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INTERNATIONAL TECHNOLOGY COLLABORATION AND CLIMATE CHANGE MITIGATION

CASE STUDY 2: COOPERATION IN AGRICULTURE: R&D ON HIGH-YIELDING CROP VARIETIES

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FOREWORD

This document was prepared by the OECD and IEA Secretariats in October 2004 at the request of the Annex I Expert Group on the United Nations Framework Convention on Climate Change. The Annex I Expert Group oversees development of analytical papers for the purpose of providing useful and timely input to the climate change negotiations. These papers may also be useful to national policy makers and other decision-makers. In a collaborative effort, authors work with the Annex I Expert Group to develop these papers. However, the papers do not necessarily represent the views of the OECD or the IEA, nor are they intended to prejudge the views of countries participating in the Annex I Expert Group. Rather, they are Secretariat information papers intended to inform Member countries, as well as the UNFCCC audience.

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Executive Summary

This case study's aim is to review experience in international collaboration in the field of agriculture research and development (R&D) in order to identify lessons that may be relevant for climate-friendly technology collaboration. To this end, it traces the role of international collaboration in researching, developing and diffusing seeds of high-yielding varieties (HYV) to the world's farmers. This is done by looking mainly at the Consultative Group on International Agricultural Research (CGIAR). The main question this paper addresses is: *What are the lessons learned from international collaboration in the field of agriculture that could inform collaboration for climate-friendly technology?*

To examine this question, the paper differentiates between two incentive structures for collaborative R&D on HYV. First it looks at the regime that ignited and sustained the Green Revolution in the 1970s and 1980s. This innovation system linked international research institutes and aid agencies to local and national governments, research institutes and universities. It therefore embodies two complementary dimensions of international technology collaboration: one is largely between developed countries and concentrates on agricultural research, and the other is mainly between developed and developing countries and focuses mainly on technology transfer and development. The second incentive structure can be seen in the current evolution of the agricultural R&D innovation system, characterised perhaps most markedly by a greater involvement of – and increased interactions between – public, private and civil society actors, as well as evolving laws and policies affecting the ownership and use of genetic material.

There are three main implications of this shift in incentives guiding crop variety R&D on international collaboration. First, the CGIAR's R&D mandate is becoming more diffuse, ambitious and less consensual as a result of a) the increasing number of actors, interests, and viewpoints, and b) the diverging needs of developing countries from international R&D. Second, the pattern of financial support to the CGIAR is becoming increasingly restricted to specific projects, programmes and research centres, which renders difficult the achievement of long-term strategies in line with the needs of developing country farmers. Third, the greater involvement of private firms poses a number of challenges to existing collaborative arrangements and requires public institutions to a) improve their understanding and skills in managing and negotiating intellectual property, and b) establish a regulatory environment suitable for private investments in agricultural R&D.

A number of lessons can be drawn both from the experience in international collaboration that enabled the Green Revolution and from how existing collaborative arrangements adapt to the changing incentive structure. Four lessons can be drawn for climate-friendly technology collaboration:

1. International collaboration on technology R&D may draw benefits from strong links between international R&D and national and local dissemination systems.

2. International technology R&D collaboration can best achieve its full potential where there is a minimum absorptive capacity in place. For low capacity parties, collaboration may best be facilitated by focusing on building capacity.

3. Striking a balance between nurturing scientific and technological excellence while taking into account complex social and environmental problems is challenging for technological R&D collaborative arrangements. Parties need to find ways to remain focused, while accommodating an increasing number of stakeholder viewpoints.

4. International collaboration can play a key role in helping countries to harness the private sector's financial potential for conducting R&D activities and to disseminate new technologies.

1. Introduction

Mitigating climate change and achieving stabilisation of greenhouse gas atmospheric concentrations – the objective of the United Nations Framework Convention on Climate Change (UNFCCC) – will require deep reductions in global emissions of energy-related CO_2 emissions. Developing and disseminating new, low-carbon energy technology will thus be needed. Two previous AIXG papers have focused on possible drivers for such a profound technological change: Technology Innovation, Development and Diffusion, released in June 2003, and International Energy Technology Collaboration and Climate Change Mitigation, released in June 2004.

The first of these papers (Philibert 2003) assesses a broad range of technical options for reducing energy-related CO_2 emissions. It examines how technologies evolve and the role of research and development (R&D) efforts, alternative policies, and short-term investment decisions in making long-term options available. It considers various policy tools that may induce technological change, some very specific (e.g. R&D subsidies), and others with broader expected effects (e.g. taxes or cap-and-trade systems). Its overall conclusion is that policies specifically designed to promote technical change, or "technology push", could play a critical role in making available and affordable new energy technologies. However, such policies would not be sufficient to achieve the Convention's objective in the absence of broader policies. First, because there is a large potential for cuts that could be achieved in the short run with existing technologies; and second, the development of new technologies requires a market pull as much as a technology push.

The second paper (Philibert 2004) considers the potential advantages and disadvantages of international energy technology collaboration and transfer for promoting technological change. Advantages of collaboration may consist of lowering R&D costs and stimulating other countries to invest in R&D; disadvantages may include free-riders and the inefficiency of reaching agreement between many actors. This paper sets the context for further discussion on the role of international collaboration by describing the globalisation of the economy and current efforts of technology collaboration and transfer. Finally it considers various ways to strengthen international energy technology collaboration.

This paper is one of half-a-dozen case studies to provide practical insights on the role international technology collaboration can play to achieve the objectives of the UNFCCC. They will all consider the past achievements of international technology collaboration, and the role it could play in helping to develop and disseminate new technologies in the future: what worked, what did not work and why, and what lessons might be drawn from past experiences.

Most of these case studies consider energy technologies that could help mitigate greenhouse gas emissions. A few others deal with areas not directly related to greenhouse gas emissions, but where international technology collaboration has proven particularly successful.

1.1 A case study on R&D on high-yielding crop varieties

This case study's aim is to review experience in international collaboration in the field of agriculture research and development (R&D) in order to identify lessons that may be relevant for climate-friendly technology collaboration. It traces the role of international collaboration in research, development and diffusion of high-yield seed varieties (HYV)[1] to the world's farmers. The main question this paper addresses is: What are the lessons from international collaboration in the field of agriculture that could inform collaboration for climate-relevant technology?

[1] Seeds of high-yielding varieties (HYV) are early maturing crop types that produce a significantly higher yield under intensive agricultural practices, i.e. applying chemical fertilisers, improving irrigation, etc., than conventional types.

The rationale for looking at HYV is two-fold. The first reason is that technologies relevant for climate change and HYV are similar in some respects. First, they aim to tackle global issues - enhancing agricultural productivity in the case of HYV – with multiple causes, scales and actors. Second, the technologies are not commercially viable – at least not in all economies – due to their 'public good'[2] aspects and could benefit from a technology push from public institutions to facilitate their deployment. For this reason, this paper focuses on the role of international collaboration to provide the technology push. Third, technologies in both areas are today developed and disseminated in similar political economy environments.

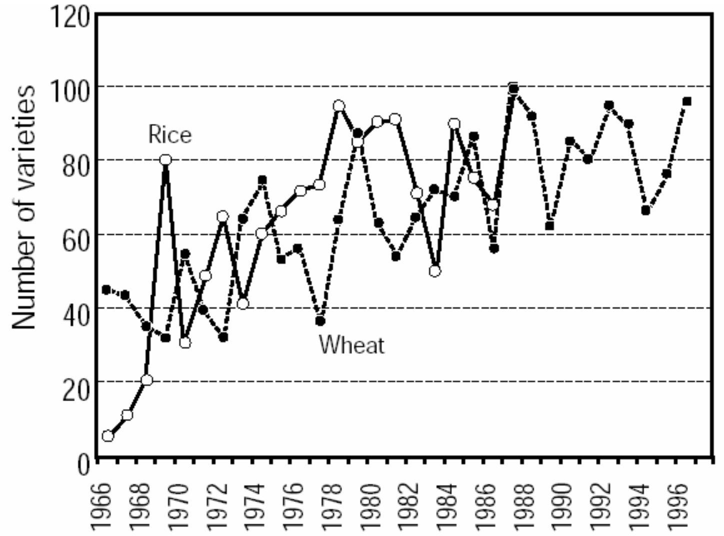
The applicability of these lessons to climate-friendly technologies, however, may be limited by a number of characteristics that appear to be more prominent in crop variety R&D, namely: a) most crop variety R&D needs to be more sensitive to local conditions and is therefore a more location-specific activity than most climate-friendly technology R&D; b) the transfer of HYV is to a very diffuse set of actors, as compared with most climate-relevant technologies, with some exceptions e.g. energy efficiency and transport technologies; and c) HYV directly benefits the users, whereas technologies to mitigate greenhouse gas emissions provide direct benefits to the population as a whole rather than to users. Yet, some of these conditions may be similar to those of decentralised renewable energy, energy efficiency, transport and agriculture technologies.

