innovation: PPB has excess transaction costs due to the involvement of many partners in its process and its realised benefit is only marginal in size due to its location-specific application. Therefore, some argue that the narrow application of new innovation (e.g. new variety with specific adaptation) does not justify the large cost involved in the innovation. However, there are ample examples and data that prove overall cost efficiency of PPB in terms of real cost for a given impact and efficiency when PPB was used for appropriate situations. Moreover, some report success in developing varieties with wide adaptability using the PPB approach. Similarly, the value of PPB may not be limited to marginal environments in developing countries as there are also some positive reports on PPB in well-endowed environments (Witcombe *et al.*, 2001.)

The second concern is rigour of scientific base for PPB. Some consider that the positive claim for PPB success is based on anecdotal evidence with subjective interpretation. During the last decade a large number of scientific papers have been published in refereed journals by scientists of international centres and well-known scientists in the United Kingdom and France, among others, presenting sound theoretical basis for the value of PPB (Joshi *et al.*, 2007; Cecarelli, and Grando, 2007; Witcombe and Virk, 2001). Atlin *et al*. (2001) presented theoretical analysis on cases where PPB has advantages over the traditional approach.

Conclusion

Technological innovation for sustainable productivity increase has paramount importance to global food security, especially in the time of climate change. The Green Revolution has benefitted most of the irrigated areas in the world, but rain-fed areas have not received as much benefit. The rain-fed regions is characterised as being marginal in terms of farm productivity potential, as well as being heterogeneous (or diverse) in terms of biophysical and social conditions. Global innovation approaches such as the Green Revolution has had only limited success in rain-fed areas since this approach is not effective in addressing location diversity and specific constraints.

There are often large yield differences between research stations and farmers' fields, and these are called yield gaps. Using this yield gap concept, we tend to make the simplistic argument that small-scale farmers could potentially boost yields as high as those obtained by scientists in research stations if they would use improved varieties accompanied by improved crop husbandry practices and necessary inputs. This is a typical linear technology transfer model used for decades for supporting developing countries. We would have a different model if we would accept the reality of traditional farmers who live in marginal areas with highly diverse environments but who often lack access to external inputs.

Participatory plant breeding (PPB) has been advocated as a cost-effective approach that combines complementary strengths of traditional farmers and modern plant breeders to address location-specific problems. Key merits of PPB include being able to produce plant varieties that are well-tailored to poor producers' needs, to shorten the amount of time plant breeding programmes needed to get appropriate materials into farmers' fields, and to accelerate adoption and seed dissemination. There is also an impact on research efficiency related to improving the overall rate of innovation and diffusion. In some situations, PPB helps to maintain or increase plant genetic diversity in farmers' fields, and to improve agricultural sustainability. PPB carried out with farmer groups improves farmers' organisational and social capital, as well as individual farmers' knowledge and skills, and their capacity to learn and experiment. All contribute to more resilient and sustainable farming systems. Impact pathway of participatory plant breeding has been clearly articulated, presenting logical reasoning for PPB as a cost-effective innovation system.

The availability of published studies on the impact of PPB has increased notably in the last decade. Ashby (2009) and Walker (2006) have made extensive studies, and compiled cases of production of positive outcome and impacts. Breeding programmes of international research centres have been the main player at global scale for application of PPB. The Consultative Group on International Agricultural Research (CGIAR) organised an international workshop in 1995 with the intention to mainstream the PPB in its main operations (Eyzaguirre and Iwanaga, 1996). Previously mentioned impacts by PPB were mostly reported by scientists who attended the workshop in 1995. Further obstacles to the application of PPB are mostly related with the shift in thinking and system of crop improvement. PPB requires a paradigm shift in the plant breeding approach, technology transfer model, and formal institutions and policy regimes such as seed related regulations. Furthermore, the shortage of breeders and extension staff who can work with farmers is another constraint for the further spread of PPB.

Note

1. President, Japan International Research Center for Agricultural Sciences (JIRCAS), Japan. The author sincerely appreciates the input of Dr. T. Kumashiro, AfricaRice, Dr. E. Guimaraes, CIAT, Dr. P. Eyzaguirre and Ms. Maria Garruccio, Bioversity, Ms. V. Wilde, Gender and Diversity Program of CGIAR for their kind provision of useful information and references. He would also like to thank Ms. Elvira Suto, JIRCAS for her able proof-reading of the manuscript.

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22. A Farmer's experience with biotech crops in South Africa

Jaco Minnaar[1]

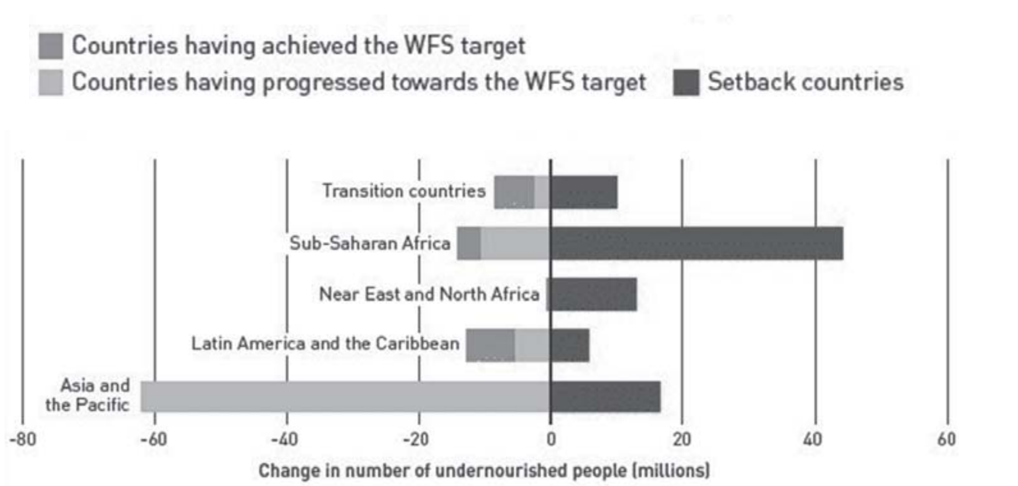
Demand for agricultural products is increasing, with most experts suggesting that food production will need to double by 2050 in order to meet food demand. To increase production, while improving the sustainability of agriculture, we need to adopt better methods, better management, tillage methods, better knowledge of resources, and better genetics. In the last two decades, the area planted with biotech crops has increased in the world to reach 10% of total arable land. The main traits are herbicide tolerance and insect resistance. In South Africa, yields have almost doubled with the adoption of biotech maize, which now accounts for a fourth of the area planted. Farm-level evidence in the Freestate Province of South Africa shows that biotech varieties are less dependent on rainfall, reduce production costs, and increase yield and profit margins (by up to 32%) compared to other varieties. Moreover, savings on herbicide and pesticide applications, and the resulting decline in fuel usage, have had positive impacts on the environment.

This section presents the experience of a commercial South African farmer farming with biotech crops. It first provides an overview of the world hunger situation and the world situation on biotech crops, with an emphasis on South Africa. It then explains the benefits of biotech crops in terms of farm income and environmental impact, drawing on a specific farmer's experience.

World hunger and population situation

On the *World Hunger Map* for 2011, published annually by the World Food Program (WPF), extreme situations are observed in Africa, including South Africa. Although the vast majority of hungry people live in Asia, about a quarter of the world's hungry live in Africa. However, the number of undernourished people declined the most dramatically in Asia between 1990 and 2003 (Figure 22.1). During this period, however, the situation in Africa continued to worsen, with North and East Africa making no progress at all. This has not changed very much since. Currently, of the top ten most food insecure countries in the world, all but one country is in Africa. In total, all countries in Africa have at least a medium risk of food insecurity.

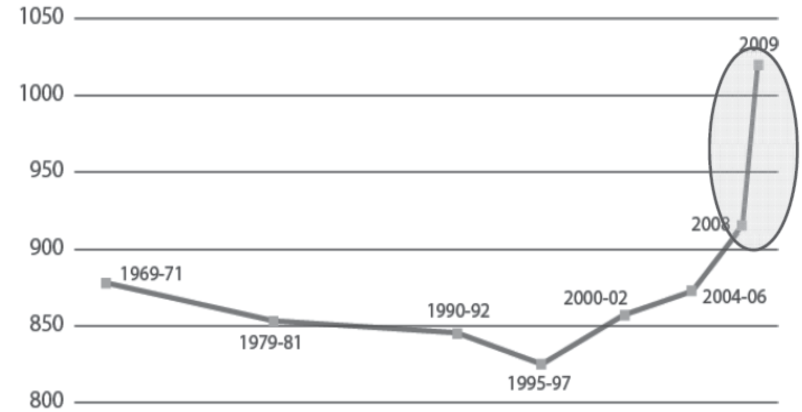
Figure 22.1. Progress and setback in hunger reduction from 1990-92 to 2001-03



WFS: World Food Security.
Source: FAO.

Looking at more recent statistics, the number of undernourished people at the global level has increased dramatically since 2008 (Figure 22.2). There has been a steady decline since 1969, with a turning point occurring around 1995-97, followed by an exponential increase. This means that we cannot continue as we have been to date.

Figure 22.2. Developments in the number of people who are underfed worldwide



Source: FAO (2009).

Population and income growth are driving an exponential surge in demand for food. Most experts are suggesting that food production must double by 2050 in order to meet the growth in food demand. In the past decade alone, corn consumption increased by 34% and soybean consumption by 52%. As incomes have risen, particularly in developing economies, meat consumption has increased dramatically, with grain-fed meat consumption growing by 21% over the same period.

This puts a tremendous strain on limited natural resources and on an increasingly fragile ecosystem. Today, 55% of habitable land is used for agriculture. Two-thirds of all annual fresh water withdrawals are used for irrigation. Energy is another vital input for agriculture productivity and experts are predicting increasing global competition for supply sources. The latest International Panel on Climate Change (IPCC) report suggests that agriculture comprises 13.5% of total greenhouse gas emissions. Factoring in the effects of deforestation to create additional areas of cropland may add up to another 15-20% of total emissions. This means we need to continue to improve sustainability in agriculture.

According to the WFP there are three main drivers of world hunger:

- political conditions, including war, legislation and government support;
- economic conditions such as poverty, debt, economic decline, poor terms of trade and fast population growth; and
- ecological conditions, e.g. climate change and available arable land.

Climate change could influence South Africa greatly.

When we look at differences in growth in population and demand around the world, it is developing regions such as Africa, India and China which are expected to see the most growth. The rate of population growth for most regions in the world will decline; in some regions, like Europe, total population will even decline. The only exception is Africa, which is on a path of rapid growth that is projected to last until at least 2050. But this is the region with the most countries suffering from extreme hunger.

In 1960, 1 acre fed one person. In 2005, one acre fed 1.8 persons per acre, and predictions estimate that in 2050, 1 acre should feed between 2.4 and 2.6 persons. One out of every six people does not have enough food. Population growth demands that we produce more food in the next 50 years than we did during the previous 1 000 years.

Biotech situation

There are only two ways to increase agricultural production: Plant more, or be more efficient.

More arable land is available in Asia, South America and Africa, but politics and other constraints must be addressed before it can be used for agricultural production. In South Africa, for example, there is a lot of arable land planted under fodder crops because of the economics and huge price variations.

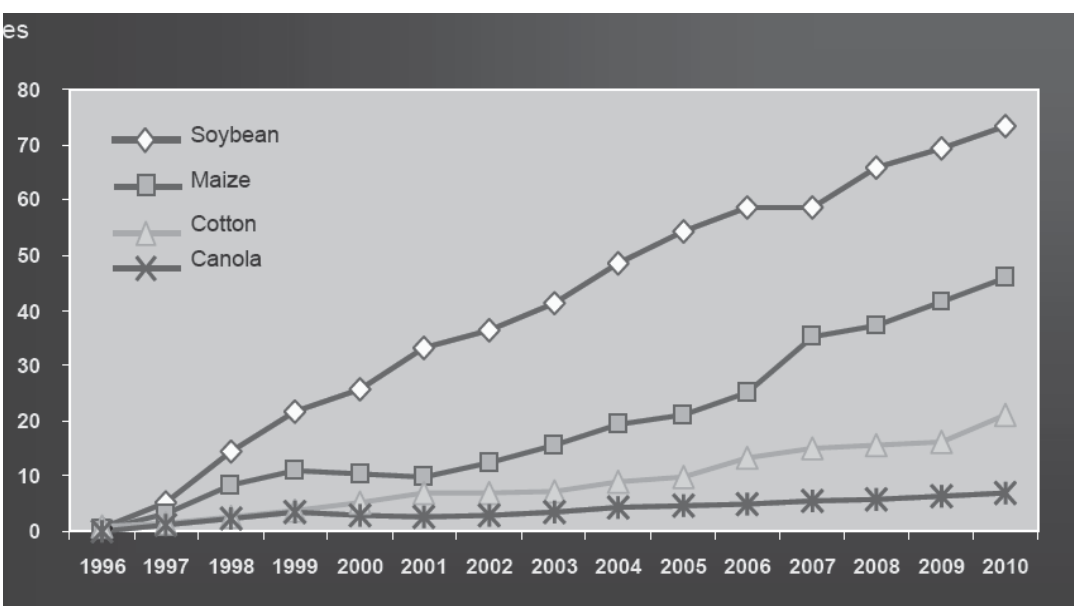
To increase efficiency, we need to adopt better methods, management, tillage methods, knowledge of the resources, and genetics. Sometimes we simply need to speed up the breeding process, other times we need to alter genetics toward a better outcome.

At global level

Among biotech crops, herbicide tolerance remains the most dominant trait worldwide, with soybeans leading the pack. Herbicide tolerant soybean was responsible for 50% of the total hectares planted with biotech crops. Maize is second, with herbicide tolerance and insect resistance (Figure 22.3). The insect resistance trait products were the fastest growing trait group between 2009 and 2010 at 21% growth, compared to 13% for stacked traits and 7% for herbicide tolerance.

Figure 22.3. Global area of biotech crops, by crop, 1996-2010

Million hectares

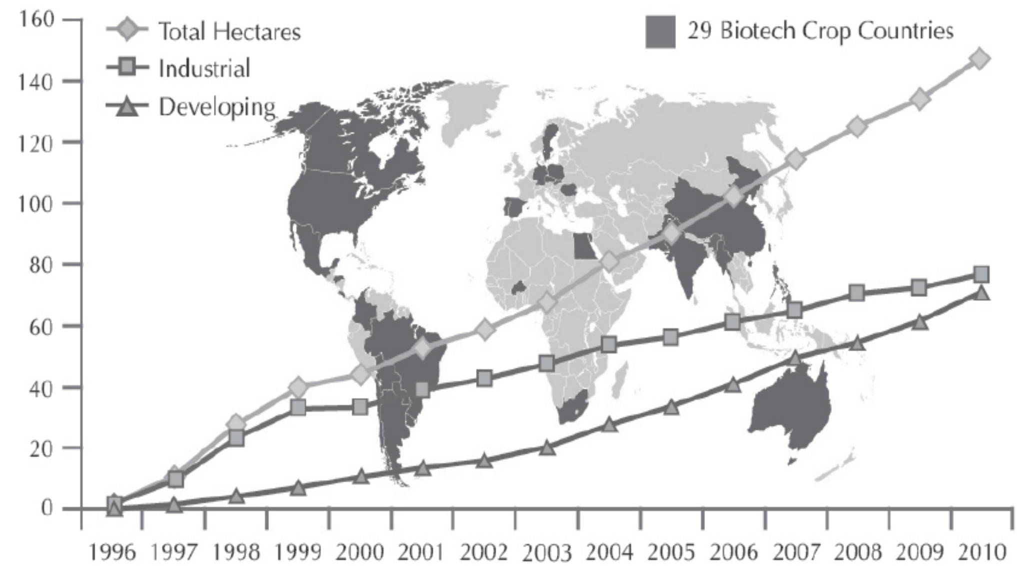


Source: Clive James (2010).

Figure 22.4 shows the steady but rapid increase in hectares planted in biotech crops since introduction. In 2010, a record 15.4 million farmers in 29 countries planted 148 million hectares of biotech crops, or 10% of all crop land in the world — a sustained increase of 10% over 2009 (James, 2010). More than half the world's population (59%, or 4 billion people) lived in the 29 countries that have adopted biotech crops.

Figure 22.4. Global area of biotech crops, by region, 1996-2010

Million hectares



Note: The above map is for illustrative purposes and is without prejudice to the status of or sovereignty over any territory covered by this map.

Source: Clive James (2010).

Developing countries had a slow start, but they have since caught up with the industrial world. Large areas in Europe, Africa, and Asia have not adopted biotech crops. In Europe, some of the eight countries that have adopted biotech have done since about 2009 and only for a specific trait in potatoes. In Africa, Egypt has approved the use of biotech maize, but only for 50 000 ha, and in 2010, Burkina Faso planted 650 000 ha of biotech cotton. Even though South Africa is a very small player in the global supply of grains, it ranks ninth in the world in terms of biotech crop area. Not surprisingly, the United States ranks first (Table 22.1).

Table 22.1. Adoption of Biotech crops, 2010

Countries	Area planted	Commodities
	Million ha	
50 000 ha or more		
United States	66.8	Maize, soybean, cotton, canola, sugar beet, alfalfa, papaya, squash
Brazil	25.4	Soybean, maize, cotton
Argentina	22.9	Soybean, maize, cotton
India	9.4	Cotton
Canada	8.8	Canola, maize. soybean, sugar beet
China	3.5	Cotton, tomato, poplar, papaya, sweet pepper
Paraguay	2.6	Soybean
Pakistan	2.4	Cotton
South Africa	2.2	Maize, cotton, soybean
Uruguay	1.1	Soybean, maize
Bolivia	0.9	Soybean
Australia	0.7	Cotton, canola
Philippines	0.5	Maize
Myanmar	0.3	Cotton
Burkina Faso	0.3	Cotton
Spain	0.1	Maize
Mexico	0.1	Cotton, soybean
Less than 50 000 ha		
Columbia		Cotton
Chile		Maize, cotton, canola
Honduras, Portugal, Poland, Egypt, Slovak Republic, Romania		Maize
Czech Republic		Maize, potato
Costa Rica		Cotton, soybean
Sweden, Germany		potato
Total: 29 countries	**148**	

Source: Clive James (2011), *www.isaaa.org/resources/publications/biotech_country_facts_and_trends/default.asp.*

South Africa

In terms of biotech/conventional ratio, South Africa ranks high. Since hitting a peak in the mid-1980s, the area of maize has steadily decreased, while production has steadily increased (Figure 22.5). The main reason is South Africa's inability to produce maize at export parity. As soon as maize needs to be exported, the following year's hectares decline because of non-profitability. Lack of adequate infrastructure and distance from international markets are mostly to blame for this.