The second reason for examining HYV is that international collaboration has played a pivotal role in agricultural technology transfer. In fact, in comparison to past and current R&D collaborative efforts in climate-relevant technologies, R&D and technology transfer in agriculture relies on a much more extensive global network of institutions that has been in place for many decades. In the past 40 years, international collaboration efforts led to the development of a system of national and international agricultural research centres linked to local farming systems. These collaborative initiatives in the 1960s and 1970s revolutionised the supply and diffusion of improved cereal varieties and resulted in the Green Revolution. The Green Revolution, characterised by considerable increases in production and productivity of basic cereal in developing countries (Parayil 2003), has often been held up as a notable example of what imaginative and committed investors and policy-makers can achieve by collaborating for the benefit of global interests (Conway 1998). Lipton and Longhurst (1989: 1, in Reece and Sumberg 2003) argue that "History records no increase in food production that was remotely comparable in scale, speed, spread, and duration" to those experienced during the Green Revolution.

Increases in wheat and rice yields in developing countries over the 1970s and 1980s clearly illustrate both the speed and duration of the Green Revolution: they rose by 3.4% and 2% per year respectively (CIMMYT 1996 and Pingali and Heisey 1996, in Traxler and Pingali 1999) (see Figure 1). While it remains unclear how much of the observed productivity increase can be attributed to the activities of international agricultural research centres (IARCs), it can be said that the increased productivity is the result of joint activities between national and international entities (Gardner 2003). For instance, more than 40% of the total wheat varieties made available in developing countries in the 1960s to 1980s result directly from the collaboration between the International Maize and Wheat Improvement Centre (CIMMYT) and those countries (Byerlee and Moya 1993, in Maredia and Eicher 1995).

[2] Public goods are characterized by "non-rivalry" – i.e. the consumption by some does not diminish the consumption by others and "non-excludability", i.e. no one can be prevented from enjoying the benefits of the good (in this case, food security and related benefits, and global reductions of greenhouse gas emission). Economic theory shows that public goods are undersupplied by free markets.

Figure 1. Total number of wheat and rice varieties released in the developing world



Source: Traxler and Pingali, 1999.

However, these success stories do not hold for all developing countries and regions, and brought about a series of other serious issues – perhaps most notably distributional and environmental problems (Conway and Pretty 1991, Bull 1982, Shiva 1991, Kerr and Kolavalli 1999). This was largely due to the fact that the R&D endeavours during the Green Revolution were guided by the modernisation paradigm,[3] which promoted the infusion of new technologies as the engine of economic development in the 1950s, 1960s and 1970s (Parayil 2003). For the purpose of this paper, international collaboration in HYV R&D can be considered successful in that it met its supporters' narrowly-defined objective, namely to enhance agricultural productivity by the transfer of improved crop varieties. Yet, of particular relevance for this discussion, are the challenges facing existing collaborative arrangements in addressing such environmental and developmental issues that were previously neglected.

This paper is structured as follows. It first takes a historical look at the drivers of international collaboration that ignited and sustained the Green Revolution, focussing on collaborative R&D in high-yielding crop varieties. This is done by looking at the Consultative Group on International Agricultural Research (CGIAR),[4] a global institution overseeing fifteen International Agricultural Research Centres (IARCs). The second section explores the new set of incentives guiding crop variety R&D and their meaning for public actors and the private sector – defined here as the business community – and discusses the implications for the CGIAR's operations and effectiveness. The final section highlights four lessons that may be relevant for future collaboration to promote climate-friendly technologies.

[3] The modernisation paradigm refers to the idea that the development of the "latecomers" could best be stimulated by the development and transfer of modern technologies (Leys 1996).

[4] The case study focuses on the CGIAR, despite the existence and significant contribution to crop variety R&D of numerous other, mostly bilateral, collaborative agricultural R&D initiatives (for examples, see Tribe 1994: 124).

2. History and success of collaboration in R&D on high-yielding crop varieties

2.1 Background on technology transfer in agriculture

It is important at the outset to clarify a number of terms and concepts used throughout the paper. This paper means by ‘technology transfer’ a concept similar to that used by the Intergovernmental Panel on Climate Change (IPCC) (2002: 55):

> Technology transfer is defined as the broad set of processes covering the flows of know-how, experience and equipment for mitigating and adapting to climate change amongst different stakeholders such as governments, private sector entities, financial institutions, non-governmental organisations (NGOs) and research/education institutions. The broad and inclusive term “transfer” encompasses diffusion of technologies and technology cooperation across and within countries. It comprises the process of learning to understand, utilise and replicate the technology, including the capacity to choose it and adapt it to local conditions.

However, recognising that technology transfer occurs between all countries – and even more between developed countries (IPCC 2002), this paper specifically focuses on transfers from developed to developing countries. Climate-friendly technologies can contribute to alleviating climate change no matter where they are used. In contrast, improved crop varieties address a global issue, namely food security, but for the objective of the technology transfer to be met, the technologies have to be transferred to countries where agricultural productivity is insufficient, i.e. developing countries.

Technology transfer encompasses three activities: research, development and diffusion (see Figure 2).

Agricultural technology research includes basic, applied and adaptive research conducted through pre-breeding and crossing programmes to develop new improved germplasm[5] (genetic material) or new seed varieties. Screening programmes are also important to evaluate the suitability of varieties developed elsewhere for use in various agro-ecological and production conditions and to enhance the performance of adaptive research.

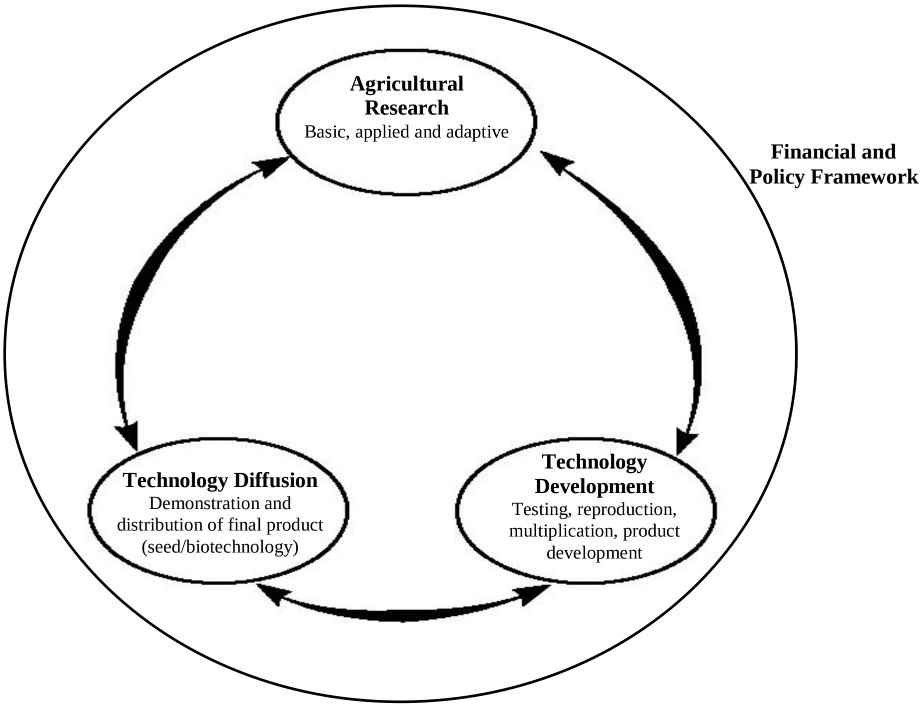
Agricultural technology development encompasses the activities which translate the results of agricultural research into tangible technology products, such as new seeds of high-yielding varieties or biotechnology. These may include processes such as field testing of new seeds, as well as seed development and reproduction.

Agricultural technology diffusion refers to the demonstration and distribution of final products to farmers.

Figure 2 shows the inter-linkages between these activities. In principle, close interactions between research and farming communities are necessary as they enhance the research products ability to respond to farmers needs. These activities and interactions occur within various international and national financial and policy frameworks.

[5] Germplasm is, within an individual or group, the collective hereditary material that is the physical basis for inheritance.

Figure 2. An innovation system in agriculture and the stages of technology transfer



Source: Adapted from Brenner, 1997.

2.2 History of international collaboration initiatives in agriculture

The performance of international collaboration in agriculture can best be understood from a historical perspective. Although colonial ties provided some links between agricultural scientists in the North and South, prior to WWII limited collaboration existed (Eicher and Rukuni 2003; Hall et al. 2000). Colonial agricultural research was mostly geared towards boosting the production of exportable cash crops.

In the mid-1940s, growing international concerns related to inadequate food supplies in developing countries were thought to be the result of inadequate levels of funding of national agricultural R&D, which in turn mobilised the donor community behind the objective of strengthening international collaboration in agricultural R&D and technology transfer (Hall et al. 2000; Parayil 2003; Falcon 2001). The main outcome was the creation of an international agricultural innovation system to backstop national efforts in developing countries by enhancing agricultural R&D efforts and sharing improved crop varieties.

The ensuing international R&D endeavours moulded the innovation system that ignited the Green Revolution. The emerging regime followed a “global-local innovation system” that linked international research institutes and aid agencies to local and national governments, research institutes and universities (Parayil 2003: 986). At the global level, countries collaborated in establishing a network of international agricultural research centres (IARCs) mainly conducting *research* to improve and create new germplasm from which to *develop* seeds (see figure 2). At the national level, developing countries’ national agricultural research systems (NARSs), composed mostly of local and national governments, research institutes and universities, conducted *research* to adapt the germplasm made publicly-available by IARCs to local agro-ecological conditions, *developed* new seeds, and *distributed* them to farmers (see figure 2).

This innovation system embodies two dimensions of international technology collaboration: One is largely between developed countries and concentrates on agricultural research and the other is mainly between developed and developing countries and focuses on technology diffusion. The activities of IARCs and NARSs were clearly complementary and overlapped in some instances. Prior to examining in more detail the incentive structure that fostered such levels of collaboration, it is worth exploring in more detail the IARCs and NARSs and their respective roles.

2.2.1 The CGIAR and its International Agricultural Research Centres (IARCs)

The CGIAR is the umbrella organisation for fifteen IARCs, twelve of which are situated in developing countries. It was founded in 1971 with the objective of boosting agricultural productivity in developing countries through new technology generation and diffusion (See Box 1). It gave the highest priority to the research in HYV of the food staples grown in developing countries, particularly cereals.

The creation of the CGIAR was inspired by the early successes of two international research centres - the International Rice Research Institute (IRRI), established in The Philippines in 1960, and the International Maize and Wheat Improvement Center (CIMMYT) set up in Mexico in 1967. These became a model for subsequent collaboration programmes which led to the rapid expansion of the CGIAR and the creation of other IARCs focussing on other crops.

The number of CGIAR's centres and staff expanded rapidly in a first wave in the 1970s and a second wave in the early 1990s (Tribe 1994). Between 1970 and 1990, CGIAR grew from four to eighteen IARCs – fifteen today – and its annual budget to some US$ 381 million in 2003 (CGIAR 2004). This compares to US$ 15 million in 1970 and US$ 142 million in 1980, a tenfold increase over the decade (Alston et al. 1998a).

The CGIAR relies on voluntary contributions from its members. These include developed and developing countries, foundations, and international and regional organisations. At its inception, private philanthropic foundations – mainly the Ford and Rockefeller Foundations - provided more than 50% of CGIAR funding, with the rest coming from bilateral and multilateral aid agencies (Alston et al. 1998a). Its sponsorship has since shifted away from private charities; the CGIAR now receives two-thirds of its financial support from member countries of the Development Assistance Committee of the OECD and a number of international organisations act as co-sponsors (see Box 1).

Developed countries – through national and multinational aid agencies - are now by far the main financial supporters (98%) of the CGIAR. The rest (2%) comes from a small group of developing countries (Alston et al. 1998a), although some in-kind contributions from developing countries are not included in these estimates.

CGIAR's main role in the HYV innovation system is agricultural research to generate new improved germplasm which are to be transferred to developing countries. For example, varieties of rice developed at IRRI were based on genetic materials from China, Indonesia and Taiwan (Binswanger and Ruttan 1978, in Parayil 2003) and successfully introduced in several developing countries in the 1960s. Beyond this research work, a central task of IARCs is the administration of multiple germplasm nurseries for them to be available for adaptive research or to be directly transformed into seeds.

The uniqueness of the CGIAR stems from its original structure: a loose cooperative arrangement without a legal identity, no formal constitution or charter, no formal requirements for membership and no central decision-making body. CGIAR acts as a forum for discussion and coordination where decisions are taken by consensus. While its budget accounted for only about 4% of global expenditures on agricultural research in developing countries (Frison et al. 1997), the CGIAR has played a pivotal role in the Green Revolution and has captured the attention of the international agriculture R&D and aid communities.

Box 1. The CGIAR

The CGIAR considers research "a collaboration enterprise". It is an alliance open to all countries and organisations which share a commitment to a common R&D agenda and willing to invest financial support, and human and technical resources. It supports agricultural research and related activities of an international public good nature carried out by fifteen autonomous research centres.

The CGIAR has five areas of focus: a) increasing productivity of crops, livestock, fisheries, forests and the natural resource base; b) strengthening national systems through joint research, policy support, training and knowledge-sharing, c) protecting the environment, and d) saving biodiversity.

The CGIAR partnership includes 24 developing and 22 developed countries, 4 private foundations, and 13 regional and international organisations that provide financing, technical support, and strategic direction. The Food and Agriculture Organization of the United Nations (FAO), the International Fund for Agricultural Development (IFAD), the United Nations Development Programme (UNDP), and the World Bank serve as co-sponsors. Member financing may allocate funding with different degrees of specificity a) to the CGIAR with flexibility regarding allocation based on CGIAR priorities; b) to IARCs or programmes without any restrictions (with or without attribution requirements); or c) targeted to a specific centre project, subproject, or activity as defined in a contractual agreement.

The CGIAR system is a network that consists of the Consultative Group (the Chairman, Co-sponsors, and other members), CGIAR committees, international agricultural research centres and centre committees, and a virtual System Office with the CGIAR Secretariat serving as its hub.

2.2.2 The National Agricultural Research Systems (NARSs)

Most developing country NARSs were built on informal research networks on plant and animal improvement dating back to the pre-independence era (Brenner 1992). In Africa, the colonial research centres established regionally were dismantled and replaced by a multitude of NARSs at independence (Eicher and Rukuni 2003). Most developing country NARSs pursued – and still do in many countries – food security objectives as a response to rapidly growing populations (Hall et al. 2000, Parayil 1992, Davies 1989).

NARSs form an innovation system (see figure 2) and conduct research, development and diffusion activities to varying extent depending on the country. Various organisations make up a NARS and play different roles in the stages of technology transfer. India provides a good example of the interactions between the various actors that make up NARSs and the importance of effective NARSs (see Box 2).

Public agricultural research institutes and universities are often organised by commodity and/or discipline and conduct some basic, but mostly adaptive research as well as most development activities. Research and development of crop variety therefore largely pertain to the public sector in developing country NARSs. R&D investments by the private sector in developing countries have been marginal and remain very low – in 1995 it accounted for about 5.5% of total investments in developing countries as compared to 51.5% in developed countries (Pardey and Beintema 2001). In Africa, most of the public research is done by government agencies whereas universities have been playing a more important role in other developing countries, notably in Latin America where they accounted for about 25% of public funding in 1991 – compared to 10% in Africa (Pardey and Beintema 2001). For comparison sake, universities in developed countries conducted 43% of public agricultural research in terms of research expenditure.

Public and private seed delivery systems are responsible for disseminating improved crop varieties developed largely by public institutions to farmers. The diffusion of new crops has been done through both public and private channels depending on the country. However, the seeds private sector remains in its infancy in many developing countries, not only in seeds R&D, but also in their diffusion (Pray and Fuglie 2000). Most private actors were involved as commercial agricultural input suppliers. While these firms have benefited from increased demand in seeds, the key technologies were developed by IARCs and national research institutes in developed and developing countries.

Farmers also greatly contributed to this learning process and to the success of the technology transfers by adapting their practices to these new technologies (Parayil 2003, Conway 1998, Biggs 1995). The contribution of farmers' knowledge to using a new technology was evidenced in Thailand by Hall and Clark (1995) by showing how the effects of a new seed varied between local farming systems – which also often correspond to different and independent knowledge systems.

Box 2. India's national agricultural research system

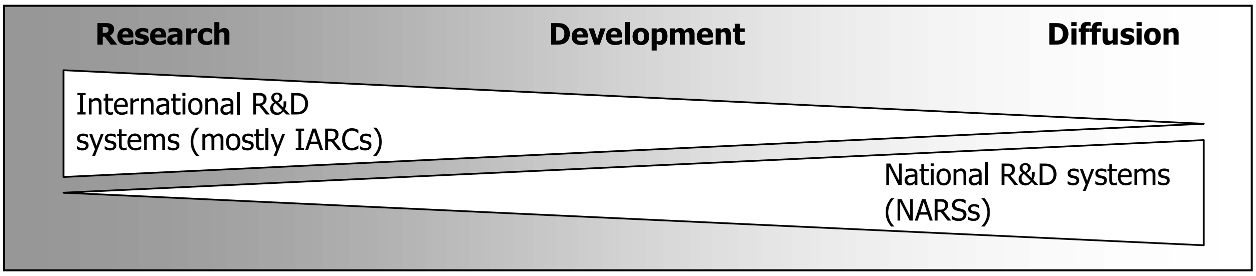
India stands out as a particularly successful example of institutional development with regards to its NARS. It comprises the Indian Council for Agricultural Research (ICAR), several smaller research organisations and a state-level agricultural university system. The ICAR brought under its wing most pre-independence research institutes to rapidly become a national network of research institutes undertaking basic and adaptive research as well as postgraduate training (Hall et al. 2000). The network of State Agricultural Universities developed in the late 1950s with the support of philanthropic foundations and bilateral aid to complement the work of ICAR. These universities had as primary objective to train scientists, conduct adaptive research and provide extension services. Their establishment followed the model of the land-grant universities of the United States, which helped facilitate knowledge and skill transfers from United States.