Production, meanwhile, has steadily increased due to increased efficiency and pressure from the cost of production side. South Africa has increased its average yield per hectare from 2.5 t/ha in 1990 to 4.85 t/ha in 2010, and the trend continues.

More recently, we see a clear effect of biotech maize on crop yields, especially since the launch of Bt maize in 1999, Roundup Ready maize in 2004, and "stacked" gene in 2007 (Figure 22.6).

Figure 22.5. South African maize area planted and production, 1989/90-2008/09

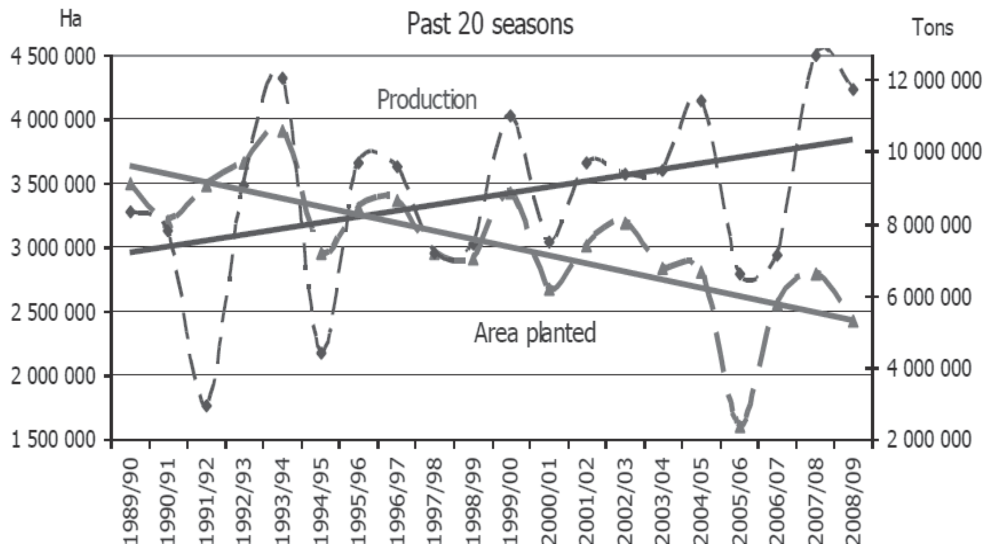
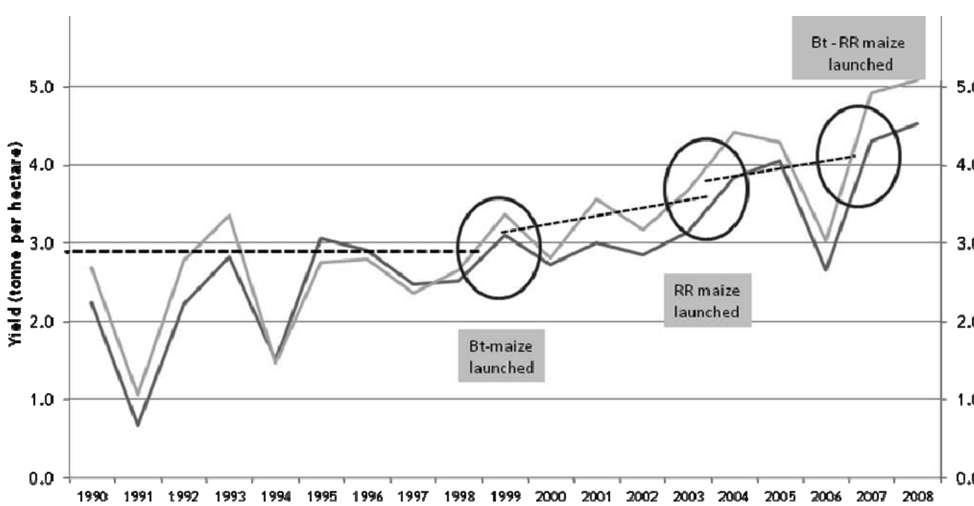


Figure 22.6. Recent developments in maize yield in South Africa, 1990-2008



The area occupied by biotech crops in 2010/11 increased for the 13th consecutive year Biotech maize stands at 76.9% of all maize planted in South Africa, and this share continues to increase. Note that 100% of all cotton planted is biotech, while non-stacked gene comprises only 5% and is located in the mandatory non-biotech area (Box 22.1).

Box 21.1. Biotech status in South Africa

Maize: 76.9% biotech

45% Bt gene

13.4% herbicide tolerant (HT)

41% Stacked gene (Bt + HT)

Soybeans

85% HT

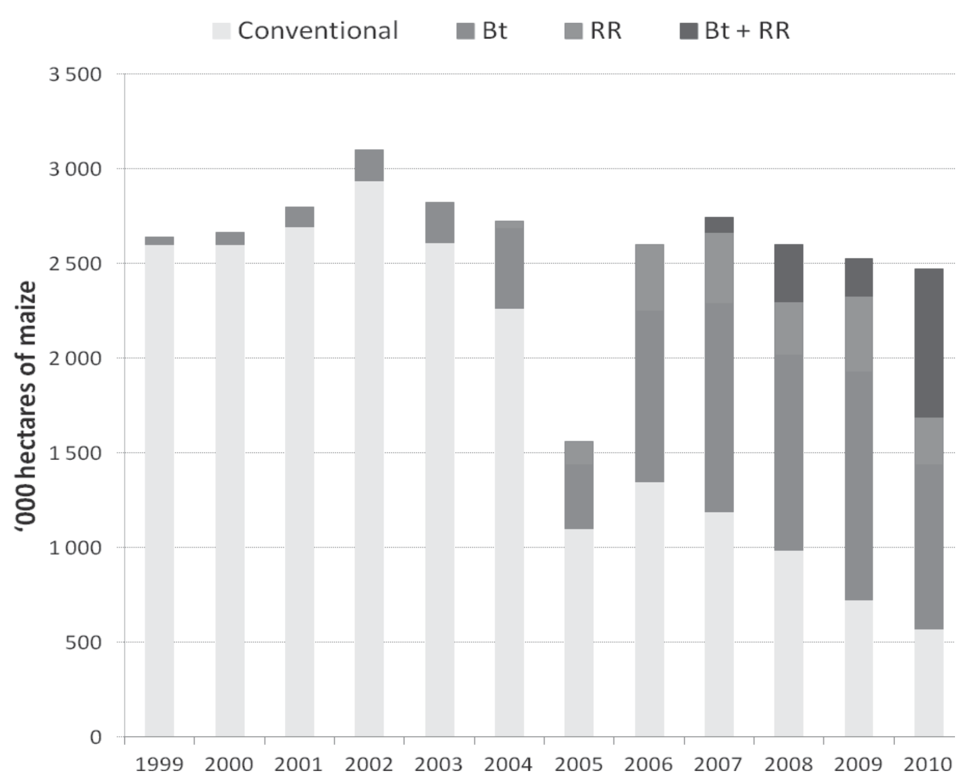
Cotton: 100% biotech

95% Stacked gene (Bt + HT)

5% HT in refugia

Figure 22.7 shows the different traits and area occupied by maize. One can see a constant growth in maize with the Bt gene. Also noteworthy is the adoption of the stacked gene (bt+RR). The pullback of the stacked gene in 2009 was a result of pollination problems with specific varieties in 2008, which accounted for a loss of about 166 000 tonnes of grain. Farmers received compensation, but this remains a risk of biotech.

Figure 22.7. Traited / GMO Maize ha in South Africa, 2010



The experience of a South African farmer

The region of Freestate

I farm in the Freestate province of South Africa, located in the centre of the country. I produce corn, wheat, sunflower, soybeans, potatoes, game and cattle. I introduced a precision farming approach in 1998 and have now reached the point where I can vary anything I apply. I began planting biotech crops in 2003 and have conducted several trials for different suppliers every year since.

The main crop-growing areas of South Africa are located in the eastern part of the country (mainly yellow maize and soybeans), and western parts of the central interior (mainly white maize, sunflowers and peanuts). Most maize in this area is white maize, produced primarily for human consumption in the form of maize meal.

The south-western parts of the country are mainly winter rainfall areas, growing mainly small grains like wheat, barley, and canola. Most of the grain in South Africa is produced in the Freestate.

The average yearly rainfall is about 550 mm per annum, most of which occurs during the summer. The Freestate is classified as a semi-arid region. Production in this area is mostly a function of the amount of rainfall, with more rain resulting in higher yields and less rain producing greater variation in amount.

There is vast variation in soil types and depths, ranging from 20 cm to 3 meters. Profitability considerations cause some of the lower yielding and mostly shallow soil to be planted with fodder crop.

Because of the distance from harbours and the decay of the railroad system, there is a huge difference between import and export parity of grain, causing a huge fluctuation in grain prices.

Yields and economic performance

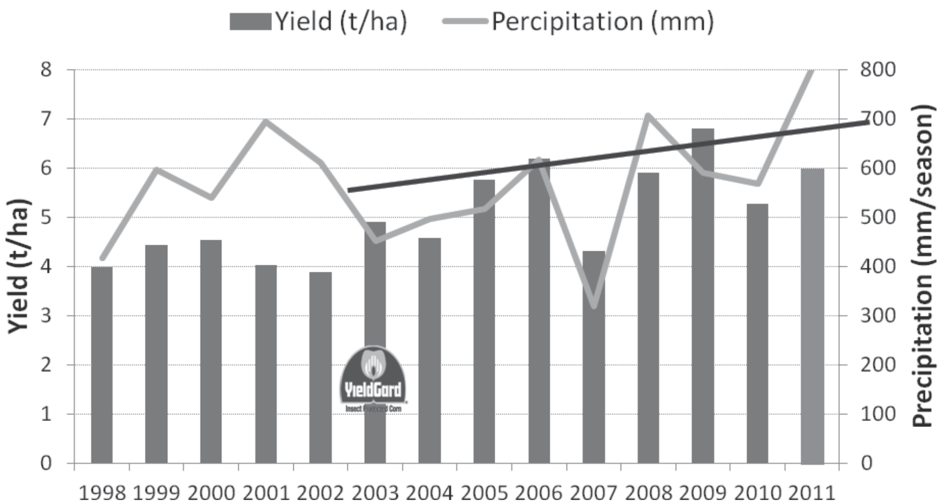
Figure 22.8 illustrates the effect of rainfall on maize yield in my farm. The yield stabilised during the late 1990's and early 2000's when it seemed that we had reached a limit of production, despite years of higher rainfall. When biotech was introduced in 2003, one could see the difference. Roundup Ready maize was introduced in 2005, with the stacked genes arriving during the 2009 harvesting season.

From 1998-2002, average rainfall was 572 mm per season, with an average yield of 4.2 t/ha. The water use efficiency was 7.3 kg of grain per millimetre of rain (Table 22.3). From 2003-10, rainfall declined, yield increased and efficiency rose to 10.3 kg/mm of rain. Can this all be attributed to biotech? I think not.

Table 22.2. Yield analysis

	Unit	1998-2002	2003-10
Average rainfall	mm	572	533
Average yield	t/ha	4.2	5.5
Water use efficiency	kg/mm	7.3	10.3

Figure 22.8. Yield versus rainfall trend



Trails on Bt traits have been conducted on my farm since 2003. The trails were done with various varieties of maize in different conditions. Table 22.3 compares the performance of different varieties with and without Bt genes. The results show that yields increase, on average, by 10%, with the worst years being 2006 (when yields were equal to those in 2005) and 2007 (when yields decreased by 21%). This is a good example that Bt in our area gives you a 10% yield increase, with equal or less input.

Table 22.3. Costs of production, yields, profits and margins, 2009/10

	Unit	Conventional	Bt	RR	Bt + RR
Seed	Rand/ha	507	629	630	732
Fertilizer and lime	Rand/ha	1 940	2 076	1 940	2 134
Weed control	Rand/ha	400	400	300	400
Pest control	Rand/ha	230	-	230	
Fuel	Rand/ha	595	553	276	276
Repairs and parts	Rand/ha	327	304	152	152
Permanent labour	Rand/ha	400	400	250	250
Marketing cost	Rand/ha	380	380	380	380
Interest on production credit	Rand/ha	232	231	207	214
Other cost	Rand/ha	1 027	1 027	1 027	1 027
Total cost of production	Rand/ha	**6 038**	**5 998**	**5 393**	**5 565**
Savings	%		**-1%**	**-11%**	**-9%**
Yields	t/ha	4.3	4.8	4.7	4.9
Income	Rand/ha	6 450	**7 200**	**7 050**	**7 350**
Profit	Rand/ha	**412**	**1 202**	**1 657**	**1 785**
Margin	**%**	**7%**	**20%**	**31%**	**32%**

Source: Actual figures.

If one looks at the cost of production, seeds of biotech crops are more expensive because of the technology fee (Table 22.3). Planting with 10% more fertiliser because of the higher yield and not spraying any pesticide reduce the cost of Bt maize of 1%. For Roundup Ready and stacked gene, the difference is bigger because the process involves less fuel and conventional herbicides. Prices in Table 22.3 are in Rand and need to be divided by about ten to get a price in Euros. Thus, the total cost of production is about EUR 600 per hectare.

Taking cost into account, and taking the actual yield realised in 2010, we obtained a 7% margin on conventional maize. But with Biotech varieties, we could obtain an even higher margin: Bt maize has a 20% margin over cost, with Roundup Ready and stacked gene at about 31%.

Cost to the environment

The adoption of Biotech varieties on my farm has also had impacts on the environment. Savings per hectare were:

- 1.8 kg of triazine;
- 1.7 kg acetochlor;
- 480 gr of organophosphate on the Bt trait; and
- 37.5 litres of diesel fuel on the Herbicide tolerant maize, i.e. 100.5 kilogramme of carbon dioxide gas.

Bt genes have an effect on other crops, and impact insects as well. I found much less damage due to bollworm on Bt maize than on non-Bt maize. Bt maize can now be planted outside of traditional planting periods, which also results in a longer planting period, reduction of weather risk and thus a higher, more stable yield.

We also found that traditional herbicides may damage crops in the early stages, whereas Roundup Ready does not have that effect. Roundup also leaves very little residuals.

However, Roundup does not come without problems, as some organisms may build up resistance to it. One has to focus on planting refuge areas, using the correct amount of herbicides, etc. Technology does not come cheap and only a few companies conduct R&D, giving them a monopolising position. In 2008, we had pollination problems with Roundup Ready corn because of bad seed production practices. This is a huge risk, both in food security and in production methods. We had to go back to conventional tillage practices because we could not get any Roundup Ready maize seed the following year.

There is the larger issue of food safety. When I planted Bt maize for the first time, I walked into the field where the Bt and non-Bt maize were planted next to each other. I wanted to pick some cobs for food and selected the non-Bt variety. That was the last time I made such a decision. Today, this does not bother me.

Over the past ten years, more than 38 million tonnes of biotech maize were produced in South Africa. This maize was consumed by more than 40 million people, 800 million broilers, 1.4 million feedlot cattle and 3 million pigs each year, with no scientific or medical incidences of adverse effects on humans, animals, or the environment.

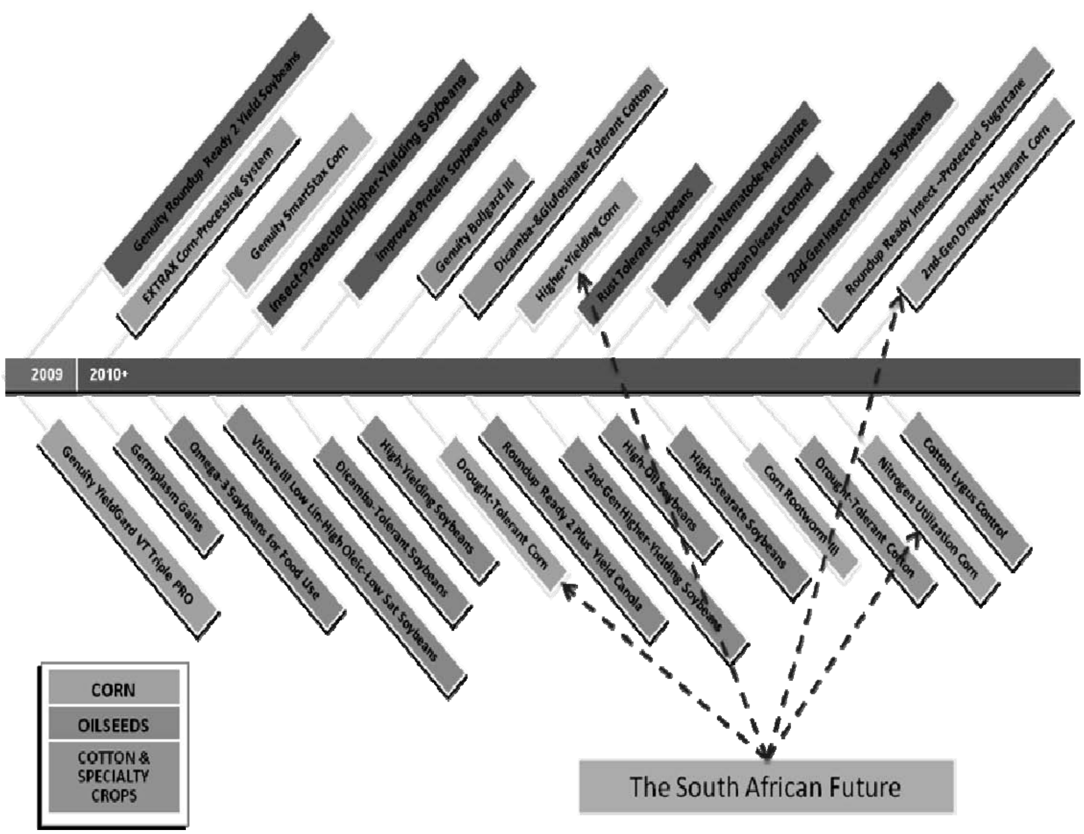
If the rest of South Africa were to adopt the same practices that I have, it would save 1 860 tonnes of triazine, 1 757 ton of acetochlor, 790 ton of organophosphate, 38.8 million litres of Diesel Fuel and 104 000 tonnes of carbon dioxide gas. All this for a country that does not produce even 1% of the world's grains.