This system created a solid base for the implementation of thousands of demonstration programmes – both through national public information campaigns and programmes to demonstrate the effectiveness of the new technology in communities' fields – which created the demand for HYV seeds (Parayil 1992). Adaptive research for instance played a key role in increasing the demand as rice and wheat HYV seeds had to be changed to satisfy culinary and cultural preferences of Indian consumers as well as to accommodate for various soil and climatic conditions (Parayil 1992). Parayil (1992) stresses the role of farmers in adapting and adopting the new technologies highlighting that changing types of seeds entailed risks and required lifestyle changes, notably due to the need to enter the market to gain credits to buy seeds and sell their products.

The synergy between the various organisations and individual farmers that make up India's NARS has been determinant in the success of the Green Revolution in the country. Thanks to imported seeds and strong institutions to adapt and diffuse them, self-sufficiency in food grains was achieved rapidly even though the 'miracle' seeds had spread to only a quarter of its arable land (Parayil 1992).

The level of research capacity of NARSs varies greatly; some NARS have effective adaptive programmes and even do some crossing of germplasm, while the vast majority rely fully on the IARCs pre-breeding and crossing programmes. According to Traxler and Pingali (1999), only four NARSs in wheat research - out of 31 - and ten in rice research - out of 53 - do some pre-breeding research and develop a significant amount of parent material from their own crossing programmes. This highlights the crucial complementarity of IARCs' and NARSs' activities (see Figure 3). Some of the weaker NARSs even have difficulties developing and disseminating seeds which have pushed IARCs to engage in all three stages of research, development, and diffusion.

Figure 3. The "global-local" innovation system of the Green Revolution



The high number of NARSs relying on pre-breeding and crossing research done in IARCs and other institutes demonstrates the crucial role of international agricultural R&D. The importance of strong research capacities in NARSs for developing countries to be able to reap benefits from IARCs' work has been highlighted in a number of studies (cf. Davies 1989, Tripp 2003, Eicher 1990, Tribe 1994, Anderson 1998) as well as at the CGIAR (OED 2003a and b). Maredia and Eicher (1995) argue that, in the case of wheat R&D, capacity building efforts should primarily focus on improving screening capacity and adaptive research programmes rather than on expanding research programmes into crossing programmes, as the latter tend to be unprofitable when implemented at the national level.

2.3 Drivers and elements of success of international collaboration in agriculture (1970-1990)

The Green Revolution relied upon unfailing collaborative efforts, among developed countries, and between developed and developing countries, to supply new crops of HYV to developing country farmers. However, the move towards closer partnership in agricultural R&D at the global level in the 1960s and 1970s is often considered somewhat of a "historical anomaly" (Wright 1999), as it was deeply embedded in Cold-War geopolitics (Parayil 2003, Hall et al. 2000). Previously countries had protected access to nationally developed seeds and crops that gave them a national advantage. Yet, the context of the Cold War enhanced incentives for developed countries to provide aid and collaborate on plant breeding only with strategic countries. Drawing lessons from the collaboration experience during the Green Revolution days may therefore offer limited insights into the incentives for collaborating in other areas or other time frames. Yet, a consideration of some drivers and elements that made collaboration more effective may shed light on the role of international collaboration for climate-friendly technologies.

A first driver resides in the significant economies of scale in agricultural research generated by the research collaboration at the level of IARCs and the IARCs-NARSs alliances. The high rate of return on investments in crop varieties R&D has been demonstrated several times through cost-benefit analyses of individual projects and programmes (see Table 1). For instance, wheat research in NARSs and the CIMMYT (IARC focussing on wheat research) from the late 1960s to 1990s has been particularly impressive at an estimated rate of 51% (Byerlee and Traxler 1994, in Maredia and Eicher 1995). The networks of germplasm nurseries administered by IARCs have also generated enormous efficiency gains – both in terms of speed and costs – for NARSs cultivar development activities as the latter could focus on screening new varieties and adapting suitable ones to local conditions (Traxler and Pingali 1999). While it was not the primary objective of research, developed countries' economies have also reaped benefits from international agricultural research that far outweigh their investments (Pardey et al. 1996; Brennan and Bantilan 2003). For instance, Pardey et al. (1996) estimate the benefit-cost ratio for US government support of CIMMYT and IRRI between 1970 and 1993 to be respectively 190:1 and 17:1.

Table 1. Returns from publicly-funded agricultural research and extension

Country	Targeted crop	Period	Rate of return (%)
Bangladesh	Wheat and rice	1961-77	30-35
Brazil	Soybeans	1955-83	46-49
Brazil	Irrigated rice	1959-78	83-119
Chile	Wheat and maize	1940-77	21-34
Mexico	Wheat	1943-63	90
Pakistan	Wheat	1967-81	58
Peru	Maize	1954-67	50-55
Philippines	Rice	1966-75	75
Rwanda	Potato seed	1978-85	40
Senegal	Cowpeas	1981-7	63

Source: Echeverria (1989), as referred to in Conway (1998).

The developed countries' desire to transfer new crop varieties to developing countries was also matched by the aspiration of developing country leaders to modernise their economies and become self-sufficient, not only in food production, but also in agricultural knowledge (Hall et al. 2000). This was particularly evident in India's post-independence vision of 'modernising' the economy (Parayil 1992). Moving towards self-sufficiency and benefiting most from international research initiatives by conducting adaptation research needed significant capacity building efforts. Some developing countries increased their capacity through collaboration; outstanding examples include India, Indonesia and Mexico (Tribe 1994). NARS may increasingly gain from CGIAR as the IARC-NARS relationship is shifting from a donor-client one to one of equal partnership (Anderson 1998). Yet, in many cases NARSs capacities remain limited (Tribe 1994, Beye 2002, Davies 1989). Although research capacities remain low in Africa, Eicher and Rukuni (2003) consider the increase of the ratio of African to non-African researchers up to 90-10 in African research institutes historically dominated by foreign researchers as one of the great achievements of the Green Revolution.

Another element of success resides in the organisational structure and institutional flexibility that characterised the international research network and the narrowly focused and consensual agenda it pursued. The conceptually simple task to be achieved and the shared sense of purpose among actors around the objectives of the collaboration lie at the heart of the Green Revolution's success (Hall et al. 2000) and allowed for a decentralised and informal organisational structure. The CGIAR's IARCs and the national research institutes based in developed countries all are autonomous and legally independent entities and conduct their activities under varying governing structures, and following their own priorities and programmes (Tribe 1994). This plurality of actors and research programmes, circumscribed by a narrow agenda, has been regarded by many observers as one of the main strengths of the system. It enabled a relatively high degree of collaboration and coordination while allowing some competition, which created a stimulus for researchers (Tribe 1994). However, as discussed in section 3.2, this structure is no longer adequate to take into account of recent changes in the political and economic environment in which the CGIAR operates.

3. Shifting roles and incentives: implications for international collaboration

Due to changes in the political economy in the 1980s and 1990s, the locus of technological innovation in agriculture, which had belonged almost exclusively in the international public domain from the 1960s to the 1990s, is now shifting towards the multinational private sector (Pingali and Traxler 2002, Parayil 2003, Byerlee and Fischer 2002, Falcon and Fowler 2002, Hall et al. 2001).

Three interrelated forces have been transforming systems for developing and diffusing agricultural technologies (Pingali and Traxler 2002, Ballenger 2001). First, in the 1980s, a renewed conceptualisation of the role of the state led to the lowering of public funding, changing roles for public and private actors, and the privatisation of some research activities. In line with this, the second force, which ensued from and accelerates trade liberalization in agriculture, is the proliferation and strengthening of mechanisms to protect the intellectual property in plant innovations. The third consists of the increasing number of actors – in part due to the growing NGO movement - involved in shaping the research agenda of international agricultural R&D.

These developments have brought about a new set of incentives for various stakeholders, radically reshaping public and private roles in developing and diffusing crop improvement technologies to the world’s farmers. The emerging innovation system nurtures a series of new interactions between downstream and upstream actors and is increasingly interwoven between public and private actors (Krattiger 2004, Byerlee 1998). Hence, the ‘global-local’ regime that ignited the Green Revolution is becoming increasingly complex. These changes have various implications for international collaboration: on the one hand, they alter the incentives for countries to collaborate in agricultural R&D, and on the other, increased international collaboration may be necessary if improved seeds are to continue to be relevant for and made available to developing country farmers.

3.1 Challenges for international collaboration

3.1.1 Slow-down and decline of public funding

In the 1980s, a renewed conception of the role of public institutions in society reshaped agricultural innovation systems to leave more room for the use of competition and markets to generate funding for R&D (Hall et al. 2000). Arguably this would increase the efficiency of R&D and transfer compared to what the public sector could achieve. The main feature of this transition is the progressive withdrawal of public funding for agricultural R&D, both nationally and internationally. International public funding decline may also be related to donor fatigue, embodied in the perception that developing countries and the private sector may be free-riding on the investments of developed countries as their financial support of international research has never been strong (Alston et al. 1998a).

Pardey and Beintema (2001) report that growth in public agricultural R&D slowed dramatically in the 1990s in most parts of the world, after having nearly doubled – from US$ 11.8 billion in 1976 to about US$ 21.7 billion in 1996. In developed countries, the growth rate went from 2.2% per year in the 1980s to just 0.2% per year between 1991 and 1996.

Largely funded by developed country governments and multilateral aid agencies, the CGIAR has also seen its growth in financial support slow down. Alston et al. (1998b) distinguish between two phases in the chronology of funding of the CGIAR. In the first phase, corresponding to 1973-1982, funding of the

CGIAR grew by 14.3% per year. This impressive growth rate in international public funding, which enabled the proliferation of NARS and IARCs in the 1970s, however was not sustained through the second phase beginning in the mid-1980s. Although funding remained impressive with a doubling in nominal terms in the 1980s, it began to stagnate in the second half of the decade, increasing only by 1.4% per year between 1985 and 1991. Between 1992 and 2001, overall CGIAR funding declined on average by 1.8% annually (OED 2003a).

The trend exhibited in these phases in CGIAR funding match the general pattern observed by Pardey and Beintema (2001) and Alston et al. (1998a) in national public funding in agricultural R&D in developed countries. This suggests that the decline of both international and national public funding may not result from a reduced interest from countries to collaborate, but rather from a renewed conception of public and private actors' roles. Tighter public funding may in fact require enhanced cooperation to increase the cost-effectiveness of agricultural R&D through economies of scale.

3.1.2 Private sector incentives and implications of its greater involvement

The role of private actors is now expanding considerably, from mainly providing commercial agricultural input supply services within NARSs during the Green revolution to conducting in-house research and entering into contractual arrangements with public research institutions and universities (Brenner 1997, Parayil 2003, Pingali and Traxler 2002). Large agro-chemical companies, based in developed countries, were among the first private actors to move into the research arena in crop varieties and biotechnology R&D. This move was partially motivated by foreseeable declines in profits in sales of pesticides (Conway 2000, in Pingali and Traxler 2002).

The main factors that influence private for-profit actors in deciding to invest in agricultural R&D are: a) the cost of developing the new technology; b) the size of the potential market for that technology; and c) the ability to capture benefits from the use by third-parties of the technology (Pray and Umali-Deininger 1998). Considering that R&D activities, especially in biotechnology, require high upfront investments, measures had to be taken to facilitate the market entry of the new technologies and enable private actors to achieve reasonable returns from its agricultural research investments (Pray and Umali-Deininger 1998).

Prior to the 1980s, no formal mechanism for proprietary protection for plant-related innovations was available (Falcon and Fowler 2002). The extension of exclusion mechanisms – such as licenses, patents, copyrights, and trademarks - has been a key instrument and a major driving force in the consolidation of "the once-sleepy seed business into large-scale genomic and life-science firms" (Falcon and Fowler 2002: 204). Many developed countries have also offered R&D tax credits to promote investments in agricultural research from private firms. While these initiatives have greatly contributed to enabling an environment suitable for private for-profit investments in agricultural research (Pingali and Traxler 2002), some barriers – such as small market size and restrictive policies on technology imports and release - still hinder such investments (Pray and Umali-Deininger 1998).

Exclusion mechanisms and other related policies have enabled firms to increasingly move into technology research. To further cover the high investments required, biotechnology firms have embraced strategies of mergers and joint-ventures to facilitate the sale of new biotechnology crops (Pingali and Traxler 2002). In this process, agricultural R&D companies acquired seed companies, first in industrialised countries and then in developing countries, in an attempt to facilitate the distribution of their research products by stretching their activities across the continuum of research, development and diffusion shown in figure 2 (Pingali and Traxler 2002). The structure of research has been significantly affected by this consolidation and the resulting high concentration of biotechnology industry as it leaves little room for smaller competing firms (Falcon and Fowler 2002, Pardey and Beintema 2001). Nevertheless, this process has facilitated the North-South transfer of seeds, at least to commercially-minded farmers and seed industries in developing countries.

The private sector has considerable financial potential for conducting agricultural R&D activities. Despite the remaining obstacles, private investment in agricultural R&D increased sharply in the 1990s; by the mid-1990s, private investments contributed one-third of the US$ 33 billion total investment in agricultural R&D (Pardey and Beintema 2001). Yet, 94% of global private investments in agricultural R&D are made in developed countries. Further, private investments in agricultural R&D account for only 10-15% of the total public and private investment in developing countries as compared to about half in developed countries (Alston et al. 1998a). For comparison, in 1998 the annual collective expenditure on agricultural research of the world's top-ten corporations was ten times larger than that of the CGIAR (Pingali and Traxler 2002).

Yet, there is much debate on the extent to which for-profit private actors can replace the public sector in developing appropriate technologies to achieve future productivity gains in developing countries. Do incentives exist, or can they be created, to harness private funds to continue addressing food security issues in developing countries? As the profit motive ultimately – and understandingly – determines the level and type of private research involvement, some markets will inevitably remain underserved, at least in the short term (Pray and Umali-Deininger 1998).

Pingali and Traxler (2002) identify three gaps in the private sector activities that will need to be addressed through public support if developing countries are to continue to have access to genetic resources developed abroad:

The *geographical gap* refers to the lack of interest of private investors in areas with small market potential and countries with inadequate intellectual property protection. Private actors are unlikely to keenly invest in research to develop seeds for marginal stress-prone environments as they present low market potentials due to the less intensive farming done in these areas (Pingali and Traxler 2002). However, Byerlee and Fischer (2002) argue that the role of the private sector in developing countries may be underestimated as the marginal costs of entry in emerging markets may be low and the liberalisation trends in developing countries will facilitate private actors' endeavours.

The *crop gap* refers to the lack of market incentives to invest in some of the world's most important crops. This arises in part due to biological circumstances, namely that some crops, such as rice and wheat, are not amenable to property protection as they are self-pollinating. Therefore, the world seed market has concentrated on relatively few crops, mainly maize, soybean, cotton and vegetables, for which second-generation seeds do not express the desired traits of the parent. This biological characteristic has made it possible for exclusive mechanisms to be set up to secure return on investments in R&D on these crops.

The *research area gap* arises from the specific expertise of the private sector. Early private sector efforts depended heavily on its access to public sector gene banks and pre-breeding material for the development of their HYVs (Morris and Ekasingh 2001, in Pingali and Traxler 2002). The private sector's limited experience in conventional plant breeding is likely to restrict its capacity to develop new biotechnologies as the public sector withdraws from its traditional role. The incompatibility of traditional basic and strategic research with exclusion mechanisms is likely to keep the private sector away from this type of research (Pray and Umali-Deininger 1998).

3.1.3 Increasing plurality of actors, interests and needs

Increasing awareness about the environmental impacts of techniques and technologies promoted during the Green Revolution and the realisation that impacts on poverty were more limited than expected have led a number of new actors to take a stake in international agricultural R&D programmes. In addition to the expanding private sector discussed above, the new context sees a more prominent role of civil society actors, which are increasingly organising in effective NGO movements (Fox and Brown 1998; Keck and Sikkink 1998), and the developing country institutes, governments and farmers, in an attempt to better tailor research to the needs of farmers (Clarke 2002, Chambers 1994). The plurality of actors is further complicated by a diversity of interests and needs between developing countries.

The adoption of a top-down approach led by researchers, rather than by technology users, has often resulted in a failure to adequately meet farmers' needs and subsequently also raised a set of environmental and development concerns (Chambers 1994). Nurturing scientific excellence, by building strong links between IARCs and leading developing country research institutes, drew attention away from farmers' needs and from the developmental and environmental goals of agriculture research (Hall et al. 2000). In fact, while NARSs are responsible for diffusing new agricultural technologies, many of them were rather centralised around a national research organisation. This impeded spillovers to flow to some farmers and some types of adaptive research to be conducted, for example for certain local agro-ecological conditions (Hall et al. 2001). Many studies argue that this technology-driven system concentrated too much on transferring new technologies and techniques to developing countries at the expense of understanding the wider political, economic and institutional contexts which greatly influence the success of the new technology dissemination (Biggs 1995). Two OECD studies (Brenner 1997; Brenner and Komen 1994) of collaborative initiatives in biotechnology also highlight problems of adoption arising from projects embracing a narrow scientific objective and to some extent omitting priorities set for national agricultural research and agriculture.

The greater plurality of actors has influenced the research agenda drawn up in the early days of the Green Revolution: it has broadened the problem definition from what was commonly perceived as "so-called isolable technical problems" (Hall et al. 2000: 74) to encompass issues such as poverty reduction, natural resource management and environmental protection (Anderson 1998).