What is in the pipeline?

The product pipeline for the future is rich and deep. It seems like Bt and Roundup Ready were only the beginning. One can only imagine what impact the future traits will have. Figure 22.9 shows new traits that will be offered for corn, oilseeds, cotton and specialty crops.

Herbicide tolerant wheat, Golden rice (Bt), Biotech potatoes with high quality starch and disease and insect resistance, and other insect-resistant vegetables are being developed, in the hopes of increasing yields and saving money on seriously dangerous insecticides and fungicides.

Figure 22.9. New seeds in the pipe



Conclusion

Ingo Potrykus, former full Professor of Plant Sciences, and expert on biotechnology of plants, at the Institute of Plant Sciences of the ETH Zurich said: "Biotech crops could save millions from starvation and malnutrition, if they can be freed from excessive regulation." We cannot go on like we used to. We need to change something in order to feed the world.

Europeans have a choice. They can go to a grocery store and choose organic or in-organic food, French or German wine, British or French beef, Dutch or Swiss cheese, Italian or Spanish olive oil, biotech or non-biotech food. This is not the case with hungry people. They either have food and eat, or die of hunger. With regard to biotech, the choice is slightly different: Die now of hunger, or die perhaps 30 years later from the possible effects of biotech.

African leaders may not admit it, but they look to Europe for guidance, especially with regard to biotech. If the Europeans are so afraid of biotech, they wonder, should we be too? As a result, they decided to follow Europe's lead by banning all biotech food in their country even though people are starving. Europe should choose for them and show them the way.

Africa focuses on poverty relief through grants and not by economic development. Europe could help us achieve that. I believe it was Abraham Lincoln who said, "Give a man not a fish, but a fishing rod." This should be our viewpoint. Help Africa conduct research. Africa does not have the money or the skills to do proper research. Infrastructure is diminishing at an extremely fast rate and without infrastructure, production is impossible. Africa needs roads, railways and harbours.

We understand the reasons for subsidising farmers in Europe, but we are worried about the impact on world markets and on countries where locals cannot produce at lower, subsidised world price. We ask for better management of subsidised products.

Food aid is great for addressing hunger, but most of the time, this aid is bought from countries which are far from the boiling point, but which influence local and neighbouring economies and reduce their market opportunities.

We urge European countries to:

- expedite breeding of better suited hybrids and varieties, traditional or bioengineering;
- share all relevant information;
- promote technology;
- apply responsible stewardship; and
- help fight world hunger.

Note

1. Commercial farmer in South Africa (Email: jaco@compuking.co.za).

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23. Latin America: Public agricultural advisory services

Matthew McMahon[1]

This section covers developments over the past ten years in selected Latin American countries. It covers the institutional innovations that have occurred, focussing on the decentralisation of service delivery, outsourcing of delivery, and co-financing by regional governments and beneficiaries. Farmers today are faced in this region with rapidly changing agricultural markets due to changing consumer demands and trade liberalisation, and thus the innovations needed are as much institutional as they are technical. This will require new partnerships, new rules and regulations and new forms of innovation. An innovation system perspective is called for, rather than a narrow Agricultural Knowledge and Innovation System (AKIS) focus.

Over the past twenty years I have had the privilege to work in many countries across Latin America, and have become intimately familiar with the various research and agricultural extension systems in place across these nations. This presentation will first provide the macro, sectoral and technical context under which many of the institutional changes have occurred in the research and extension systems in Latin America. It will also provide a summary of the evolution of the agricultural advisory services in place across the region. It will then discuss reforms that have taken place within the last 20 years, and how these can be built upon with an eye toward the future. It should be noted that this presentation will only examine the public sector, since public money is a major driver of agricultural agendas, and can have a very important impact on the development of the private sector. The subtitle of this presentation is "A Quest for Relevance" — an accurate description of the ongoing struggle that policymakers involved in agricultural extension across the region face on a daily basis.

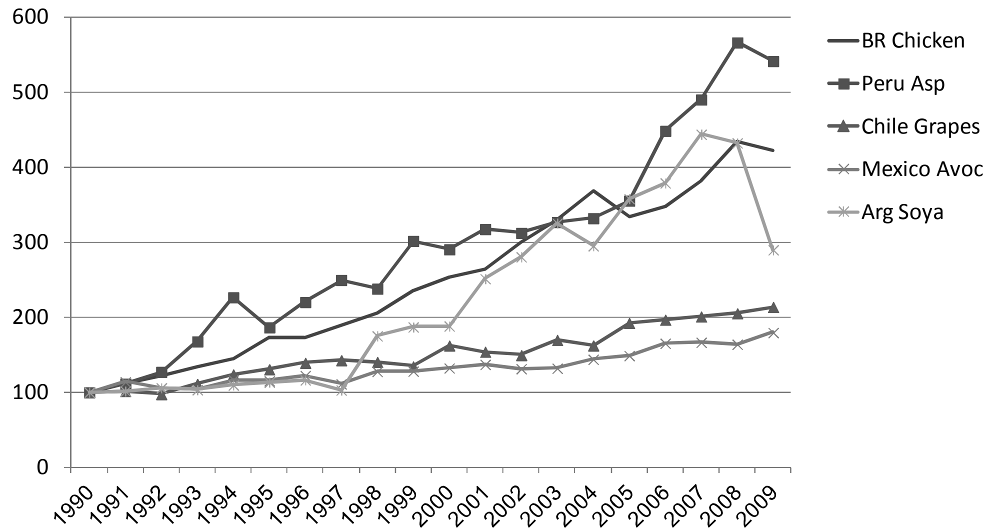
Context

Over the past 20 years, increased openness to trade has increased diversity across the agricultural sector. Agriculture has become a very tradable sector in Latin America, and this trade has had profound effects within the region. In response to this openness, there have been many agricultural success stories across Latin America in recent years, thanks in large part to technology spill-ins. Most of these success stories have involved export commodities. In Brazil and Argentina, production of soybeans has increased dramatically over the last 30 to 40 years. In 1982, Argentina's Secretary of Agriculture set a goal to raise Argentinean grain production from 32 to 40 million tonnes. Last year, the country produced 95 million tonnes. We have observed similar growth with fruit and wine in Chile, cut flowers in Colombia and Ecuador, and the fruit and vegetable sectors in Mexico and Peru. Chicken production has increased across the entire continent. Figure 23.1[2] displays trade-driven production increases for five commodities over the past 20 years: chicken production in Brazil, asparagus production in Peru, grapes in Chile, avocado in Mexico and soybeans in Argentina. In most cases, production has increased by a factor of between three and five.

Technology spill-in has played a prominent role in all of these cases. Initially, most soybeans came from the United States, fruit came from California, and cut flowers came from Holland and Israel. The private sector has played an important role in this adaptation and in some cases, the public sector has played a strategic role, by providing knowledge and information in key areas, such as markets, climate, pest control, etc.

Technology spillins also played a prominent role in the introduction of zero tillage in both Argentina and Brazil. This technology has expanded to approximately 40 million hectares between the two countries. In this case, patents played a major role in spurring policy. In Argentina, for example, the expiration of the patent for Glyphosate triggered the country's zero tillage expansion, due to the fact that its price dropped by about 90%.

Figure 23.1. Trade-driven production increases, 1990-2009

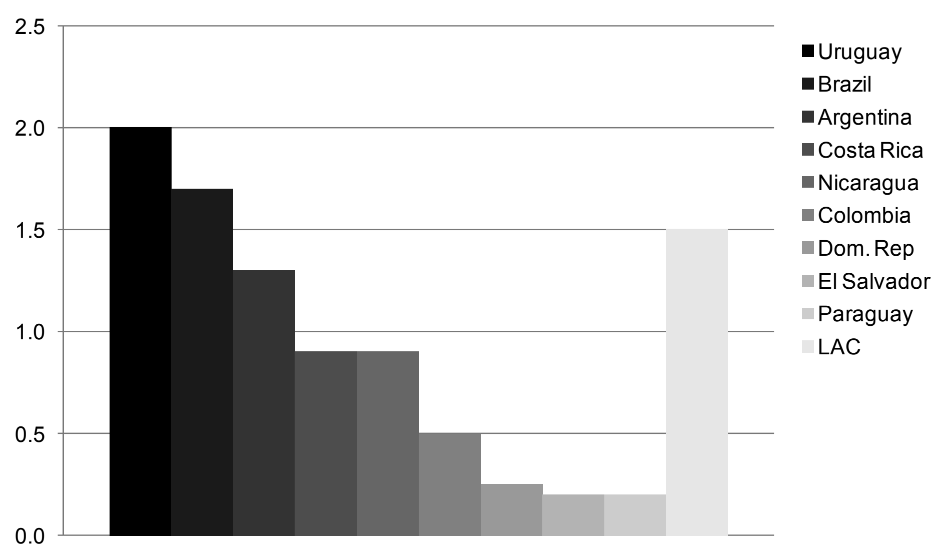


Source: FAO.

At the same time, we have observed increasing differentiation in Research and Development (R&D) investment levels across Latin American countries. Twenty-five years ago, there was very little difference across the region. Now, however, some countries are pulling ahead, while others are left behind.

Figure 23.2 demonstrates the differentiation in R&D intensity across different countries. As the figure makes clear, some countries have seen fairly high levels of R&D intensity, while others have not. The regional average is about 1.5%, though this discrepancy should give smaller countries cause for concern. This is an issue that must be addressed.

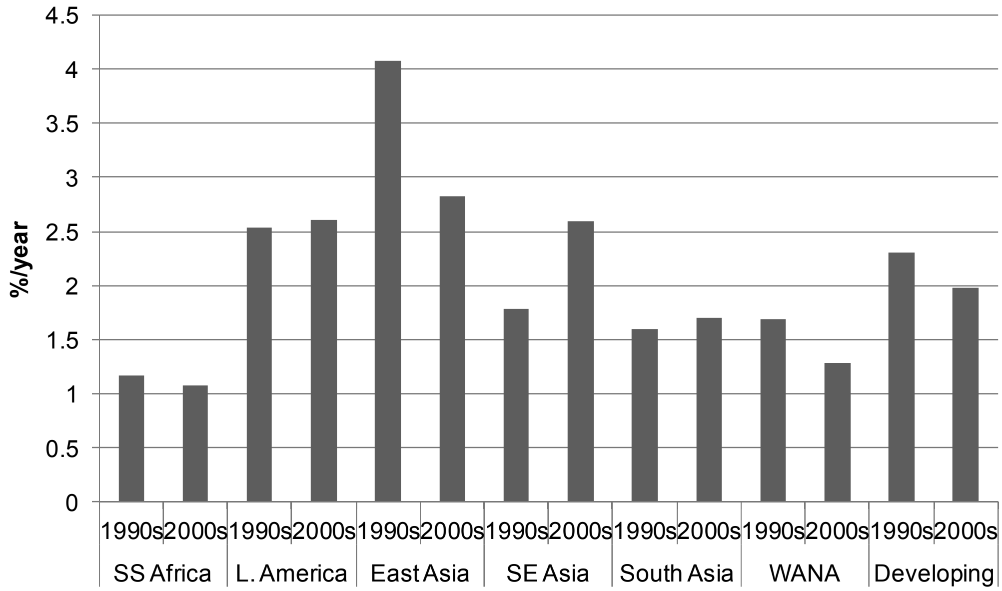
Figure 23.2. R&D intensity (% of agricultural GDP)



Source: Gert-Jan Stads and Nienke M. Beintema (2009), *Public Agricultural Research in Latin America and the Caribbean; Investment Capacity and Trends*, ASTI Synthesis Report, March.

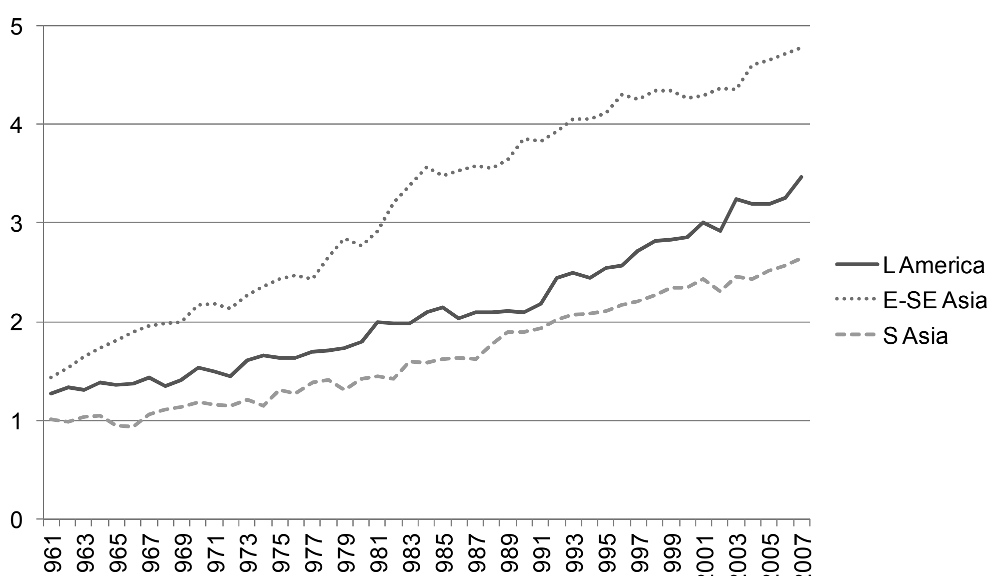
As Figure 23.3 shows, TFP has remained fairly steady and respectable compared to other regions. Cereal yields have also been relatively stable. As Figure 23.4 demonstrates, these yields have not increased as rapidly as those in East and Southeast Asia, but have grown at a higher rate than those in South Asia – especially within the last 10 to 15 years.

Figure 23.3. Total factor productivity (% per year)



Source: Derek Byerlee, *Agricultural Technology Adoption and Productivity Growth in sub-Saharan Africa*, Evidence Summit USAID, 2 June 2011

Figure 23.4. Cereal yields (mt/ha), 1961-2007



Source: OECD (2011), *Review of agricultural extension in Mexico*, OECD, Paris.

There is also observed increasing differentiation among producers. This has had significant impacts upon the design of agricultural extension and delivery systems. In most countries, agriculture is now divided into a capital intensive commercial sector, a smallholder sector with ties to the internal market, and a subsistence sector, which produces for household consumption and depends upon outside activities for a large part of its income. In the case of Mexico, for example, these sub-sectors comprise 15%, 35% and 50% of all agriculture, respectively (OECD, 2011). In terms of production value, however, these figures are reversed. Furthermore, each of these sub-sectors relies upon different information and technology, and responds to different social and economic needs. When designing systems, it is important to take these elements into consideration.

Evolution of agricultural extension systems in the region

In the early 1900s, most of Latin America's agricultural industry consisted of demonstration farms. The dawn of the modern system began in 1949, with the Point 4 Programs, named after US President Harry S. Truman's Marshall Plan, which he unveiled during his inauguration speech. This initiative was designed to encourage technology spill-ins. The US foreign programme soon became involved in many Latin American countries, where policymakers were hoping to transfer American technology for use on domestic farms. The Point 4 Programmes led to the establishment of public extension services focused on basic staples and the management of natural resources, i.e. water, soils, etc. This approach was driven by technology, and was implemented from the top-down, in a "one size fits all" fashion. The results, however, were limited since the approach depended on the import of technology without the basic knowledge required for its adaptation. The recognition of this problem led to the development of national research institutes in the late fifties and early sixties.

Beginning in the 1980s, the public sector in much of Latin America was in crisis, due to high levels of national indebtedness. As a result, nearly every country on the continent embarked upon reform programs in the agricultural sector. The agenda of this widespread reform included the disbandment of national extension programs across almost the entire continent, including Brazil, Chile and Mexico. This institutional reform was founded upon the principles of enhanced client participation, decentralisation, outsourcing to the private sector, and co-financing with beneficiaries.

It was also felt that the existing bureaucratic public extension systems were incapable of reform from within. At the time, the only realistic option was to implement bold reforms, and to consider new modes of operation.

Examples of reforms

The nature of these reforms has varied across different countries, and is often dependent upon unique institutional and cultural histories, among other factors. In Mexico, reform involved the disbandment of the country's national extension service, which once comprised approximately 25 000 employees. In its place, Mexico implemented incentives for the creation of a private extension market founded upon outsourcing, and funded through public assistance programs for farmers. As of 2010, there were an estimated 8 000 private contractors working under this system (OECD, 2011).

Reforms in Venezuela, meanwhile, focused on decentralisation to the municipal level, encompassing 135 municipalities out of a total of 180. They also resulted in the creation of a legal entity at the municipal level, known as a Civil Association for Extension (CAE). Each CAE essentially consisted of a partnership between public and private actors. These associations involved co-financing among beneficiaries at the federal, state and municipal levels, and were executed by private agents. They remained, however, largely dependent on federal funding (85%), and very little co-financing existed at the local levels. Nevertheless, the CAE system provided an important forum for local actors (World Bank, 2004).

Chile was among the first countries to introduce public funding and private delivery of agricultural technical assistance, representing a major institutional development. This initiative was part of a broader programme specifically designed to enhance the productivity of small family farms, while providing credit support as well. Chile's definition of a "small farmer," however, has remained unchanged over the decades. To this day, a small farmer is still defined as any producer who owns 12 hectares of basic irrigation, or less. Anyone who meets this qualification is eligible for assistance. The country has also maintained support for its public extension system, which has seen increased investment, and several institutional adjustments over time.

Like Venezuela, Colombia also decentralised its system to the municipal level. The crucial difference, though, is that this system was still executed by public extensionists. This reform focused on small farmers and resulted in the addition of more than 3 000 extensionists encompassing 700 municipalities and 300 000 farmers.

In Peru, policymakers assumed that agricultural advisory services were a private good. They were guided, however, by the belief that the creation of any market requires initial public support. Peruvian reform focused on small farmers, indigenous groups and women. All projects were of a three-year duration, co-financed with beneficiaries, and approved on the basis of a business plan. Ultimately, the private sector was charged with implementing this reform.

Present situation

Today, all of these systems continue to undergo change. This is part of a continuous quest for justification, and models continue to be experimented with. However, certain trends are apparent. In general, centralised extension systems have been abandoned; public support for commercial farmers is reduced, or eliminated entirely; and there is a clearer focus on objective populations – namely, small, medium and subsistence farmers.

These systems are largely fluid and varied, but in recent years, many have focused on local control. Farmers have become much more active participants within these systems. The real weak point is the lack of impact evaluation in any of these systems. Throughout the region, the culture of impact evaluation simply does not exist, yet it remains crucial to justifying the benefits of agricultural extension systems.

Looking forward

Looking to the future, countries will continue to identify more clearly both objectives and target populations. Today's systems often have undefined objectives, as well. Policymakers must therefore focus on real objectives, and work toward implementing new impact evaluation mechanisms to help realise these objectives. There is need to improve the quality of services and quality control, while enhancing accountability across a larger population of local participants. Quality control can pose especially significant problems when transitioning to a decentralised system and will require strengthening local capacity across both private and public sectors. There is also a need to strengthen institutional integration across innovation systems and to propose more realistic co-financing levels among participants both public and private.

Countries will have to adopt a dual approach to agricultural extension to address the twin goals of increasing productivity and alleviating poverty. With regard to the former the service would focus on increasing productivity and competitiveness by targeting small and medium farmers who are organised and who are already operating within, or who have the potential to incorporate themselves into productive chains. In light of limited resources, systems should focus on organised farmers, with a particularly strong emphasis on innovative farmers. As farmers become more integrated into productive chains and acquire the skills needed to manage their own technology and information, they should be allowed to graduate from the system. Such a system would also demand rational expectations for co-financing. In the past, policy maker expectations have sometimes been too high.

In the case of subsistence farmers who comprise a very large population within Latin America, agriculture by itself will not allow them to escape the poverty trap but it could help in terms of household food security and in increased income. Programs for these farmers should focus on the welfare of the household, i.e. education, health, etc. which would allow for an exit out of agriculture. Subsistence farmers today simply do not see a role for them in agriculture in the long run, and need resources to transition into other areas. It is imperative that these countries improve quality of their services. Advisory services should be implemented by properly accredited private agents with adequate skills. Whenever outsourcing is involved, there is a need to finance support that service firms require. These are often small firms that need significant support from the public sector, especially in areas concerning training and capacity building.

All of these countries possess the basic components of a healthy innovation system, but lack the institutional interaction, collaboration and feedback loops that are characteristic of effective innovation systems. These linkages should be established, strengthened and maintained across research and extension institutions, private sector firms and farmers.

The most important element to any effective system, however, remains institutional innovation. Too often, we tend to put systems in place, without the tools to learn and adapt. Instead, there is a need to constantly adopt new organisation and management strategies within innovation, while promoting institutionally dynamic settings in which organisations and systems can permanently learn from their experiences, and adjust to changing circumstances. If these systems are to be effective, they must be learning institutions, and have the ability to adapt as such.

Achieving such a system will not be easy, for several reasons. Policymakers tend to create unwarranted expectations. These expectations are often based upon short-time horizons, and fail to account for lag times in adoption. Sometimes, a country may simply promote policies that are unfavourable to a healthy extension advisory system. As a result, institutions will not thrive in these environments. Rather, we must remind ourselves that persistence pays, and construct our expectations based on long-term horizons, while taking lag times into consideration.

Ultimately, of course, there is no general theory that can be uniformly applied to any context. Designing research and extension programs is more of an art than it is a science. The more we practice it, the more artful we will become.

Notes

1. Consultant.
2. *Source*: FAOSTAT.

References

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24. The Brazilian Agricultural Research for Development (ARD) System

Maurício Antônio Lopes[1]

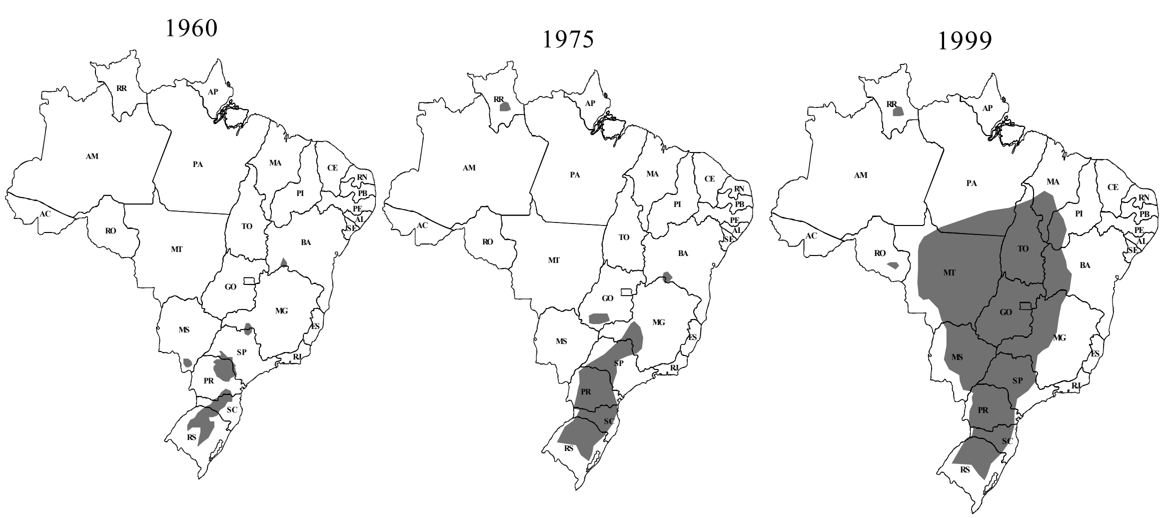
There are many challenges related to environmental sustainability, social inclusion, globalisation and technological changes that are driving Brazilian organisations towards more dynamic modes of operation. Many government programmes are currently dedicated to improving infrastructure, research and development (R&D) strategies, communication and technology transfer in line with today´s realities and challenges. Embrapa, the Brazilian agricultural research organisation has been pursuing new ways to deal with these challenges for more than three decades. A semi-autonomous federal agency administered by the Ministry of Agriculture and Food Supply, Embrapa is the largest agricultural R&D organisation in Latin America and a world leader in development of innovations for tropical agriculture. Embrapa is consolidating a management strategy designed to integrate and align its efforts in R&D, communication and technology transfer towards effective delivery of innovations to farmers and the Brazilian society. Embrapa is also developing new ways to share technologies developed for tropical agriculture with countries in Africa and Latin America. While this system is still evolving, it has helped Embrapa to move in the direction of more co-operative efforts, expanding its networking capabilities, and intensifying its efforts towards agricultural innovation in closer interaction with its stakeholders and with society as a whole.

Covering an area of 8 511 965 km², Brazil is one of the largest countries in the world, with an extensive surface of continuous land, a large supply of fresh water, abundant solar energy, and a rich biodiversity. Among the 250 000 species of higher plants, nearly 60 000 are native to Brazil. In addition to the world's largest tropical forest, the country has over 200 million hectares of savannas (known as *cerrados*) with immense agriculture and livestock production potential.

Brazil has used its diversity and resources to successfully become a world leader in many sectors, including agriculture. The wide range of climatic conditions, from temperate to tropical, together with advanced capacity in technology development, allowed considerable diversification of the agricultural production, which have made Brazil the world's largest producer of citrus fruits, frozen concentrated orange juice, sugarcane, and coffee. The country is also a serious global competitor for many other products — soybeans, tobacco, poultry, corn, beef, biofuels — and self-sufficient in the production of most agricultural goods.

Technology development for tropical agriculture has been one of Brazil´s main strengths, as illustrated by the evolution of soybean cropping systems in the country, since the 1960s (Figure 24.1). Today, Brazil is the second producer in the world, with a volume, in 2009, of 58 million tonnes, exceeded only by the United States. Introduced on a commercial scale in the years 1960-70, soybeans adapted well only to temperate regions in the southern part of the country. Technology in breeding and genetics, crop and soil management, and biological nitrogen fixation developed by the Brazilian Agricultural Research Corporation — Embrapa and other partner organisations — allowed adaptation of this legume crop to low latitudes, in the Savannahs, and in other agro ecological zones located in central, north-eastern and northern Brazil. Over the past 30 years, average soybean yields have increased more than 130%, with the quality as high as any produced in the world.

Figure 24.1. Evolution of soybean cultivation in Brazil – from 1960 to 1999



Note: This map is for illustrative purposes and is without prejudice to the status of or sovereignty over any territory covered by this map.

The evolution of the agricultural sector in Brazil

Historians describe organised agricultural research beginning in Brazil in the 19th century at the Botanical Garden of Rio de Janeiro, established in 1808. During that period, Brazil's predominant agricultural products were coffee and sugarcane. By the end of the century, the Imperial government established the Agronomic Station of Campinas, a federal institute that was transferred to the state government of São Paulo in 1891. Renamed the Agronomic Institute of Campinas (IAC), and fully operational to this day, IAC is the oldest agricultural research organisation in the country (Rodriguez, 1987).

World War I, the economic crisis of 1929, and the Brazilian Revolution of 1930 led to substantial changes in the focus of agricultural production, with intensification of cropping systems other than coffee and sugarcane. Products such as cotton, corn, orange and other foodstuffs started to gain expression, supported by public policies of import substitution (Araújo and Nascimento, 2004). Increasing government support to agriculture was observed in the first half of the 20th century, with the creation of institutes and agencies such as the Office of Cocoa (1931), the National Coffee Department (1933), the Institute of Sugar and Alcohol (1931), the National Institute of Rubber (1942), among others (Beskow, 2001). However, agricultural innovation was limited and most agricultural production remained concentrated in a relatively narrow strip along the Atlantic coastal area.

Only in the 1960s did the modernisation of the agricultural sector begin in Brazil. In 1965, a National Rural Credit Program was created, providing financing for modern inputs and equipments. Other important support policies, like the Warranty Policy for Minimum Prices, of various agricultural products were also created, improving stock control, commercialisation and logistics (Araújo and Nascimento, 2004; Belik, 1998; Gasques, and Conceição, 2001). In the 1970s, the government created PROAGRO – a Rural Insurance Program, the Brazilian Agricultural Research Corporation – Embrapa, and the Enterprise for Technical Assistance and Rural Extension – Embrater. Many state governments also created their own agricultural research organisations. Embrapa, state research institutes and agricultural universities became part of the National System for Agricultural Research (SNPA), one of the largest agricultural research networks in the tropical world (Gasques and Conceição, 2001; Gasques *et al.*, 2004; Gasques *et al.*, 2008; Pastore and Alves, 1976).

Therefore, the modernisation of agriculture in Brazil, observed in the 1970s and early 1980s, was the result of co-ordinated policies that led to increased R&D capacity and increased volumes of credit, tied to support policies of stock management, improved distribution and commercialisation of food and agro industrial products. These co-ordinated policies and support mechanisms led to a better allocation of resources, increased productivity, improved product quality and reducing food prices (Beskow, 2001; Belik, 1998; Gasques, and Conceição, 2001; Gasques *et al.*, 2004; Gasques *et al.*, 2008; Alves and Contini, 1988).

However, this phase was dominated by subsidised credit, which had to be almost totally discontinued by the end of the 1980s due to successive crises and high inflation. In the first half of the 1990s, due to the scarcity of public resources, a substantial downsizing of rural extension was carried out throughout the country. Still, in the late 1980s and the 1990s, some remaining compensation policies favoured the expansion of production in central Brazil, supported by the development of innovative technologies to overcome the severe limitations of the savannahs, known as "cerrado". Technologies to remove soil acidity, build soil fertility, improve crop and animal management, among others, were developed and quickly incorporated by farmers (Araújo and Nascimento, 200; Gasques and Conceição, 2001; Gasques *et al.*, 2004; Gasques *et al.*, 2008; Alves and Contini, 1988).

With the end of inflation and stabilisation of the economy, in the second half of the 1990s, the private sector started to occupy a more active role in credit, marketing, commercialisation and agricultural innovation, with increasing investments in R&D. The Government gradually moved away from functions like price controls, production management and sole provider of R&D capacity (Gasques and Conceição, 2001; Gasques *et al.*, 2004; Gasques *et al.*, 2008; Alves and Contini, 1988). More recently, special attention has been given to the Agrarian Reform and to social policies to support family farming, like the creation of PRONAF – the National Program for Strengthening Family Agriculture. Also, policies and programs directed to increase sustainability in the agricultural sector are gaining increasing attention.[2]

Also, and considering demands for more sustainable production models, Brazil took important leaps in a short period of time towards increasingly safer and sustainable agricultural systems. The country is a leader in crop management based on no tillage, which significantly helps decrease erosion and improve general soil quality and groundwater recharge. Biological nitrogen fixation, through an inoculation technique using endophytic diazotrophic bacteria, has led to a significant decrease in the amount of chemical fertilizers applied to crops such as soybean and, more recently, sugarcane. This, in turn, has significantly reduced environmental impacts such as water resources contamination with nitrates or other harmful elements. Biological control, regularly used in a number of crops such as soybean, sugarcane, cotton and fruit-bearing plants, has also reduced the need for chemical pest and disease control in several management systems, which has had a positive impact on the environment, rural workers' quality of life and product safety and quality. Over the last decades, plant breeding programs have made it possible to mobilise genetic variability in order to adapt crops to a wide variety of environmental conditions in the tropics. This has been achieved by incorporating adaptation to different latitudes, tolerance to acid soils – especially to toxic aluminium, and increased efficiency in nutrient use (like phosphorus and nitrogen), as well as resistance and tolerance to biotic factors that are especially severe in tropical regions (Lopes *et al.*, 2007; Lopes, 2009).

Development and consolidation of the Brazilian ARD system

In order to achieve these advances, Brazil has developed a large and complex agricultural research basis which is composed of public institutes, universities, private companies and non-governmental organisations. This capacity stands as one of the most comprehensive and most efficient in the tropical belt of the world (Gasques and Conceição, 2001; Pastor and Alves, 1976; Alves, 1988). It is estimated that in 2006 the 27 countries of the Latin America and the Caribbean region spent a total of nearly BRL 3 billion on agricultural research and Brazil alone accounted for 41% of this total. The country has been investing over 1% of its agricultural GDP in agricultural R&D, most of it from public sources (Stads and Beintema, 2009).

Beginning in the 1970s, Brazil improved its structure and capacity substantially, developing a two-tier system of federal- and state-based agencies. This so-called National

System for Agricultural Research and Innovation (SNPA) has developed and promoted a wide array of technological innovations that has triggered the expansion of agribusiness over the past four decades. The SNPA is responsible for organising, co-ordinating and implementing research that objectively contribute to the development of agriculture, sustainable use and the preservation of natural resources. Implementation of the SNPA concept led to the strengthening of agricultural R&D capacity in Brazil, with improved infrastructure, human capacity, management mechanisms and support policies on a national scale (Beintema *et al.*, 2001).

State research institutes, universities and the Brazilian Agricultural Research Corporation – Embrapa are the major components of the SNPA system in Brazil. Sixteen of Brazil's 26 states operate agricultural research agencies. For example, the São Paulo Agency for Agribusiness Technology (APTA) coordinates all crop and livestock research activities in 64 experimental units and 43 research laboratories located across the state. Brazil also has a substantial number of federal and state universities that conduct research at more than 100 faculties or schools of agricultural sciences. Only a few private universities undertake agricultural research in Brazil, and the non-profit sector plays only a modest role (Beintema *et al.*, 2001).

Embrapa is by far the largest component of the Brazilian SNPA System. A semiautonomous federal agency administered by the Ministry of Agriculture and Food Supply, Embrapa is the largest agricultural R&D agency in Latin America in terms of both staff numbers and expenditure (Pastor and Alves, 1988; Alves and Contini, 1988; Stads and Beintema, 2009; Beintema *et al.*, 2001). The agency is headquartered in the capital Brasilia and operates 40 research centres throughout the country.

Embrapa: A case of successful institutional innovation

Embrapa is a case of successful institutional innovation that has many distinctive characteristics: a public corporation model of organisation; scale of operation at national level; spatial decentralisation; specialised research units; enhanced training and remuneration of human resources and a vision of an agriculture based on science, technology and innovation. Dr. Eliseu Alves, a scientist and visionary leader that helped create and consolidate Embrapa provided one of the most complete overviews, to date, on Embrapa´s model and achievements (Alves, 2010). The main aspects of the organisation´s development and consolidation process covered in his study are summarised below, with emphasis on those who made Embrapa a successful case of institutional innovation.

Continuous support from the Federal Government. Without strong and continuous support from the federal government, Embrapa´s consolidation would not have been possible. In the early years, it took the form of the federal government having understood the importance of technology for the development of agriculture. The battle for budgets has been constant over the 36 years of the organisation´s existence but once the results proved Embrapa as profitable investment for the Nation, the battle for budgets and support benefited from the corporation´s widely recognizes status of strategic organisation.

Diversified R&D portfolio. Embrapa´s management has always been aware of the risk that the lack of achievements represents for an R&D organisation´s future. To overcome this risk, Embrapa always had priority on short-term goals coupled to attention to the dissemination of existing results.

Timing and social support. Brazil experienced a food supply crisis at the beginning of the 1970s caused mainly by a rapid displacement of the population from rural to urban areas. This led to high prices for basic foodstuffs, queues in supermarkets, and social unrest. Still, the stock of knowledge was largely insufficient and on the macro-economic level, there was pressure and understanding for the need to reform public research in agriculture; a typical case of induction of institutional reform, as provided by Hayami and Ruttan (1971). Thus, Embrapa was created under conditions that were very favourable for its success.

Option for a public corporation model. The option taken in 1972 to organise Embrapa as a public corporation was a bold decision of the government to release Embrapa from the bureaucratic rules used in public administration. This gave it the flexibility to administer resources and personnel, to plan, to assess performance, to implement the budget, to disseminate results, and to be transparent. The model allowed Embrapa to develop its own personality, which has since developed a unique reputation on the national and international levels in the field of public research.

Scale, interactivity and decentralisation. The leaders and decision makers that created Embrapa reasoned that in a country of continental dimensions like Brazil, the success of a national R&D organisation would depend on its size, diversity of talents, and level of decentralisation. It was very important for Embrapa to have a presence throughout the national territory. This presence helped to attract the interest of the state governments and the National Congress. It was understood that Embrapa needed to be a network with a critical mass of researchers capable of engaging in active co-operation with universities, state research institutes, private sector and overseas organisations.