Finally, the capacity gap between developing countries seems to be widening, which translates into diverging needs, and concerns to be addressed by international collaboration. Some high-capacity NARSs are becoming as strong as IARCs, which reduces their incentives to cooperate. A classification of NARSs according to their research capacity concluded that about 20% of the NARSs surveyed had a high capacity and therefore conducted pre-breeding research and developed a significant amount of parent material from their own crossing programmes (Traxler and Pingali 1999). This type of research had historically been conducted primarily by IARCs and developed country institutes. For comparison the Brazilian NARS is of a similar size as the entire CGIAR system (Falcon and Fowler 2002). The widening range of capacity of NARSs has begun to challenge international collaboration as the latter is now required to respond to a wider variety of concerns and needs. This, however, may not mean independence in crop variety R&D, but rather greater interdependence in crop variety R&D (Traxler and Pingali 1999).

3.2 Implications for CGIAR and international collaboration

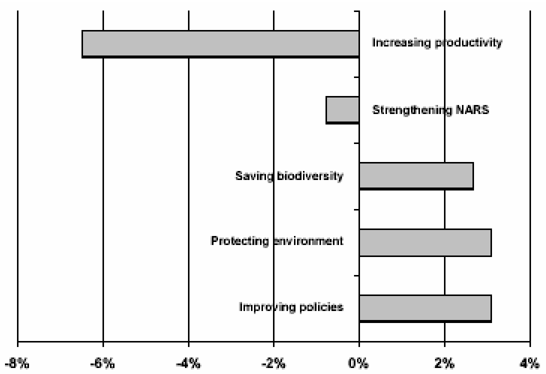
Due to the scientific and legal complexity that represents both the advent of biotechnology and intellectual property protection, few have an accurate and complete understanding of what these changes may mean and what policy responses they may require (Falcon and Fowler 2002). The way national and international agricultural innovation systems have responded to these changes remains limited and experimental (Hall et al. 2000). Yet, there is widespread consensus that increased funding alone is not the solution (Pardey et al. 1997); a much more encompassing, system-wide reform in the case of the CGIAR (OED 2003a) is necessary to adapt to the new environment in which agricultural research must be conducted if new crop varieties are to be successfully supplied to the world's farmers.

3.2.1 Dealing with plurality and changing patterns in financial support

The 2003 meta-evaluation of the CGIAR (OED 2003a and b) provides evidence of the impact of the greater plurality of actors and of changing patterns in donor funding on the operations of the CGIAR. The CGIAR engaged in a 'Renewal Process' in the mid-1990s, which aimed to reform itself to address issues close to the hearts of donors' constituencies. This was done partly in an attempt to minimize the impacts of funding cuts and changing patterns of support. This led to the creation of a number of committees to reflect a greater diversity of viewpoints, including those of the private sector and of civil society. In a similar attempt to enhance its accountability, the CGIAR established the Global Forum for Agricultural Research to be more responsive to NARSs' views and interests. While these changes broaden the CGIAR's political support, they have also "fundamentally altered the character of the organisation - from that of a technical organisation of scientists and donors interested in funding science for the benefit of the poor, to pursuing a broader agenda involving the views of diverse stakeholders" (OED 2003b: 83).[6] A manifestation of this lack of consensus on CGIAR's priorities is the continual tension between topics that can generate funds and those that need to be addressed to ensure benefits for the largest number of poor people.

The composition of the overall programme shifted from strategic research aimed to increase agricultural productivity to encompass a broad range of activities related to environmental protection, farmer participation and improving national policies. The CGIAR (1995, in Anderson 1998) reports for instance that a similar amount, 11% of CGIAR resources, is spent on germplasm enhancement and plant breeding as well as on each of the 'add-on' issues of biodiversity conservation, agricultural policy, training and communications, crop-oriented production research and environmental production. This represents a shift away from what had historically been the CGIAR's main comparative advantage and core competency (OED 2003a) (see Figure 4). It also increases transaction costs and reduces the efficient use of resources at both the CGIAR and its IARCs.

Figure 4. Average annual change in Centres' expenditure by type of research activity (1992-2001)

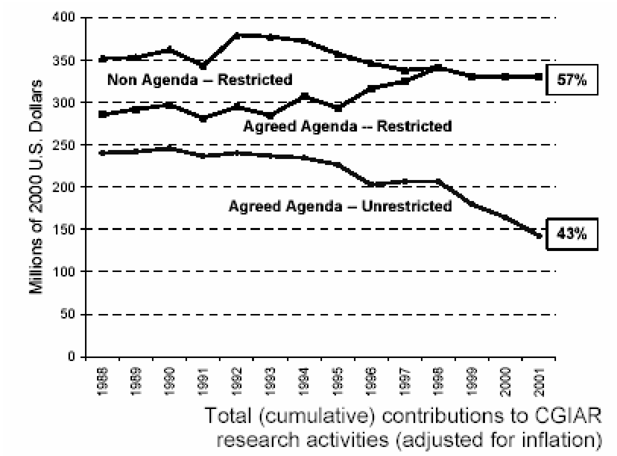


Source: Calculations by Operations Evaluation Department, World Bank (OED 2003a), based on CGIAR Financial Reports, 1992-2001.

[6] The CGIAR first expanded its mission in the mid-1980s to include sustainability and in the late 1990s to formally incorporate poverty reduction and environmental sustainability (OED 2003b).

Given greater expectations from stakeholders, aid agencies have also increasingly restricted their funding to specific projects, programmes and centres. The CGIAR has in response developed "high-visibility, time-bound partnerships", which have in effect resulted in the CGIAR addressing more the short-term donor agenda items than developing countries' long-term interests and concerns (OECD 2003a) (see figure 5).

Figure 5. Changes in research pattern in CGIAR



Source: OED (2003a), based on CGIAR Financial Reports 1988-2001.

Developing countries also have increasingly diverse needs and interests, and this poses an additional challenge for the CGIAR (OED 2003a). With tighter budgets and pressure to expand their mandate, IARCs pre-breeding and crossing programmes are competing for resources with other issues, and subsequently reducing activities in research that may be most vital for low-capacity NARSs (Traxler and Pingali 1999). In other instances, collaboration with low-capacity NARSs was stopped midstream as it was unfruitful for all parties (Tribe 1994).

Against this background, the continued growth in the number of international research centres' staff and the expansion of the centres' mandates only increase the pressure on an already resource-tight system. These funding difficulties led increasingly to significant budget cuts in IARCs and to the inevitable downsizing of their operations (Anderson 1998). While increased funding in the 1970s allowed the number of CGIAR's IARCs to grow up to eighteen in 1992 and to cover more commodities, the CGIAR has now been downsized to fifteen centres.

This situation puts into question the governance of the CGIAR system as a whole for two main reasons. First, the CGIAR has no formal or legal persona, written charter or even a memorandum of understanding, unlike more recent global programs, such as the Global Environment Facility (GEF). This has constrained the ability of the "CGIAR to speak with a single voice and to develop system-wide policies and long-term strategies" (OED 2003a). Second, the independent legal status of IARCs, governed by self-nominating boards, combined with a broadening of board membership to a wide range of stakeholders have diluted board accountability and responsibility for quality (OED 2003a). The combination of these two factors has made it difficult to reach consensus among members on the governance, organisation, management, and financing issues needed to achieve the CGIAR's mission.

The meta-evaluation of the CGIAR concluded that, "regaining focus requires that the System determine key issues of high priority requiring System-level attention" (OED 2003a: 15). This is aimed to refocus its efforts in areas closer to its core competences, and regain trust from donors in an attempt to raise funding with as few restrictions as possible. This process of defining strategic priorities is aimed to alleviate the tensions between the issues that can attract funding and those that have the greatest impact by mobilising donors and stakeholders "around the importance of an idea", for example water or climate change issues (OED 2003b:103). In this sense, it appears clear that "well-defined strategic priorities should drive funding rather than funding driving priorities" (OED 2003a: 9).

3.2.2 Harnessing the private sector's potential

The greater involvement of private firms poses a number of challenges to public institutions related to filling the geographical, crop and research gaps identified above. International collaboration may play an important role in harnessing the private sector potential in agricultural R&D for continuing to deliver improved crops to developing country farmers. Yet, national and international public institutions need to use caution in dealing with their intellectual property.