A concentrated organisation model for the research units. Embrapa research units are distributed throughout Brazil and are specialised in products, resources and themes. Farmers and other stakeholders know where to go with demands for information and results, which gives them ownership in the centre, and providing help with the political leadership and the economic area of government. This model also facilitates and encourages interaction within the network, since centres dedicated to specific products will strongly depend on effective interactions with complementary teams from thematic and resource centres.

Human resources. The human resources policy of Embrapa, which has been constantly perfected over the years, aims to develop the human capital of the corporation and it is from this capital that Embrapa derives its success. This comprehensive policy is based on several key factors, among them: the establishment of a career that stimulates the desire to study and progress; a salary that allows the researcher to have a dignified living; a retirement plan, with voluntary membership; a health plan paid by Embrapa and the employees; opportunities and stimuli for all employees to accumulate knowledge and experience; a system of a merit-based promotion, focused on individual, group and research unit´s performance; a training programme at post-graduate and post-doctoral levels that meets both the interests of the corporation and the researchers, among others.

Professional relations and co-existence with power. Politicians represent Brazilian society and Embrapa considers it important that they take part in the organisation, especially on aspects related to defining priorities for research and institutional development. The hiring of top managers by an open public selection is an instrument that has promoted co-existence and professional relations with the political power. Embrapa has been able to develop productive relations with the political world, while guaranteeing its independent and competent leaders.

Independent reviews and evaluations of impact. Over the years Embrapa has used a diversified set of instruments to demonstrate its importance in the modernisation of agriculture and the agribusiness sector in Brazil. Several aggregate studies have demonstrated the role of Embrapa´s R&D in technological change of the agricultural sector and to increase exports in Brazil (Gasques *et al.*, 2004; Gasques *et al.*, 2008; Beintema *et al.*, 2001). Also, Embrapa publishes regularly its social balance (Embrapa, 2008a), that has been showing that every Brazilian Real (BRL) invested in the organisation returns between BRL 12 and BRL 13 to the Brazilian society (USD 1.00 = BRL 1.77). The social balance of Embrapa in the past ten years amounts to USD 49.7 billion.

Communication with society. Embrapa has always pursued good answers to the question: what makes a result easily understood by society? This is a complex issue that involves a range of concepts and strategies, and demands talent and abilities to establish the connection between the media and the organisation with the minimum possible of noise. From the beginning, Embrapa invested in professionals able to create strong ties with the media, making its results well publicised, both in Brazil and abroad. More than one can imagine, Embrapa has become a symbol of pride and national success.

Foresight and institutional flexibility. Embrapa has always invested a great deal of effort in foresight (Embrapa, 2003; Lima *et al.*, 2007) strategic planning and improvement of institutional processes (Embrapa, 1988, 1994, 1998, 2004, 2008b). In 36 years, the organisation has experienced three different models of R&D management in response to changing times and innovation trends and methods (Goedert *et al.*, 1995). The implementation of its current model, called *Sistema Embrapa de Gestao* (SEG) (Lopes, 2002), was an important move towards stronger networking to tackle national and international challenges. This R&D management process introduced an internal competitive system strongly sustained in peer review (Lopes, 2002).

Opening up to the world: The internationalisation of EMBRAPA

Embrapa was open to the outside world at a very early stage of its development, when Brazil's external exposure was still low. After the creation of Embrapa, a strong post-graduation programme sent hundreds of young professionals abroad, the majority to the United States and Europe, and to a lesser extent to the United Kingdom, Canada, Spain, Holland, Germany and Australia. The good performance of these students helped to form important bridges with the academic world abroad. Projects financed by the World Bank, Inter-American Development Bank and the Japanese government have been very important in financing this human development programme as well as equipping research units. Because these programmes were well designed and implemented, they solidified the image of Embrapa as a serious and responsible organisation (Alves, 2010).

Currently Embrapa has 78 bilateral agreements with 89 institutions in 56 countries. It has multilateral agreements with 20 international organisations. At the project level, there are numerous agreements involving several countries, organisations and research networks. For example, Embrapa's ties with the CGIAR system extend to its origin, and the relationship with CGIAR's International Centres has brought many good results. This relationship, especially at the beginning of Embrapa, was very important in setting directions for research and training scientists. Embrapa recognises that important shares of the Brazilian seed market of wheat, maize, beans and rice are derived from varieties improved by using genetic material received from CGIAR centres (Beintema *et al.*, 2001). The relationship with the CGIAR system continues to be very important, especially for joint work in Africa, Latin America and Asia (Alves, 2010).

In 1998, Embrapa developed and implemented the innovative concept of Virtual Laboratory, or Labex, as a means to increase its scientific and technological ties with advanced research organisations around the world (Alves, 2010).[2] Instead of building its own platform abroad, Embrapa uses the concept of a virtual lab, or lab without walls, to negotiate access to its partner organisations' existing facilities. The concept has been tested and validated in the United States, in partnership with the Agricultural Research Service (ARS-USDA). Given the success of Labex in the United States, Labex Europe was created based in Montpellier (France), and more recently in Holland and England by separate agreements with these countries. In 2009, it was extended to Asia, in partnership with the Rural Development Administration (RDA), of South Korea.[3] The development of the Labex concept was based on the evidence that Embrapa scientists needed to strengthen contacts with the best research organisations abroad, not only by training students, as Embrapa had done for more than three decades, but also by involving its senior staff in international co-operation (Alves, 2010).

The success of Brazilian tropical agriculture motivates countries with similar problems and challenges to seek information and support for technology transfer from Embrapa. Besides the traditional instruments of support, Embrapa has decided to post researchers in less developed countries, creating Embrapa Africa in Accra (Ghana) in 2006, and Embrapa Venezuela in Caracas in 2007. In 2010, Embrapa initiated Embrapa Americas in Panama with the deployment of one researcher and one technology transfer analyst to support the organisation's collaboration in Mexico, Central America, the Caribbean, Colombia, Ecuador and Peru.

Both the Labex model and the structures of transfer of technology in developing countries are flexible models that can be expanded with new scientists or by transfers of scientists among countries, according to identified common interests. This goal is benefiting agriculture and helping combat hunger in developing countries (Alves, 2010).[4]

Future challenges and opportunities

Sustainable development is one of the most challenging goals for mankind, and is vital to Brazil. The technological standards of global agribusiness are now being substantially modified by the introduction of new technologies brought forth by recent scientific advances. A new body of knowledge is starting to configure an agriculture that, besides aiming at food production, is also designed to meet a set of requirements that might form a new technological standard. These requirements include: 1) attention to the environmental services needed to enhance the sustainability and productivity of the natural resources base that underpins agriculture; 2) competitive products whose added value stems from differentiation and specialisation ; 3) safe and healthy products, differentiated in order to meet consumers nutritional, health and convenience needs; 4) production of renewable energy, feedstock and bioactive molecules for different industries, so broadening the scope and usefulness of agricultural systems, especially in the interface with the nascent bioindustry (Lopes *et al.*, 2007; Lopes, 2009; Lima *et al.*, 2006).

Climate change will impose additional stresses to many delicately balanced agro-ecosystems, especially in tropical areas, where significant intensification of biotic and abiotic stresses is expected in the next decades. If the expected trends in climate change are confirmed, severe constraints will be imposed on future advances the research community could achieve, using conventional methods and tools of innovation. Therefore, a paradigm change is much needed to address this emerging agricultural problem, especially in the tropical belt of the world (Lopes *et al.*, 2007; Lopes, 2009). The genomics revolution of the past decade has dramatically improved our understanding of the genetic makeup of many agriculturally important species. Together with the achievements represented by complete genomic sequences, high-throughput and parallel approaches are available for the analysis of transcripts, proteins, pathways and, more importantly, to help extract useful variability from the wealth of resources stored in our germplasm banks. New genomic technologies coupled to breeding approaches bring opportunities to reduce the impacts of biotic and abiotic stresses on agricultural system´s productivity and to improve safety, quality and functionality of crop and animal products (Lopes, 2009; Lima *et al.*, 2006).

Agricultural innovation has to be understood as part of a complex process. Complementarities, mix of technologies and capabilities, together with effective approaches to networking must be viewed as key ingredients in developing this process. One of the key problems limiting the effective implementation of a complex process is the difficulty to build effective teams and networks (Lopes, 2000). Approaches to networking and partnerships have become important means of enabling organisations attain otherwise unattainable goals, add value to their products and processes and reduce costs. In order to face these challenges it is crucial to establish wide alliances, bringing together professionals from different areas of expertise. Also, the demand for efficiency and relevance presses R&D programs to move in the direction of cooperation efforts. Therefore, the need for an expanded networking approach to agricultural R&D will always be an objective to be pursued.

The future configuration of any ARD system is dependent on knowledge to guide strategic decisions about structures, methods, and capacities, in order to take advantage of new opportunities and technological niches that can benefit from strong innovation programs. More prospective efforts must be directed to thinking the future of agricultural research and innovation around the world, especially in developing countries. Research organisations need information that is not currently available, about current and future changes and influences and their impact in the countries key activities (Lopes *et al.*, 2007; Lopes, 2009; Lima *et al.*, 2006). To obtain and organise this information, prospective studies on the present and future performance of the innovation system and their related activities will have to be intensified and systematically improved. These prospective studies and priority setting mechanisms, together with cost benefit analysis will be valuable to guide informed decisions in the future.

Notes

1. Mauricio Antonio Lopes, PhD, Executive Director of Research and Development, Brazilian Agricultural Research Corporation (EMBRAPA), Ministry of Agriculture, Livestock and Food Supply (MAPA), PqEB, Av. W3 Norte (Final) – Edificio Sede, 70770-901, Brasília-DF, Brasil (Mauricio.lopes@embrapa.br; De.pd@embrapa.br).
2. Labex Programme –*labexkorea.wordpress.com/about/*
3. Labex Korea – *labexkorea.wordpress.com/*
4. Labex Programme –*labexkorea.wordpress.com/about/*

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25. Facilitating adoption and technology transfers: Discussion

This section outlines the remarks and questions brought up by John Preissing, FAO and Thomas Schäfer, Novozymes, who were asked to discuss the presentations made during the session on "Facilitating adoption of innovations and technology transfers," reported under Sections 21 to 24 of these proceedings.

Comments by John Preissing, Senior Officer for Extension systems at the Research and Extension branch of FAO (OEKR)

FAO's work in Research and Extension focuses on providing policy support, project and technical assistance support and networks and partnership development support. Our mission is to support the enhancement of inclusive agricultural innovation systems for small holders.

I found each presentation very interesting. I felt the presentation on Participatory Plant Breeding (PPB) provided an outstanding example of how small holders and researchers can be brought closer together. I would have liked to hear more on how the actual technology transfer functions occurred, and if they demanded new research skill-building, or intermediaries. It would also be interesting to explore whether this example is truly a sustainable model, or simply a one-off initiative. It would be productive, therefore, to explore the long-term prospects of PPB.

During Mr. Minnaar's presentation on South Africa, I was struck by the processes and methods used to transition from a system without GMO-based products or new innovations, to a more advanced framework. It would have been helpful, however, to know whether these processes were spearheaded by industry, or by actors and workshops on the ground. On a more general level, I am interested in all methods by which learning and change occur.

Mr. McMahon's presentation provided a long-term view that I greatly appreciated. I was particularly struck by the dangers of technology off the shelf versus building and enhancing local capacity. I was also struck by the challenges that small countries face to conduct credible research.

From my own experience working in the Caribbean, for example, I have observed that many governments find challenges within the Caricom (Caribbean Community) system. If we bifurcate the issue, there are outstanding examples in countries like Colombia and Argentina, but there are many other countries that cannot keep up. What will happen to these countries that are resource-poor in terms of human capital and other sources of innovation? This is a very real and significant challenge

Mr. McMahon's presentation also highlighted the importance of institutional innovations. We heard a similar emphasis during the presentation from EMBRAPA. As both of these presentations demonstrated, long-term stability and progressive change within an institutional setting is very important, and should be emphasised. Furthermore, EMBRAPA's work along the continuum of research, extension and farmer support is based on very strong linkages. This work demonstrates that even if strong institutions are in place, they may not realise their full potential if they are not properly linked. Finally, I thought the emphasis on communications strategies with urban populations was very important, because most of the funding and political support for agricultural research typically comes from urban populations.

I would like to conclude with two considerations to reflect upon. The first revolves around the importance of benchmarking innovation. The challenge here is to identify the differences, in terms of input and output, under an innovation-based framework, and to isolate the impact that innovation brokers make. Some of these differences can be described in individual projects or case studies, but to evaluate an entire system remains a challenge for us all.

Secondly, we still face significant needs in terms of human capital and capacity development, and especially with regard to extension- and innovation-based institutions. Extensionists are ageing, and their profiles and skill sets are different from those that are needed today. According to some figures, there are nearly six million extensions today, with approximately one million in China alone. How are these individuals going to be skilled for the needs and challenges we will face in the future? Will other individuals take these roles? This remains an issue for future investigation.

Comments by Thomas Schäfer, Senior Director, Innovation Office, Novozymes

I am a researcher at Novozymes, a Danish biotechnology company. It should be noted that Novozymes is not an agricultural company, but I nevertheless attended this conference for two reasons:

- because I can provide insights into innovation as the leader of our corporate innovation office; and
- because I am leading R&D within Novozymes' bio-agricultural efforts, including those related to bio-fertility, bio-pesticides and bio-yield enhancements.

At Novozymes, we are guided by rethinking tomorrow. Earlier during this conference, someone said that agriculture is important. I would rephrase that statement: Going forward, agriculture will be *critical*.

We live in a world today that is both agricultural and petrochemical. At some point, however, the petrochemical role will no longer exist. The entire leverage for chemicals, fuel and feed will therefore have to derive from agriculture. From a conceptual point of view, this idea may sound trivial, but from a more practical perspective, it remains an enormous challenge. At Novozymes, we address both the input to, and output from bio-refineries because we realise that all fuels, feed, food and fibres will eventually come from agriculture. This, we believe, is of utmost importance.

It is also important that we differentiate between R&D and innovation. To paraphrase a former CEO of Evonik, a German chemical company, R&D turns money into knowledge, but innovation turns knowledge into money, profit and products. Of course, this statement raises several issues surrounding the roles of the public and private sectors. At Novozymes, we are involved in both. That is to say, we aim to facilitate both knowledge and profit generation alike.

Indeed, there is a significant commercialisation angle to this discussion. Generating knowledge is easy, but generating profit is not. This reflects many presentations we have heard during this conference. Producing highly innovative products does not guarantee these products will make it to market. Being a business-to-business firm, Novozymes focuses on both technology-driven innovation, and market- or partner-driven innovation. Technology-driven innovation, as we have seen, is not enough to guarantee profit. A company may have a cutting-edge technological platform in place, but that is only the base. The challenge thereafter lies in bringing products to the market.

As a result, we adhere to a variety of open innovation models that provide us with significant insight into our customers. As an example, we are currently selling washing powder enzymes to Proctor and Gamble. Proctor and Gamble has 80 000 suppliers, but we have been its preferred supplier for four consecutive years. In other words, a small

Danish company is among the top three suppliers for one of the world's corporate giants. This is because we deliver innovation and value.

This brings up another clarification that was not significantly addressed during this conference. Innovation does not simply bring a product to the market, it adds value to the market – not only for companies like us, but for our customers and shareholders as well. In other words, innovation is about value generation, and not merely profit generation. In fact, profit and value generation often go hand-in-hand.

I noticed a similarly strong emphasis on consumer insight during the presentation from Dr. Masa Iwanaga. When Dr. Iwanaga conducts participatory plant breeding, he creates customer insight – namely, by involving farmers. This increases his chances for innovation because he effectively brings his customers onboard. I appreciated that very much and found it to be analogous to our own practices at Novozymes.

During the presentation of the experience of a South African farmer, we explored the interesting dilemma of technology push innovation. This kind of innovation does not always make it onto the market, or its arrival could be significantly delayed. As a result, new innovations may not be effectively communicated and explained to consumers. Some farmers may understand the issues, and they certainly know the results. Their yields are up, water usage is down, margins are up, chemicals are down, and sustainability is up. Even with these elements in place, however, an innovation may not make it to the market within a timely gap, largely due to issues of communication. Our colleagues from the Netherlands reminded us of the perils of thinking that science is "just another opinion." This should not be underestimated because we are often unable to effectively communicate science to the public. Going forward, then, we must develop more effective ways to communicate biotechnology and GMO crops.

In that sense, I very much appreciated the presentation from Embrapa because it demonstrated holistic thinking — thinking that extends beyond the 40-year time horizon and focuses on the green growth revolution. Embrapa also demonstrated that if a firm has technology, processes, communication and education frameworks in place, it can dramatically increase its chances for innovation, thereby creating value and products that consumers will appreciate.

Part VI.

Responding to broader policy objectives

26. Final round table: Responding to broader policy objectives

Remarks by Pascal Bergeret, General Directorate for Education and Research of the Ministry of Agriculture, Food, Fisheries, Rural Affairs and Spatial Management, France

Challenges and opportunities for global agriculture

The major challenge facing global agriculture is the need to double food production by 2050 so as to accommodate population growth and changing diets, while at the same time satisfying ever-more pressing demands concerning food quality (as regards health, nutrition and organoleptic quality, along with the cultural dimension of food).

The dominant production systems of today are not sustainable. If they continue to be deployed without improvements, the result will be irreversible and unacceptable environmental damage, such as the destruction of the planet's last great forest basins (for example, Congo and the Amazon). In Europe, the dominant production systems consume too much energy, they are based on plant protection strategies that are too costly and generate pollution, they are ill-suited to the droughts to be expected in connection with global warming, and they result in excessive biodiversity losses.

Even so, these production systems are highly coherent and robust, and it would be very difficult to change them. New models need to be designed and implemented, reconciling economic, environmental and social sustainability. Doing so will entail seizing the opportunities available to agriculture, thanks in particular to the rising trend in consumer purchasing power and the emergence of new sources of income for farmers (local production and distribution networks, ecotourism, etc.).

It is important to transcend the productivity/sustainability dilemma and to accept the fact that medium-term benefits may offset short-term sacrifices. Trade-offs – at times complex and difficult –will need to be found between consumption, investment and Research and Development (R&D) expenditure. In France, for example, despite the acute public financial crisis, the government has opted to invest massively in R&D in connection with a programme of forward-looking capital investment.

There is consensus on the cost of inaction and on the urgent need to act.

The new agri-food chains we need

Under such circumstances, no stone must be left unturned. Some people expect that the application of biotechnologies to the agricultural sector will trigger progress comparable to what information and communication technologies have brought – and continue to bring – to the service sector. But the lessons to be learned from the operators of such alternative production systems as organic farming should not be disregarded, and they can be incorporated into other production systems.

It is important to shift the basis of agricultural production systems to ecological functionalities, and to tailor them in an intricate and diversified manner to local conditions. The farming trade is destined to become increasingly knowledge-intensive.

Bio-inspiration in agri-food chains is another area to be explored. The aim of this way of thinking is to harness our knowledge of living things to inspire industrial processes, such as the development of molecules that mimic plants' natural mechanisms of resistance to diseases and pests.

In order to maximise the use of solar energy, production systems should be designed that cover the soil at all times. Integrated crop and livestock management is another avenue to explore and develop. New strategies for soil and water management should be formulated. Designing and managing agricultural landscapes will also become an increasingly important activity for farmers.

The environmental services rendered by these new agricultural production systems will have to be duly recognised by society. These services include preservation of the quality and quantity of water resources, protection of catchment areas against erosion, carbon sequestration and conservation of biodiversity, including landscapes.

The key role of research

To succeed in developing sustainable agricultural production systems, a great many solutions already exist and should be exploited to the full. But new knowledge is also needed, and there is broad agreement that public and private research and development efforts need to be expanded further. A number of studies show that research yields a high return on investment.

Yet the volume of resources earmarked for research is not the only issue; the way research is conducted needs to be changed as well. From a scientific standpoint, research is now becoming systemic and holistic: new tools and models are now available to process an extraordinary number of data in record time. These models allow research to be more predictive. For example, they can be used to assess the combined effects of elementary techniques, to measure the impacts – including unintended ones – of agricultural practices and policies and to achieve close monitoring and control of complex systems using batteries of relevant indicators.

From an organisational standpoint, research will be increasingly co-operative and co-ordinated. Co-ordination between countries has already begun and will gather pace (joint planning initiatives, global alliances, etc.). Increasingly sophisticated and costly research infrastructure will have to be shared and managed jointly. The same holds true for databases and expertise. Public/private co-operation is more than ever a priority. Modern research equipment is very often too costly for businesses (even for large enterprises), which are prompted more and more systematically to outsource their own research to public laboratories. Research clusters have been developing at a faster pace, and explorations of open innovation have reached a new dimension. Ever-greater use of prospective studies is being made to shed light on the major orientations for research.

A policy framework conducive to the development of sustainable agriculture

Research alone, however, cannot do everything and it must not be asked for more than it can deliver. The policy framework plays a major role in the development of sustainable agriculture.

Numerous policy options are available to us, between which it is often very difficult to choose. Should the emphasis be put on prices, with a goal of incorporating the value of ecological services rendered by agriculture into product prices (at least partially)? Or should economic incentives be used to encourage farmers to produce ecological services? Who should pay for these incentives: the direct beneficiaries, as is often already the case in certain mineral water-producing areas, or governments, for example in connection with the second pillar of the Common Agricultural Policy (CAP) of the European Union, or via contracts with farmers? Should "credit" systems be introduced and a market set up to trade those credits, along the lines of what is done for carbon? Should ecological damage be taxed (eco-taxes)?

Given all of these options, which are already being tried out on a variety of scales in different countries, a review of these trials is needed urgently in order to identify the best options, along with the circumstances under which they have proven their worth, in order to reach a series of policy recommendations.

One gauge of policy effectiveness is to set fairly precise and quantified objectives that harness the energies of the players involved and indicate the scope of the changes that are needed. For example, in France the Ecophyto plan, which seeks to achieve if possible a 50% reduction in the use of phytosanitary products by 2018, encourages a complete overhaul of crop systems, and not just marginal improvements to existing systems.

Agricultural Knowledge Systems

All of these requirements show clearly the need for better co-ordination between agents throughout the agri-food chain in order to stimulate innovation. Public and private research, entrepreneurs in the production, agri-supply, processing and distribution sectors, consumers-citizens, vocational and general teachers at the secondary and higher levels and policymakers should all interact within flexible and fluid innovation networks and within territorialised clusters.

Such complex entities can be instituted and function thanks to the use of information and communication technologies.

The aim is to generate ideas, share know-how, encourage initiatives in any direction – bottom up, top down, sideways – and nurture a spirit of co-innovation.

A major aspect of future agricultural knowledge (and innovation) systems will consist of risk-management approaches and mechanisms: new insurance schemes will need to be devised whenever that makes sense, and new agricultural income stabilisation mechanisms will need to be instituted and to tap solidarity. Collective grassroots approaches will spur the formation of new networks for swapping and acquiring shared know-how. Agricultural advisory systems will have to be re-organised accordingly.

Remarks by Herman Eijsacker, Wageningen University, Netherlands

I have several comments to add to the broad discussions we have heard during this conference. First, it is clear that we must pay more attention to education, not only in Africa, Asia or South America, but in Europe as well. This is important because public understanding is key to garnering public support for technology-driven developments.

Two major Dutch reports have underscored this significance. The first, undertaken by the Dutch Advisory Council for Societal Development, found a growing gap between well-educated and lesser or non-educated populations within the Netherlands. The second study, from the Rathenau Institute for the Parliament, characterised at least 25% of surveyed internet users as "sceptical." These individuals were mostly low educated and accustomed to absorbing information through non-traditional media. As these studies demonstrate, we must convince people that new technology is important and necessary to improve our world.

Changes are needed at the university level as well. Universities can no longer rely on their selective or elite status, nor can they focus on education and research alone. Today, we must transition to a "third generation" university which would rely on network knowledge systems. Such a university would work not only with academic publications in mind, but also with an eye to societal implications. It would be mission-driven and receive mixed funding. In short, a third generation university would combine fundamental research, applied research, and applied education.

Today is an important day for the Netherlands because this country has, for the first time, developed a top-sector research agenda which places industry in the lead. As a scientist, I am very interested to see what this agenda will bring that is both new and different, and whether it will be possible to combine industrial co-operation and co-ordination with entrepreneurial competition. How is it possible to have a general research agenda when different industries have their own agendas? This is a major challenge.

We are addressing these issues by programming research in an academic way. This programming is conducted by scientists, and involves both industry actors and policymakers. But the general public must also be involved. This is undoubtedly a difficult task, but one with which we already have some experience through public assessments conducted at the beginning and end of research programmes. These have proven to be very useful, especially at the very beginning of a programme when uncertainties tend to arise. When public meetings were organised, and during which the risks associated with new developments were discussed, we were able to garner substantially more support for our programmes.

It is important to communicate with the public at the very beginning of new research programmes to attain sufficient public support. Such interaction would also foster a greater general understanding of the reasons for which we must transition from a linear-based approach to a network-based research, while more effectively communicating the reasons for which technology-driven research is crucial to food security.

Remarks by Pierre Bascou, DG-AGRI, EU Commission

This conference comes at a crucial time for the European Union (EU) and the global agricultural industry as a whole. The issues discussed at this conference are of great importance to the European Union. It is clear that we must reinvest in systems of innovation and agricultural knowledge.

I would like to make two points about the discussions thus far. The first concerns the policy environment. We are currently in the process of finalising a policy proposal that should shape the future agricultural policy within the European Union; it is a proposal being discussed and debated from both a political and a financial perspective. During such a development, I think it is always important to specify where discussions stand at any given moment, especially as they concern the European Union.

It is also important to acknowledge that the EU agricultural sector is facing a number of challenges of economic, environmental and territorial nature, most notably specific societal requirements for food security and food safety, price and income volatility, and the declining profitability of the agricultural sector.

These issues concern the whole world, but they are of acute concern in the European Union, where we face real problems with regard to the preservation of natural resources. We have a limited supply of land and resources, and face challenges related to climate change. All of this takes place in a context of declining productivity, increasing demand for agricultural products, and both renewed pressure for social and territorial cohesion.

As Mr. Bergeret noted in his presentation, we cannot and should not separate productivity from sustainability. These two elements go hand-in-hand, and should be addressed as such. In the European Union and, perhaps, the rest of the world, we will not be able to increase production in the agricultural sector without taking into account both environmental and social dimensions. The social dimension is of particular importance.

At a time when many are looking to increase productivity, I think it is important to remember that we must also make the agricultural sector more sustainable. We must find a way to integrate short-term challenges with long-term concerns.

These challenges have manifested themselves in the recent policy reflections from the European Commission (EC) which for the first time identified the preservation of natural resources as a primary goal of the agricultural policy. Previously the focus had been on production, but today this has broadened to include environmental and territorial concerns. The CAP third objective is the improvement of the territorial balance within the European Union.

This, in effect, is the policy manifestation of the challenges that the agricultural system is currently facing. These challenges have been explicitly recognised by EU institutions. This marks a major step, and one that will have consequences in both the medium- and long-term.

We have already discussed the importance of public support for AKIS, which is especially essential within the European Union. It is clear that the market orientation adopted by the European Union in designing its farm policy, and the policy environment it has created, can only be accompanied by strong public support for research systems and Agricultural Knowledge Systems (AKS). In effect, this is the *sine qua non* necessary for agricultural producers to face the challenges of profitability and sustainability. I would argue that we are currently facing a production and policy model that aims at addressing and supporting "How do we produce", rather than "How much do we produce" This distinction is of utmost importance.

The second point I would like to make concerns our response to these challenges. To do so, we must develop and reinforce our education, knowledge, innovation and research systems. In other words, we must do more and do better. Within the European Union we are still at a stage of policy conception, but in the next few years we aim to take the first steps toward the development of a stronger Agricultural Knowledge System (AKS). In today's large European community, this type of AKS (in particular extension services) has declined, if not disappeared in some countries. It is extremely important that we recreate this dynamic and reinstate AKS's that are strong, powerful and capable of not only increasing productivity, but of opening up entirely new avenues of environmental and social development.

The other element concerns research. This is something that should be developed not only for the benefit of the agricultural sector, but for the entire food supply chain and economy. It is important to note that although research continues to make progress in the European Union, in recent years it has become increasingly focused on the bio-economy. I believe it will be important to reinforce and support research for the primary sector.

Finally, we must also diffuse knowledge and research more effectively among different actors, including producers, scientists, advisors, businesses and public administrations. In the European Union, we have extensive experience with co-ordination, networking, and exchange, and we should build upon that experience. The development of innovation partnerships is equally crucial to diffusing knowledge.

I would like to conclude by thanking the OECD for holding this conference. This has allowed us to share our reflections on AKS development and innovation in agriculture. Another important topic for future discussion could be performance evaluation. As we discussed earlier, we still need to expand the field of indicators used to measure productivity and environmental or social factors. This may be an area in which the European Union has valuable insight, and one from which everyone would benefit.

Remarks by Masa Iwanaga, Japan International Research Center for Agricultural Sciences (JIRCAS)

I have four main points to make in response to what I have seen and heard at this conference. I expected that OECD member countries, as representatives of affluent societies, would examine food security from a global perspective. Instead, however, we primarily focused on food security within exclusively OECD contexts.

When considering the question of increasing yields, it is important to separate the issue into two areas. The first concerns increases in yield potential, including, for example, initiatives that convert rice plant into C4 plant , or introduce nitrogen fixating capacity to rice by genetic engineering . The second area concerns the yield gap. When overall food production increase is globally evaluated, it tends to favour investment that reduces the yield gap. Instead of aiming to increase rice production by doubling yields from five to ten tonnes per hectare, for instance, it would be better to invest in increasing the yield of rice in Africa from two to four tonnes per hectare. This type of investment would be especially beneficial in light of concerns over poverty and food security. Within an OECD context, economists tend to think of food security only in terms of trade and its price. In the case of staple food, food security is directly related to a local productivity increase, availability and accessibility. During this conference, however, we did not discuss such local food issue.

We have also devoted much of our attention to supply side issues, in examining how we can increase production in a sustainable way, yet we devoted comparatively little time to the demand side of the equation. Here, in my opinion, lie many of the most salient questions. As societies grow and demand increases, for example, is it possible that we may over-consume meat? Is it possible that we are over-dependent on energy consumption? Should we change our society to make our behaviour more sustainable and to reduce meat consumption? Such an endeavour would require a restructuring of the entire livestock sector, which is one of the world's largest emitters of carbon dioxide, surpassing even the transport sector.

Eventually, we will have to discuss potentially broad changes to our lifestyle and consumption habits, if we are to arrive at a more equitable society and more sustainable planet. Due to the recent major disaster in Japan, my institute has begun examining ways to reduce energy consumption by 15% to 20%, as mandated by law. I believe the world community should take a similar approach to reducing meat consumption. Such over-consumption has been a major driver behind the rise in obesity. Today, there are now one billion obese people in the world – ironically nearly the same number of people who are suffering from food shortage and malnutrition. In the future, then, our world will be very different. It is not adequate for us to look into the future without considering both supply and demand.

Finally, we need to enhance communications and dialogue with farmers and scientists. Over the course of this conference, we have heard very little from real farmers. This begs the very important question of whether we are adequately representing the concerns and interests of farmers, or simply representing our own sector, profession, or national pride.

Remarks by Roger Beachy, Professor Department of Biology, Washington University, St. Louis, Missouri

As the former director of the National Institute of Food and Agriculture (NIFA) and an early participant in the development of biotechnology, the topic of this conference is of great interest to me. I have worked on the development of tools that control trait expression and virus disease resistance in transgenic crops, so I have an interest in fundamental science, the management of science and the applications of biotechnology.

I truly appreciated the opportunity to learn about the different agriculture knowledge systems that are in place in different countries, notwithstanding the fact that many policymakers and economists use a lexicon that scientists like myself typically do not use. Though your models may not be accurate to the highest degree of probability, each of you provided thought that can shape policy as well as technical approaches to agriculture systems.

There are imperatives in having strong AKSs across the globe, as the world food supply will ultimately depend on appropriate systems in this sector. In this discussion, we have agreed that philosophy cannot be the sole deciding factor in designing an AKS. AKS development must be made based on scientific consensus, whether presented by scientists or within economic models. At this point, however, we are not sure which models will prove more successful than others. We have seen a number of models during this conference, with each designed for specific parts of the globe. The Brazilian model, for instance, is different from the Indian model, which, in turn, is different from the Chinese model. The US system, meanwhile, is unlike any of the others we have seen during this conference, though a more thorough dissection of these differences is a topic for another discussion.

It is very likely that none of these models is perfect, though it remains unclear whether we have enough time to identify those that are most successful. Each, however, has the opportunity to provide some, but perhaps not all agricultural products. Agriculture is not exclusively comprised of the “four F's” (food, fibre, fuel and feed). It also encompasses the biochemicals industry, the natural products industry, and the raw materials we currently obtain from petroleum, but will someday derive from plants and animals. Once we run out of stored carbon, we will have to invest in new sources of carbon-based materials. Clearly, then, the term “agriculture” is much larger than it was 20 years ago, when we were concerned primarily with food, fibre and feed. Today, the bioeconomy is a growing industry, and one that will only become greener.

However, if we do not allow innovation in this field because of reluctance to adapt new technologies we will not be able to harvest the benefits of the investments in science discovery, and other economies may harvest them instead. Each of us must therefore come to grips with our new roles as scientists and policymakers. Some of the breakthroughs in solar energy technology have come directly from research on the photosynthetic capabilities in plants. Researchers are using their knowledge of photosynthesis to create new ideas for solar energy cells; similarly, knowledge about biomass crops of the future are expanding options for farmers to be involved in the bioenergy/biopower/biochemicals industries. Knowledge gained through scientific inquiry has enabled many new innovations.

Scientists have come to realize that answers to complex problems require system-wide approaches to achieve a solution, and making adjustment to outcomes/products that results in pull from users. Agriculture systems approaches to food security will require responsiveness of upstream science and technology to address the needs of those who provide products for the market, and that those who create markets, and those that distribute products to consumers. Systems approaches are, therefore, of paramount importance. At the National Institute of Food and Agriculture about 60% of the grants awarded competitively in 2011 were based on a logic model that 'pulls' rather than pushes' research to achieve a desired outcome. In these projects economists and social scientists consulted with genomics scientists, and genomics scientists consulted with translation scientists. In some cases, projects that require reductionist approaches are being guided by economists, not by genomics experts.

These models can also play a major role in creating change in the way that academic research is conducted. Today's academic scientist can no longer simply function as a single person or even a lab. His or her work must increasingly be integrated with other fields if desired outcomes are to be achieved.

While linking upstream research to outcomes is of great benefit, there remains a need to generate new knowledge that, to some, may seem speculative or high-risk. Open ended research is often the engine of innovation, and research and invention have brought us new tools for agriculture. For example, mathematical modelling can now more accurately predict climate than in the past; other technologies provide information that can ensure efficient delivery of chemical fertilisers and water. Advances in engineering have led to the development of improved methods for planting seeds and harvesting products. Similarly, advances in seed improvement must continue, including through advanced breeding techniques and genetic engineering: these and future advances will make it possible to develop sustainable, high yielding agriculture. Science-based research must continue.

The needs and demands of our food systems must be safe, sustainable and acceptable to end users. We may need to recapture the word "sustainability" and transform it from a term at is, at times, more philosophical than scientific. Some have made word equivalent with "organic," but that is not necessarily accurate. Sustainability in agriculture has as a strong environmental component as well as a strong economic component; furthermore, it is definable and can be quantified.

The willingness or unwillingness to accept new technology or products depends upon the manner in which these products are predicted, developed, marketed and perceived: this is certainly the case in food agriculture. Marketing is of especially great importance and in my opinion, we must do a better job of marketing the outcomes of the new genetic sciences that are being applied in agriculture, including informing the public of what we are doing, how we are doing it, and how it will provide benefits. In contrast with the relatively modest acceptance of new agriculture technologies, the medical community has taken a taken a far different approach to marketing the outcomes of advances in biomedical research, and have done so with great success.

In the case of agricultural biotechnology, the last 20 years of development, deployment and marketing of products and technologies that comprise agriculture biotechnology have shown the technologies to be safe – for consumers, farmers, and the environment. This is an amazing safety record that has accumulated and which be built upon. When questions are posed about GM crops *versus* conventional agriculture that requires use of high levels of pesticides and insecticides, or organic agriculture, often requiring use of high levels of "natural chemicals" (some of which are highly toxic), I choose genetics and genetic engineering every time.