There is a growing concern that public genetic resources may be patented and appropriated by a private actor, and thereby taken out of the public sphere. With the advent of intellectual property protection, part of the public germplasm collections – composed of more than a thousand gene banks containing a about six million accessions (varieties or landraces) (FAO 1998, in Falcon 2001) – may be under threat if the managing entities have not taken preventive action. Yet, most public agencies are not prepared or organised to deal with the protection of intellectual property as it is foreign both to their organisational structure and to the outlook and expertise of their staff (Falcon and Fowler 2002; Nottenburg et al. 2002). The CGIAR has also come under pressure recently to prevent some of its germplasm collection as well as its new biotechnologies from being patented by a private actor. This, however, is not the case of most of the 670 000 accessions held in the eleven gene banks of CGIAR as about 500 000 of them are held in trust under an agreement with FAO dating from 1994. These accessions, arguably the most valuable to developing countries (Falcon 2001), thereby remain freely available to the international community. As discussed above, the CGIAR is now considering various options for restructuring itself as a legal entity, which would enable it to better deal with the growing challenges of property protection (OED 2003a).[7]

In this sense, the strengthening of intellectual property rights may have provided the incentives for much needed private investments in R&D in times of dropping public financial support, but it also means that the 'public goods' aspect of public R&D is eroding as public entities are now restricting access to "once-public materials", in effect closing the commons (Falcon and Fowler 2002, Brenner 1997). Nevertheless, protecting current public genetic resources may also become necessary for bargaining purposes if public actors are to form alliances with private firms (Falcon and Fowler 2002).

This leads to a second, and perhaps more critical, issue of harnessing private investments for developing countries to continue to have access to improved crop varieties, and now biotechnology. Enhancing collaboration and fostering partnerships among actors, especially across the public-private line, is a frequently mentioned avenue to help bridge the gaps left by the changing roles between public and private actors (Pray and Umali-Deininger 1998, Byerlee 1998, Nottenburg et al. 2002, Wright 1999, Hall et al. 2001, Pingali and Traxler 2002, Spielman 2003). Ways for developing country NARSs to access private firms' technology include acquiring licences through, *inter alia*, cross-licensing agreements, research-only or cost-free licenses, and joint ventures (Nottenburg et al. 2002, Wright 1999, Byerlee and Fischer). Such initiatives will become increasingly important as public funding for agricultural research in developed and developing countries alike is slowing.

[7] Two models have been examined so far to give the CGIAR a legal entity: a corporate model with a centralised board and a Federation of Centres (OED 2003a). The corporate model was rejected in 1999 by the Group as it clashed with the System's culture of consensus decision-making while the Federation proposal of 2000 is still under discussion (OED 2003b).

Public and private actors respond to a different set of incentives and therefore often hold complementary strengths in research and technology transfer, which may foster partnerships (Pingali and Traxler 2002, Pardey and Beintema 2001). The rationale for public actors to engage with the private sector comes from its search for new funding sources, which may be provided by firms' access to and experience with international capital markets (Byerlee and Fischer 2002). Assets of the public sector that may be of interest to private actors include its connections to a global network of researchers, seed delivery systems and public sector extension services as well as knowledge of local agro-ecological and institutional conditions in developing countries (Byerlee and Fischer 2002, Binenbaum et al. 2001).

However, the success of public-private partnerships largely depends on the ability of public institutions to manage and negotiate intellectual property. While the public sector may have some attractive assets, which it can use as bargaining chips, it still risks having its research priorities influenced by private interests (Pray 2001). Worth noting is that, since most of germplasm developed in public institutions is made freely available to all, most of its genetic wealth cannot be used as a negotiating asset (Nottenburg et al. 2002).[8]

It is also costly to search, negotiate and register patents, which impedes public actors' efficiency in engaging in partnerships with the private sector (Byerlee and Fischer 2002). Forming regional consortia of NARSs or other collaborative arrangements, for instance with IARCs, has been a strategy used to render access to private material more cost-effective. For example, a consortium of public sector organisations led by IRRI purchased the right to a gene owned by a private Japanese company (Byerlee and Fischer 2002). Likewise, Cohen et al. (1999, in Byerlee and Fischer 2002) report more than 50 instances in which Latin American NARSs have jointly purchased agricultural R&D products. Another initiative is ISAAA which offers services in brokering transfers between the private sector of developed countries and the public sector of developing countries.

International collaboration could also play a vital role in reducing these costs through the establishment of information systems and clearinghouses. Examples of such initiatives include CAMBIA and REDBIO, which both provide intellectual property information to NARSs and help researchers to identify prior patent claims and "thus travel more safely through the international patent minefield" (Nottenburg et al. 2002: 406).

Facilitating private sector investments requires setting up adequate regulatory frameworks to protect intellectual property and to deal with biosafety issues (Krattiger 2002; Tripp 2003; Byerlee and Fischer 2002). Krattiger (2002) argues that some of the main constraints to biotechnology transfer are the low absorptive capacity of national programs, i.e. the capacity to assess, adapt as needed and disseminate improved technology, and the often lacking regulatory capacity in developing countries, most notably in biosafety and food safety. This situation calls for capacity building efforts, which could be achieved through greater international collaboration. For instance, Krattiger (2004) examines options for UNIDO to play a greater role in such capacity building efforts.

Byerlee and Fischer (2002) suggest that regulatory frameworks could be established more cost-effectively on a regional level. Such regional initiatives are particularly relevant for regions made up of many small and medium-sized countries as it would enlarge markets in which private firms can operate and reduce costs of biosafety approval and intellectual property transactions for both public and private organisations. The establishment of centralised regional offices could facilitate the implementation of such a regional regulatory framework. Africa, for instance, already allows centralized patent registration (Byerlee and Fischer 2002). Other similar regional R&D collaborative networks are already underway in Asia and Latin

[8] Nottenburg et al. (2002) estimate that the CGIAR holds fewer than ten patents (neither related to biotechnologies nor granted in developed-country jurisdictions). This compares to Monsanto's 437 patents, obtained between 1994 and 1998.

America but, just as the CGIAR, they could benefit from adopting a legal status to effectively protect their R&D findings. Yet, concerning biosafety issues, as they are rather new and controversial, it is unlikely that national authorities be willing to cede jurisdiction until more experience is developed (Tripp 2003). Nevertheless, the adoption of regional non-binding guidelines on risk assessment for biotechnology may be possible, as such guidelines were agreed upon among ASEAN countries in 1999.

Through international collaboration, public organisations may facilitate the use of the new technology transfer channels enabled by private sector involvement, while at the same time ensuring their independence in achieving their public R&D policy objective.

4. What lessons for international collaboration for climate-friendly technology?

This paper differentiates the incentive structure for conducting high-yielding crop variety R&D that prevailed during the Green Revolution in the 1970s and 1980s and the one within which agricultural R&D is conducted today. The Green Revolution thrived thanks to an innovation model that rested on close collaboration between various international and national research centres and networks in developed and developing countries as well as the sustained support of developed country aid agencies and private foundations. The current evolution of the innovation system – characterised perhaps most markedly by a greater involvement of and increased interactions between public, private and civil society actors, as well as evolving laws and policies affecting the ownership and use of genetic material – marks a bifurcation in the technological trajectory of R&D on high-yielding crop varieties. This shift is apparent in the failed attempt to revive the Green Revolution in the late 1980s and 1990s (Parayil 2003), captured for example in the vision of a “Doubly Green Revolution” (Conway 1998). The Green Revolution would arguably not have taken place under the current economic and political context (Falcon 2001; Traxler and Pingali 1999). This new regime challenges collaborative institutional arrangements that grew and eventually enabled the Green Revolution.

A number of lessons emerge from this international collaboration experience in agriculture. While the discussion of each lesson attempts to provide relevant insights for collaboration for climate-relevant technologies, they should also be considered as part of a wider set of lessons that will emerge from the other case studies that are part of this project.

A starting point for drawing lessons is that some key dimensions of this environment are relevant for climate-friendly technologies and will be lasting, at least in some form and for a long-enough time to influence near-term technology developments. These include the trend towards trade liberalisation relevant for all types of technologies, mechanisms for the protection of intellectual property rights, corporate involvement in technological R&D and the increased role of civil society in policy-making processes.

4.1 Linking international R&D to national and local innovation systems

Lesson 1: International collaboration on technology R&D may draw benefits from strong links between international R&D and national and local dissemination systems.

This paper covers two dimensions of collaboration, among developed countries and between developing and developed countries. The former enabled the establishment of the network of IARCs (international agricultural research centres) which generated improved crop varieties for developing countries. The latter embodies the strong alliance between IARCs, donor agencies and NARS (national agricultural research centres), which allowed IARCs’ research products to reach developing country farmers. The need for this strong alliance is reflected in the move away from the donor-client relationship that prevailed in the early days of the CGIAR and towards partnership between IARCs and NARSs (Anderson 1998).

This highlights the role international collaboration can play to facilitate different stages of technology innovation, namely conducting research, developing new technologies and disseminating them (see figure 2). Ensuring complementarity between IARCs’ and NARSs’ activities was central to the effectiveness of this system; IARCs developed improved crop varieties that were made publicly available for NARSs to adapt to prevailing conditions if necessary and to disseminate. As the CGIAR evolved, however, some NARSs became stronger than IARCs while others still lack the capacity to effectively adopt and diffuse IARCs’ products. The challenge for the CGIAR, as well as for collaborative arrangements in other technologies, is to determine how to best serve these diverging needs among technology users. The idea of building on complementarities has led some authors to argue that donors should focus on building the capacity of NARSs in assessing their HYV and biotechnology needs, which should subsequently serve in adequately prioritizing between which R&D products should be imported from the global research system and for which crop variety or biotechnology should in-country R&D capacity be developed (Maredia and Eicher 1995, Brenner 1997).