As science is learned and scientific consensus is built (about a product or technology), it should logically lead to science-driven decisions that themselves that cross geographical boundaries. Following this logic trade regulations that deal with agriculture products should, if guided by science-based consensus, cross geographical boundaries. It can be argues that not every country or individual needs to reinvent a new wheel just because it covers a different road. In agriculture technology this implies that knowledge gained during the approval of a biotech crop in one country or region should transfer to other countries to facility both the practice of agriculture and the trade of agriculture goods. It simply does not make sense to encourage the use of agrichemicals that cross country lines but to restrict product of advanced genetics to do so. As a result, many countries "reinvent the wheel" in a way that it is not informative or results in over-regulation and reduces the use of new technologies and new products.

It is not necessary, nor helpful, to over-relegate technologies or products that have a history of safe use; over-regulation in many sectors, including in agriculture, can inhibit innovation. In order for knowledge to create innovation and new jobs, our regulatory processes must be relevant, based on science, and consider benefits as well as risks in judging safety. At the moment, I and many colleagues in the agricultural sector do not believe that many of the regulations applied to agriculture biotechnology are relevant. As a consequence many of the potential innovations that can bring benefit to those that we serve are not being developed. Stifling innovation in the food and agriculture sector reduces the capacity to meet the challenges of a growing population in the midst of climate change.

The title of this meeting includes a description of the goals of AKSs in each of our countries, yet we have spent little time talking about the goals related to climate change or sustainability. We focused heavily on policy, and I was hoping to see a stronger sense of urgency on both the policy and the technical sides. Without such urgency, the (AKS) system may flounder and will not become as effective as it could be. On this matter, there is simply no choice, and I hope that participants in this conference will continue discussions that bring science and policy together.

The importance of science in setting policies has been emphasised in recent years; Professor Bruce Alberts, former president of the US National Academies of Science was among the global science leaders who urged that nations focus on engaging science more closely with policy making. Some countries may not allow such alignment; we are fortunate in the United States and have a President that appointed about 35 well-respected academics on its staff. Science can give policymakers the useful information that to make pertinent decisions, including decisions in agriculture. Without a close alliance between policy and science, it will be difficult to make hard decisions about future production in agriculture and establishing guidelines for sustainability, ensuring food safety, and other important goals.

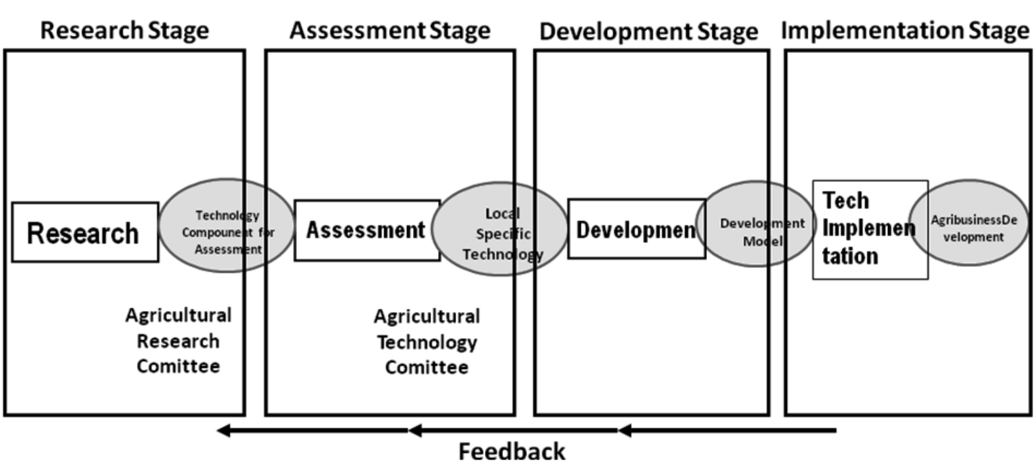
Remarks by Kasdi Subagyono, Indonesian Agency for Agricultural Research and Development, Jakarta

In order to achieve higher levels of productivity and production in agriculture worldwide, there must be technology transfers. Indeed, when the green revolution first started, technology adoption was the most important factor in increasing the levels of agricultural productivity and production, although in many cases this same technology had a negative impact on the environment. As a result, it has since become important that more environmentally friendly technology be developed. On the supply side, numerous research centres, university and private sector business have developed a variety of technologies that need to be transferred to users.

In Indonesia, technology transfer in the agricultural sector has become very important since the so-called "BIMAS" was implemented under a series of five-year development programmes that began in 1969. This programme focused on agriculture intensification and used technology intervention to increase rice production in Indonesia, leading to self-sufficiency in this food by 1984.

Today, Indonesia encourages "Research for Development" (as opposed to Research and Development), and the activities undertaken bear in mind the demand of the users. Technology needs are identified and used for research planning. From the research to the implementation stage, government policies have played an important role, as shown by Figure 26.1 which outlines the research and development process based on the Agriculture Ministerial Decree Number 03/2005. At the research stage, research centres and research institutes under the Indonesian Agency for Agriculture Research and Development (IAARD) are in charge of research. The upstream technologies which result from their work are then assessed by the Assessment Institute for Agriculture Technology (AIAT). AIAT is also assigned for implementing technology transfers at the development and implementation stages. Feedback is expected from the users with the research centres and institutes, as well as AIAT, following up with more research to improve the technologies.

Figure 26.1. Research and development process*



* Based on Agriculture Ministerial Decree Number 03/2005.

Technology transfer and adoption

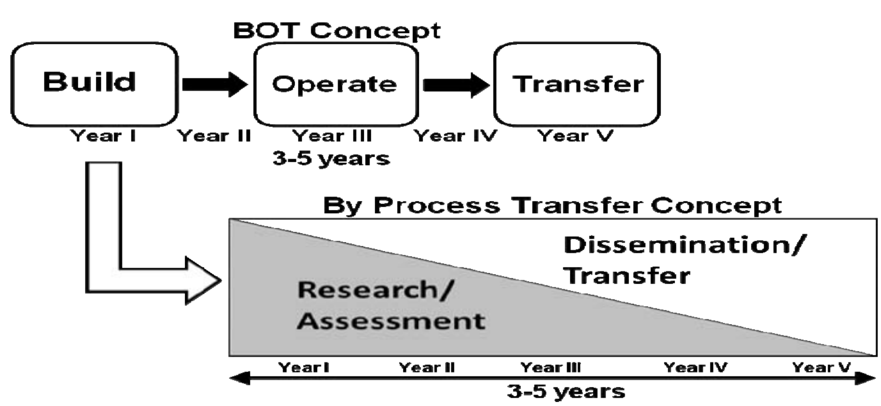
Indonesia's experience in agricultural technology transfer demonstrates the need to accelerate adoption of technology by farmers. Many innovative technologies have been created by various research centres, but they have been adopted relatively slowly by farmers. Due to this fact and the dynamic nature of technology demand by users, technology transfer must be accelerated.

Indonesia has experiences with two approaches of agricultural technology transfer: 1) the build-operate-transfer (BOT) approach and 2) the process technology transfer approach (Figure 26.2). The first approach is more time consuming compared to the second approach because the technology will be transferred when the construction and operation of the technology have been completed. The second approach is better in that users (farmers) are involved in the process of technology transfer.

In addition, intensive study has been undertaken to find the most appropriate method for technology transfers by evaluating best strategies and approaches of technology transfers over the past 5-10 years. Matching and linking the best technology transfer strategies and approaches into an integrated technology transfer model is crucial. An information system is set up to support technology transfer at the central, provincial and district levels by introducing cyber extension. This cyber extension is linked to the available innovation technologies from the AARD, which is periodically updated with the recent innovations.

Information system for technology transfers starts with the establishment of a data base of site specific technologies, farmer groups, extension institutes, extension workers, and other related data and information. For a more functional information system, the decision support systems may be combined with the work of policy makers to determine the technology needed for the development of farming systems. The setting up of this information system is valuable to extension workers before they train farmers group with various innovations.

Figure 26.2. Two approaches of agriculture technology transfer in Indonesia



Incentives of technology transfer and adoption

In term of incentives of technology transfers, farmers must receive incentives as is the case in Indonesia and other agriculture based countries. Incentives must be provided by government due to the fact that farmers themselves are not able to cover the costs of new technologies and their implementation; in general, farmers are able to afford the application of only one or two technology components instead of the full package given their limited capital assets. Indeed, capital is a major problem faced by farmers in Indonesia and since not all farmers receive government incentives, other sources of funding may be provided by the private sector.

The government has provided various types of subsidies through schemes, although in many cases these schemes may not cover all actual needs. Indonesia is focusing on a programme that seeks to increase rice productivity and production and which utilises innovation technology to achieve this. Good seed quality, appropriate fertilisers and water are the most important factors of rice productivity. Farmers receive these inputs yearly from the government in order to increase their rice productivity. In terms of capital, the "PUAP" government programme provides IDR 100 million per farmer group for seed capital. Many other credit schemes are also available, such as Kredit Usaha Rakyat/KUR (community-based business credit), Kredit Ketahanan Pangan dan Energi (food security and energy-based credit), Kredit Usaha Penggemukan Sapi (cattle fattening based credit), etc. At the village level, credit is available in many rice mailing units to which farmers have access.

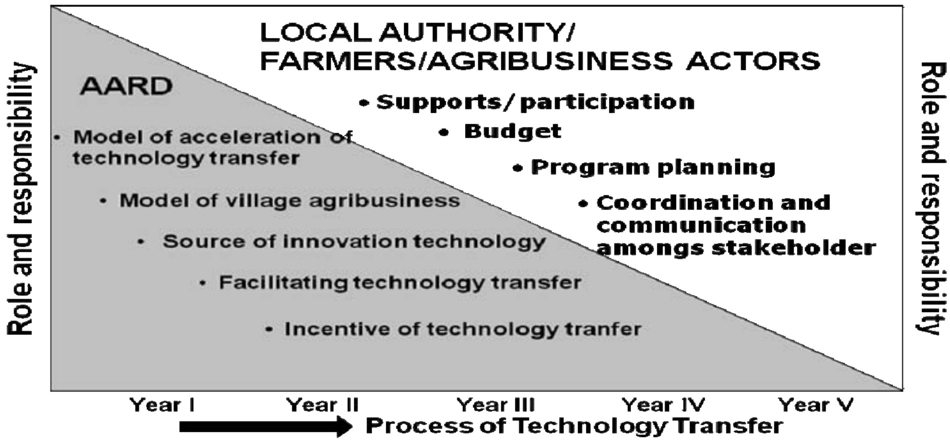
In order to promote technology transfers, a mechanism needs to be developed to encourage farm work that is based on the innovations recommended by research centres. For example, in Indonesia farmers may receive a credit if they apply a recommended innovation technology. Such a mechanism could be more widely developed to improve farming and increase benefits for farmers.

Sharing system to accelerate technology transfer

To accelerate technology transfers, a sharing system between technology producers (Agency for Agricultural Research and Development/AARD) and target users (local authorities, farmers, and agribusiness actors) has been developed. AARD provides various innovations including models of acceleration of technology transfer and of village agribusiness, innovation technologies, incentives of technology transfer, etc, while local authorities provide additional budget, co-ordinate activities, programme planning, develop regulations to implement innovation technologies and policies to adopt technology, etc. The roles and responsibilities of both parties fall at the opposite spectrum of AARD, which plays a bigger role at the beginning of the technology transfer process, while the local authority do so at the near end (Figure 26.3).

The sharing of roles and responsibilities can also be done between the producers and private sector and other technology users. Many private companies have produced fertilisers, pesticides, insecticides, agricultural machinery, etc. and need technology. Collaboration on research and technology transfer is also done between research centres and universities.

Figure 26.3. Roles and responsibilities of innovation producers and receivers in technology transfers



Concluding remarks

Agricultural technology transfer is a prerequisite for spreading the use of more appropriate farming techniques. In developing countries, technology transfer incentives are still needed to help farmers improve their farming. In Indonesia, government policy plays an important role in accelerating technology transfer. This policy must be incorporated in the planning process to develop programs and activities that promote technology transfer. Capacity strengthening must be addressed in order for farmers to understand the innovations and to increase their ability to work with these in their farming.

Part VII.

Conclusions

27. Summary of some key issues raised and implications for the policy agenda in OECD countries

David Blandford[1]

Productivity growth has been a major feature of global agriculture. In an analysis of productivity in more than 90 countries, Coelli and Rao (2005) conclude that the mean rate of growth in total factor productivity (TFP) averaged 1.02% *per annum* over the period 1980-2000, which is quite high considering that the group included a number of developing countries in which agricultural productivity growth was lagging during this period. This estimate also compares favourably with the average rate of growth in TFP of 0.96% *per annum* for the economy as a whole in 23 OECD countries over the period 1975-90 (Maudos *et al.,* 1999). Increased productivity has enabled the populations of OECD countries to have access to an expanding supply of food and agricultural raw materials. The real (inflation-adjusted) price of food has declined globally and the share of the average consumer's disposable income spent of food has fallen substantially. The increase in productivity has been made possible by a continuous supply of new technology and an improvement in knowledge and skills of farmers and others engaged in the food system. To a large extent we have come to consider rapid productivity growth in agriculture as the norm and we may have become unduly complacent about the system for research and development (R&D) and knowledge transfer that underpins this.

Recent experiences of two periods of rapidly increasing global food prices have raised questions about the ability of the food system to continue along the path of rapid gains in efficiency and providing an ample supply of food and agricultural raw materials at reasonable prices. The OECD meeting provided an opportunity to take stock of the current situation and future prospects in the Agricultural Knowledge System (AKS) in a range of countries, and the implications for future policy.

The challenge of adapting AKS to future needs in food and agriculture

The agricultural sector in OECD countries and globally is likely to face major challenges in the years ahead due to pressures on both the supply- and demand-sides of the food balance equation. The United Nations projects that by 2050 the World's population be over 9 billion, compared to roughly 7 billion currently, an increase of roughly one-third (UN, 2010). At same time, average income is likely to continue to increase. The combination of population and income growth will likely contribute to a significant increase in the demand for food. It is estimated that in order to maintain a global average food availability of 3 130 kcal per person per day by 2050 an additional billion tonnes of cereals and 200 million tonnes of meat would need to be produced annually (compared to levels in 2005/07) (Bruinsma, 2009). At the same time, the demand for agricultural raw materials will also continue to increase. The land-based industries are now being seen as a source of energy and part of the solution to the challenge of transitioning to a low-carbon economy. Growing demand for bioenergy and biomaterials will place additional pressure on agriculture and the natural resources upon which it is based.

Agriculture is likely to face increasing supply pressures. Higher output will require more intensive use of agricultural land and will generate increased demand for water, at the same time as the demand for water for non-agricultural purposes will be increasing. Climate change is also likely to have implications for agricultural output, if not for average productivity then for its variance due to an increased incidence of extreme weather events and greater climatic variability.

In the meeting, evidence of a general slowdown in the rate of productivity growth in agriculture was presented. There has been a tendency to under invest in agricultural R&D, as indicated by the very high estimated rates of return associated with such investment. At the same time, existing AKS may suffer from being locked into old paradigms based on a linear approach to productivity growth, i.e., one in which a set of providers generates new technologies which are then expected to be adopted by users. In contrast, in order to make the most effective use of the resources for R&D a more interactive approach is likely to be needed in which feedback from users guides the development of new technologies and serves to align research with emerging needs. A major challenge for AKS is in transforming **Knowledge** Systems into **Innovation** Systems. As one participant observed “R&D turns money into knowledge; innovation turns knowledge into value”. Achieving this outcome is not simply a question of developing a set of new technologies but also of developing the institutional framework within which such technologies can be deployed efficiently.

A major challenge for AKS will be securing sufficient financial resources to support R&D at the level that will be needed in the future. Public funding, in particular, is likely to be increasingly difficult to obtain. Urban constituencies and key interest groups may not be aware of the benefits of agricultural R&D, much of which can require a long-term funding commitment to come to fruition. It is becoming increasingly challenging politically to secure the resources to maintain the necessary continuity of R&D effort. One approach that is being used is “levy funding”, i.e. applying an R&D charge on the value of agricultural output rather than providing financing through general taxation. This approach can have the advantage that the costs of research are borne by its primary beneficiaries – the producers who use the research to improve their profitability, and consumers who may bear part of the costs through higher product prices in the short-term, but can expect to gain in the long-term from increased efficiency in food production. This approach is particularly relevant where the private benefits from research are high and the payoff to beneficiaries is rapid and highly visible. Support for the approach among farmers or local funders is less likely where there are large public or non-local benefits or the advantages are not immediately apparent. Systems which rely primarily on local funding for research that has significant non-local benefits may be particularly prone to “market failure” in the sense that the provision of funds for R&D will be significantly less than justified by its overall public benefits.

There are other barriers to generating adequate support for funding agricultural research. One of these is incomplete information. Farmers (and consumers or taxpayers) may have limited awareness and understanding of what innovations will be needed to address future challenges in the food system, in particular those associated with climate change. They may also be unwilling to support investment in research that aids future adaptation by agriculture to the effects of climate change because of the high uncertainty associated with that type of research.

The implication is that it will be challenging to secure the necessary funds to support the level of R&D in agriculture that will be necessary to meet the major challenges that the sector will face in the future. In the light of this, there may have to be changes to AKS in three broad areas:

- Improved effectiveness in the supply and diffusion of new technology within existing structures.
- Changes in institutional design and operations.
- A change in the balance between public and private sector activities.

Improving the effectiveness of existing AKS

Shared experiences at the meeting revealed a range of new approaches and innovations that are being introduced to increase the effectiveness of existing AKS. Just a few examples are provided here. They include increased private sector involvement to leverage public resources (e.g. in Australia and New Zealand) through such mechanisms as the provision of matching funds for agricultural R&D; the reorientation of public resources for R&D to areas with particularly strong public good elements; and system rationalisation, for example, the creation of centres of excellence to concentrate available R&D competency, and the expansion of international collaboration to exploit synergies. Some emerging economies (e.g. Brazil, China and India) are managing to maintain a high profile for agricultural R&D and have made significant advances in exploiting new production and information technologies in order to improve productivity. However, major resource challenges persist for the AKS in many developing countries, particularly those in sub-Saharan Africa, because of the lack of financial and human capital (particularly that needed to support an effective research base).

Changing institutional design/operation

A second approach to increasing the effectiveness of AKS is to modify the way these are designed or how they operate. One important area is strengthening the role of farmers and the private sector in the development and implementation of new technologies. Several cases were identified where this has been important. For example, the development of no-till crop production methods involved considerable farmer participation and the same could apply to the adaptation of crop and livestock production systems to climate change. Similarly, the food industry could play an important role in the future development of energy-saving technologies and the production of energy from "waste" products. Rather than the current linear structure that tends to characterize many AKS, the challenge is to create learning and innovation networks in which there is continuous interaction between farmers, the food and agricultural industry, and research and extension professionals in the development and application of new technologies.

Networking can play a vital role in leveraging scarce resources that support innovation in the food and agricultural system. The expanded use of public-private and international research partnerships can be used to economize on resources and increase system effectiveness. A range of other methods, for example, greater use of performance evaluation in AKS, competitive grants for research and diffusion activities, and the development of research/higher education clusters (centres of excellence) can help to make more efficient use of available AKS resources, and create stronger networks by strengthening the link between research and its application. However, as one participant observed "we don't have the luxury of constantly stopping and sitting back to do strategic thinking and to reorient our activities… we need to adopt a continuous and on-going process of adaptation and reorientation".

Altering the balance between public and private sector activities

With increasing demands upon scarce public resources in many countries, it is inevitable that the balance between public and private activities in AKS will have to change in the future. If the private sector is to play a larger role in AKS incentives must exist for it to generate, develop, and diffuse new technologies. In other words there must profit opportunities. One of the key issues for the private sector is the protection of Intellectual Property Rights (IPRs) since the ability to control the deployment and use of new technologies is essential if these are to yield a return to private investment in R&D.

The protection of IPRs can be a controversial issue, particularly in the provision of essentials to human existence, such as food. The public may not understand the benefits of private sector involvement in improving the ability of the sector to meet food needs. Emotive arguments can be involved if access to food is viewed to be a right. The principle of generating private returns from new technologies that enhance the supply of food may be viewed to be morally unacceptable if some individuals do not have enough to eat. In addition to ethical considerations, extended periods of protection of IPRs for innovations that have a large public good element may be difficult to justify. Nevertheless, the incentive for innovation by the private sector can be reduced substantially if some measure of protection for IPRs is not provided.

Some new technologies may be viewed to be risky, for example on health or environmental grounds. The assessment of risk can be challenging and controversial. Most countries provide regulatory oversight for the diffusion of new technologies that may involve an element of risk. An important issue is how much regulation is needed and what criteria to apply so that the public is adequately protected but the process of innovation is not retarded.

In terms of meeting the needs for new technologies, institutional inertia may be a significant barrier to progress in AKS. Current structures may not be well-suited to supporting the enablers of change ("innovation brokers") in the food and agricultural system. These enablers can involve a wide range of actors, including, farmers and their organisations, food processors and retailers, non-governmental organisations, educational institutions and public agencies. The range of potential contributors to the process of innovation suggests that broad sectoral involvement (not just by farmers) may be critical, but the challenge is how to secure this. Existing sectoral networks can act as either a facilitator or a barrier to change, and new networks may need to be created, particularly if an effective two-way flow of information between the developers and users of new technologies is to be fostered. Often it is simpler and cheaper for an AKS to focus on the development of standard technology packages but "one size fits all" approaches may not work. On the other hand, it can be challenging to develop customised alternatives without these being prohibitively expensive. What is clear is that the creation of effective innovation systems may require a range of difficult issues to be addressed, for example, improving the quality of human capital and the physical infrastructure that allow the benefits of new innovations to be realised by farmers and food consumers.

Policy coherence, innovation and AKS

The development and application of new technologies in agriculture and the food system in OECD countries takes place within the context of a set of existing agricultural policies that are broader in scope than those that focus explicitly on AKS. Despite some reduction in the overall level of financial support for agriculture, in many OECD countries the traditional emphasis on providing price and income support for farmers remains important. The provisional estimate for total transfers to OECD agriculture for 2009 was USD 252 billion, equivalent to 22% of the farm-level value of output. An estimated 46% of the total was provided through market price support. In contrast, public expenditure for agricultural research and development was roughly 3% of the value of total transfers. There are questions about whether even this relatively modest public investment in R&D can be maintained given budgetary pressures and in the light of resource pressures what the focus of the R&D effort should be in the future.

In recent years, some OECD countries have tended broaden the focus of policies for agriculture to address a wide range of issues and objectives, such as environmental quality and the protection of natural resources or rural development. These will continue to be important, but there are questions as to whether the growing pressure on agriculture to meet the growing demand for food, fibre and energy and to supply food at reasonable prices requires some rebalancing of emphasis to increase the priority on productivity enhancement and resilience in the sector, particularly in the face of projected changes in global climate. A key issue is whether it will be possible to reconcile the pressure for agriculture to perform a broad range of functions with the need for higher productivity and environmental sustainability. There will be a need for policy coherence for the sector, so that the policies employed do not work at cross-purposes in seeking to achieve multiple goals. Coherence will be needed both nationally and internationally, particularly in an economic environment in which public resources are likely to be increasingly constrained. It will be a considerable challenge to meet the needs for funding AKS given the many demands on public resources. The sentiment expressed by one of the participants in the conference seems to sum up the feelings of many: “We can’t afford to wait to change things in AKS… time is running out… we need to act now!”

Notes

1. Pennsylvania State University, University Park, PA 16802, United States, Email: dblandford@psu.edu.

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28. Implications for OECD work

Frank van Tongeren, OECD[1]

This meeting has demonstrated a wide diversity in approaches to AKS, with each responding to different agro-economic, social and institutional challenges, and each with a different history. Most strikingly, all of these approaches are currently in development. The question going forward is whether these developments will successfully address the challenges we have identified at this conference — namely, those arising at the nexus of food security and climate change.

Some speakers have emphasised public approaches, while some have emphasised private; some have focused on biotechnology, while others have concentrated on co-development and networks, and the shift from R&D to innovation.

The landscape may be multi-faceted, but there are several areas in which the OECD can provide support. Discussion of future OECD work is still very preliminary at this point, and demands further discussion, but we have identified three primary areas in which we can focus our work: benchmarking; policy advice; and networking.

Benchmarking

Benchmarking, supported by information and data, is one of the OECD's strengths. Measurement of AKS must be multi-dimensional. There has already been significant work devoted to characterising what goes into the system (R&D, etc.), but few have measured the output and results of these systems. We also need to measure the institutional features of each AKS. More measurement, along with stronger system benchmarking across countries would be a fruitful area for us to explore. We have already sent out a questionnaire in the context of ongoing work on innovation systems in agriculture to address this.

In this benchmarking exercise, we must not focus exclusively on R&D and innovation policies related to agriculture. We would also like to include an assessment of other policies that affect agriculture, since some of those policies may be more conducive to innovation than others. During this event, we have heard only one presentation that focused on such a broad approach to agricultural development.

Policy advice

The OECD has always played an active role in providing policy advice. As we have learned from this conference, there is probably not a one-size-fits all solution. Rather, the solution will likely be more multi-faceted. Finding a solution will demand more work, in order to define appropriate frameworks for analysis. This work would allow us to identify the appropriate boundary between private and public sectors, while constructing appropriate incentives for private actors to address the global commons issues that have been identified during this conference.

Such a broad approach should also encompass a well-balanced system of intellectual property rights protection (IPR). We have had significant discussions of IPR during this conference, but we only addressed the breadth of the protection, rather than the duration (depths) of the protection.

The beauty of R&D- and innovation-centric policies is that they are “no regret” policies. Underpinning them is a fundamental paradox: high return, coupled with underinvestment. Trying to understand and model that paradox could help shape future policies.

Networking

As this event has demonstrated, the OECD has a very useful role to play in networking, and in the development of strategic intelligence. Going forward, we must explore opportunities to leverage these kinds of events to provide a platform for strategic thinking. We are already conducting work on long-term scenarios in the agro-food system, which could also be a part of this endeavour. With more than 40 countries regularly attending our meetings, we can reach out to policymakers, while mobilizing people and resources. Network facilitation is an area that could be explored much more, and one that merits further work, considering the lack of exchange and the wide diversity in approaches to AKS.

Note

1. Head of the Trade and Agricultural Policy Division (PTA), Trade and Agricultural Directorate, OECD, Paris, France.

Annex A.

Agenda of the OECD Conference on Agricultural Knowledge Systems: Responding to global food security and climate change challenges

<table>
<tr><th colspan="2">Wednesday 15 June 2011</th></tr>
<tr><td>9:30-9:45</td><td>Session 1. Context and purpose of the Conference</td></tr>
<tr><td></td><td>Introductory speech by Mr. Ken Ash, Director of Trade and Agriculture (TAD), OECD

Welcome
Purpose of the Conference: Explore how to foster the development and adoption of innovation at national and global level in order to meet global food security and climate change challenges. The conference will look at developments in AKS institutions and relationships between the different components at national and international level, discuss whether they are functioning and are responsive to emerging issues. It will review incentives and disincentives to both public and private activities in the AKS, and will look at policy coherence and best practices.
Background questions: What are the global challenges related to food security and climate change? What is expected from AKS? What technological and organisational solutions are available or being developed? How can they contribute to meeting those global challenges?
Outline of the Conference: Description of the various components of AKS, their relationships and their functioning; Are they responsive to new challenges (Session 2)? What can be done to improve the situation (Session 3)? How do they respond to broader policy objectives? (Session 4)
Context of the Conference: The OECD has organised two AKS meetings in the past; A recent OECD Symposium identified a number of challenges for the food and agricultural sector; The Ministerial Communiqué outlined the importance of innovation to tackle food security and climate change issues, The outcomes of the Conference will provide valuable inputs into the OECD project on innovation systems in the Programme of Work and Budget of the Committee for agriculture for 2011-12; The Conference will be one of the events organised to celebrate the 50^{th} Anniversary of the Committee for agriculture; There are a number of links with recent or on-going OECD work in TAD and other Directorates and elsewhere. The Conference is organised in collaboration with the OECD Co-operative Research Project (CRP).

Presentation of the OECD Co-operative Research Project by Dr. Leena Finér, Finnish Forest Research Institute, CRP theme co-ordinator.</td></tr>
</table>

9:45-13:00	**Session 2. How well do AKS respond to new challenges?**
	Chair: Mr. Yvon Martel, Chief Scientist, Agriculture and Agri-Food Canada ***Questions*** • **How do AKS function?** How are they organised? What are the relationships between the different components: education, R&D and extension; private and public sectors, agricultural production and other food chain elements; national/international? Who does what? How do national and international institutions and the public and private sectors (research, education, extension) work together? How have they evolved to respond to new challenges in the past? • **How do they respond to new challenges?** How are priorities defined and implemented? How well do AKS react to new challenges? Do they provide the innovations needed on time? Are technologies adapted and accessible to those who need it? What incentives work? What disincentives do they face? Can we identify best AKS practices? ***Keynote speakers*** • Global and US trends in agricultural R&D in a global food security setting, *Pr. Julian Alston, UC Davis, United States* • Agriculture knowledge and innovation systems in transition - Findings from the EU SCAR Collaborative Working Group on AKIS, *Mr. Krijn Poppe, Chief Science Officer at Ministry of Economic Affairs, Agriculture and Innovation, the Netherlands* • Australia's approach to rural research, development and extension*, Mr. Allen Grant, Executive manager, Agricultural Productivity Division, Department of Agriculture, Fisheries and Forestry (DAFF), Australia* • China's Agricultural Innovation System: Issues and Reform, *Pr. Ruifa Hu, School of Management and Economics, Beijing Institute of Technology, and Jikun Huang, Center for Chinese Agricultural Policy, Chinese Academy of Sciences, China* • Agricultural R&D in Africa: Investment, human capacity, and policy constraints, *Mr. Gert-Jan Stads, program coordinator of the Agricultural Science & Technology Indicators (ASTI) initiative at the Rome office of the International Food Policy Research Institute (IFPRI)* ***Discussant:*** Ms. Leticia Deschamps, Inter-American Institute for Cooperation on Agriculture (IICA) ***General discussion***
	Session 3. Improving the responsiveness of AKS
	Theme: How can the functioning of AKS, the coherence between the different components and the responsiveness of the whole system to food security and climate change challenges be improved? What kind of national and international, private and public institutions, regulatory framework, and incentive/disincentive structures can facilitate the development of adapted solutions and their adoption by producers and consumers? What specific role for governments and international organisations? A range of issues are discussed in successive sub-sessions.

14:30-18:00	**Session 3.A. Institutional Framework**
	Chair: Pr. James Fraser Muir, International development and research advisor and evaluator, Professor Emeritus, University of Stirling, Scotland, United Kingdom ***Questions*** How to strengthen linkages between components and dimensions of AKS (education, R&D, extension; public, private and other institutional sectors; national/regional/ international levels, along the food chain; technological/institutional and marketing innovations)? And improve coherence in the whole system? ***Keynote speakers*** • Experience with CGIAR reorganisation, *Mr. Lloyd Le Page, Chief Executive Officer of the Consultative Group on International Agricultural Research (CGIAR)* • Institutional reforms of AKS in New Zealand and International Networks in AKS, *Ms. Karla Falloon, Counsellor (Science and Technology), New Zealand Ministry of Science and Innovation, New Zealand Mission to the European Union, Brussels* • Innovative institutional approaches for agricultural knowledge system management in India, *Dr. V. Venkatasubramanian, Assistant Director General in Indian Council of Agricultural Research (ICAR), New Delhi, India* • Transmission of agricultural knowledge: from agricultural extension to «Internet platforms, *Mr. José Abellán Gómez, Deputy General Citizen Information, Documentation and Publications, Ministry of Environment and Rural and Marine Affairs, and Mr. Jaume Sió Torres, Deputy-Director of Rural Innovation within the Agriculture, Livestock, Fisheries, Food and Natural Environment Department of the Catalan Regional Government, Spain* • Responses of the French AKS to new challenges, *Dr. Pascal Bergeret, DGER, MAAPRAT, France* ***General discussion***
Thursday 16 June 2011	
9:30-11:00	**Session 3.B. Public/private roles**
	Chair: Mrs. Eva Blanco Medio, Agricultural Counsellor, Permanent Delegation of Spain to the OECD ***Questions*** What role for private and public sector in education, R&D and extension? What defines the boundaries: market failures, public goods? How to strengthen complementarities ***between*** private and public sector? ***Keynote speakers*** • IPRs and the role public and levy funded research: Some Lessons from International Experience, *Pr. Richard Gray, University of Saskatchewan, Canada* • Public/ Private roles, *Mr. Phil O'Reilly, CEO of BusinessNZ, New Zealand* • Partnerships in Agricultural Innovation Systems: Who puts them together? And what comes next?, *Dr. Andy Hall, UNU-MERIT, Netherlands* ***Discussant:*** Dr. Laurens Klerkx, Communication and Innovation Studies Group, Wageningen University, The Netherlands ***General discussion***

<table>
<tr><td>11:30-13:00</td><td>Session 3.C. Regulatory framework conducive to innovation</td></tr>
<tr><td></td><td>Chair: Dr. Nordine Cheikh, Director, Regulatory Sciences, Monsanto Company
Question
What are best practices regarding regulations about Intellectual Property Rights (IPR) and authorisation of innovations?
Keynote speakers
• EU system for health and consumer protection, Mr. Niall Gerlitz, EU Commission, Directorate General for Health and Consumer Policy
• The US approach for fostering new biological technologies and assuring their safety, Dr. Michael Schechtman, Agricultural Research Service, US Department of Agriculture, United States
• “Breeding Business”: Plant Breeder’s Rights and Patent Rights in the Plant Breeding Business, Mr. Hans Dons, Management Studies Group, Wageningen University, The Netherlands
Discussant: Mr. Dominic Muyldermans, Senior Legal Consultant to CropLife International
General discussion</td></tr>
<tr><td>14:30-18:00</td><td>Session 3.D. Facilitating adoption of innovations and technology transfers</td></tr>
<tr><td></td><td>Chair: Ms. Eija Pehu, World Bank
Questions
How to encourage innovations that are needed? How to facilitate adaptation and adoption? How to reduce the gap between demand and needs?
Keynote speakers
• Participatory plant breeding: A successful example of local technology innovation and adoption by combining knowledge of traditional farmers and modern scientists, Dr Masa Iwanaga, President, Japan International Research Center for Agricultural Sciences (JIRCAS)
• Experience with biotech crops in South Africa, Mr. Jaco Minnaar, South Africa
• Latin America. Public Agricultural Advisory Services, Mr. Matthew McMahon, consultant
• Agricultural innovation and challenges in promotion of knowledge and information flows in agrifood systems in Brazil, Dr. Maurício Antônio Lopes, R&D Executive Director, EMBRAPA, Brazil
Discussants
• Mr. John Preissing, Senior Officer for Extension systems at the Research and Extension branch of FAO (OEKR)
• Mr. Thomas Schäfer, Senior Director, Innovation Office, Novozymes
General discussion</td></tr>
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<table>
<tr><th colspan="2">Friday 17 June 2011</th></tr>
<tr><td>10:00-12:30</td><td>Session 4. Responding to broader policy objectives</td></tr>
<tr><td></td><td>Questions
How to improve the coherence of AKS with broader policy objectives? What incentives need to be put in place and disincentives removed?
Recap of some issues raised in the meeting and the policy Agenda for OECD countries: Pr. David Blandford, The Pennsylvania State University, United States
Panel discussion including high level government officials and representatives of R&D systems, including implications for the role and functioning of AKS in OECD and selected non-OECD countries.
Panel members
• Mr. Pascal Bergeret, DGER, MAAPRAT, France
• Pr. Herman Eijsackers, Wageningen University, Netherlands
• Dr. Pierre Bascou, DG-AGRI, EU Commission
• Dr. Masa Iwanaga, President, JIRCAS, Japan
• Pr. Roger N. Beachy, President Emeritus, Donald Danforth Plant Science Center, and Prof. Department of Biology, Washington University, St. Louis, MO; Former Director National Institute of Food and Agriculture, US Department of Agriculture, United States
• Dr. Kasdi Subagyono, Director Indonesian Center for Agricultural Technology Assessment and Development (ICATAD), Indonesia
• Mr. Christophe Terrain, farmer, FNSEA administrator and president of ARVALIS, crop institute, France
General discussion</td></tr>
<tr><td>12:30-13:00</td><td>Concluding remarks by OECD
• Implications for OECD work</td></tr>
</table>

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Improving Agricultural Knowledge and Innovation Systems

OECD CONFERENCE PROCEEDINGS

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