Responding to national and local needs through forging strong links between international R&D and national systems rest on NARSs' capacity to adopt and disseminate the new technology (see lesson 2), and the ability to mobilise actors behind a sharply-focused objective (see lesson 3). Further, international collaboration may foster the use of new private sector channels of technology transfer (see lesson 4).

4.2 Collaboration cannot work without capacity, but it can build capacity

Lesson 2: International technology R&D collaboration can best achieve its full potential where there is a minimum absorptive capacity in place. For low capacity parties, collaboration may best be facilitated by focusing on building capacity.

Since the early days of the Green Revolution, the capacity of developing country NARSs has determined their ability to benefit from IARCs' R&D. For the CGIAR, NARSs' ability to assess, test, adapt and disseminate the products of its R&D is critical to ensure its impacts and the effectiveness of the IARCs-NARSs alliances (OED 2003a and b). The importance of NARSs' capacity to identify technological priorities in line with their national development plans cannot be understated in forming a sharply focused, consensual and lasting collaborative arrangement. The high national capacity to identify technology needs may be especially crucial when the negotiation of intellectual property is required (IPCC 2002).

Also of fundamental importance for the dissemination of imported technologies is the NARSs' expertise in adaptive research and capacity to enable an environment that fosters public and private distribution of the new technology and adoption by farmers. Experiences from many other collaborative initiatives, in crop variety and biotechnology, point to the necessity of building these capacities to enhance the effectiveness of collaborative R&D programmes (OECD 2002, Krattiger 2004, Brenner 1997, KFPE 2001).

The effectiveness of collaboration for climate-relevant technologies also depends on countries abilities to assess and select technologies and subsequently to adapt them to prevailing local climatic and socio-economic conditions (IPCC 2002). For example, Worrell and Levine (2002), with regard to climate-relevant technologies in industry, argue that the more attention is paid to adapting a new technology to local conditions, the more successful the technology transfer is.

As developing countries needs in terms of research products and services from IARCs appear to be increasingly diverging, developing more targeted, possibly regional, programmes may prove effective (CGIAR 2002). All NARSs surveyed for the CGIAR meta-evaluation (OED 2003a and b) have expressed interest in enhancing direct cooperation for capacity building between high- and low-capacity NARSs of similar agro-ecological and development conditions. This could lead to regional or other types of smaller scale collaboration among NARSs with similar interests. These adjustments require institutional and organisational flexibility at the CGIAR in order to create new fruitful collaborative arrangements. Given the tightening of public funding, however, it appears unlikely that these NARSs will continue to receive the greatly needed scientific and institutional capacity building support (Krattiger 2004, Traxler and Pingali 1999).

4.3 Linking collaborative structure, plurality of actors, and focus

Lesson 3: Striking a balance between nurturing scientific and technological excellence while taking into account complex social and environmental problems is challenging for technological R&D collaborative arrangements. Parties need to find ways to remain focused, while accommodating an increasing number of stakeholder viewpoints.

This lesson might be self-evident from the history of the CGIAR presented above. However, there is evidence in numerous other technology collaboration schemes of the difficulty of striking a balance between focus and comprehensiveness in the issues to be tackled. Some struggle to refocus their expanding mandate; for example the World Bank, which has faced similar challenges as the CGIAR (Fox and Brown Fox, Wade 2003). Others remain too science-driven, such as a number of international initiatives in biotechnology which were conducted in isolation from the overall national context (Brenner and Komen 1994; Brenner 1997). Most climate-friendly technologies also cannot be separated from the wider context in which they operate (IPCC 2002). The Clean Development Mechanism (CDM) provides a good example of a collaborative mechanism to transfer technology that has been caught in a crossfire between the climate and development communities to determine how technology-focused it should be (Mathy 2002).

There are two key interlinked questions: a) how focused should the objective of collaboration be; and b) what institutional structure would be most effective for the collaborative arrangement to meet this objective? The CGIAR's success in developing and diffusing its new crop varieties was due in part to its narrow focus and science-based character. Casting the problem of food security as a technical problem rallied many like-minded developed and developing countries (Hall et al. 2000). However, this narrow objective increasingly became thought of as the source of CGIAR's dubious environmental record and mixed success in alleviating poverty. Increasing awareness of these problems, combined with the greater plurality of stakeholders, including NGOs and private firms, expanded the CGIAR's mandate, making it more diffuse, ambitious and less consensual among its members. As a consequence, the CGIAR's "current mix of activities reflects neither its comparative advantage nor its core competence" (OED 2003a: 5). Numerous observers (Krattiger 2004, Hall et al. 2000, Anderson 1998) as well as CGIAR's meta-evaluation (OED 2003a) call for deep reforms of the CGIAR to regain focus while ensuring that its core activities take into account possible ancillary environmental and developmental benefits and minimise negative environmental and social impacts.

The CGIAR experience shows how intimately linked the issue of determining the focus of collaboration is to the institutional structure needed for collaboration to be effective. The loose collaborative arrangement of the CGIAR at its inception was successful in disseminating its R&D products to developing countries largely because of the consensual view of the problem definition among its supporters. However, as the environment in which the CGIAR operates evolved and diversified in the number of actors and interests, this flexibility and the lack of formal rules to govern and coordinate IARCs' activities and their relationships to donors "has created a chaotic market place for global public goods research" (OED 2003a: 18). Funding became increasingly driven by short-term interests of donors and targeted to projects and programmes rather than for use by the CGIAR in line with its own priorities and long-term mandate. The on-going discussion on how to reform CGIAR's structure calls for a more centralised entity, able to speak with a single voice, develop CGIAR-wide policies and long-term strategies (OED 2003a and b). Further, it may be appropriate to reduce the scale of the collaboration to render it more efficient and tailored to stakeholders' needs.

International R&D collaboration to tackle climate change is likely to occur at different geographical scales and focus on technologies that may not be widely accepted. CGIAR's experience suggests that the governing structure of collaborative arrangements should be a reflection of the level of controversy of the new technology and of the diversity of interests to be accommodated. This means that the more diverse the views, the more formal the governance structure will need to be and/or the smaller the scale of collaboration will need to be.

The CGIAR's experience also provides insights on the difficulties for established institutions to redefine its governance system and institutional boundaries as the global market and geopolitical context around it is shifted. A key lesson therefore for those engaging in international collaboration is that there is a need to accommodate sufficient flexibility for the continuous process of institutional change in order to enhance responsiveness to changing factors in the operational environments and keep its relevance.

4.4 Harnessing private sector's potential through international collaboration

Lesson 4: International collaboration can play a key role in helping countries to harness the private sector's financial potential for conducting R&D activities and to disseminate new technologies.

There are various ways to facilitate private sector R&D investment in crops for use in underserved markets. They include the negotiation of public-private partnerships, development of information systems and clearinghouses, establishment of research consortia and common regulatory frameworks. Given the high transaction costs of negotiating agreements and patent search and registration (Byerlee and Fischer 2002), this paper argues that international collaboration may increase the efficiency of these initiatives.

Examples of public-private partnerships abound in the literature on climate change (IPCC 2002, Forsyth 1999). Yet, relatively little emphasis has been put on the role of international collaboration in improving their effectiveness and reducing the technology costs.

International collaboration in negotiating agreements with the private sector may enhance public actors negotiating power and help them pursue their public policy objectives more effectively and at a reduced cost (Nottenburg et al. 2002). International collaboration can play a vital role in the establishment of information systems and clearinghouses, which in turn can help countries evaluate opportunities for cooperation with private actors. Such collaborative initiatives have already been taken in the climate change arena, for example the Centre for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET) and the Greenhouse Gas Technology Information Exchange (GREENTIE).

There may also be scope for collaborative policy initiatives to enlarge markets in which private firms can operate and reduce costs of biosafety approval and intellectual property transactions for both public and private organisations. The establishment of centralised regional offices could facilitate the implementation of such a regional regulatory framework. Yet, on policy issues with which governments have little experience, such as biosafety, it appears unlikely that national authorities would be willing in the short term to cede jurisdiction (Tripp 2003). Regional non-binding guidelines therefore may be an interesting approach.

At the CGIAR, the need for a system-wide reform is also related to the increasing necessity of the CGIAR to partner with the private sector and to protect collective R&D products from being appropriated by a private actor. This issue, however, is perhaps more specific to the CGIAR as more recent similar collaborative initiatives, e.g. the GEF, have a legal entity which provides for dealing with intellectual protection issues. As this may not be the case of all collaborative agreements on climate-friendly technologies, the CGIAR experience points to the need for public organisations to improve their understanding and skills in managing and negotiating intellectual property.

References

Alston, J.M, P.G. Pardey and J. Roseboom (1998a), “Financing Agricultural Research: International Investment Patterns and Policy Perspectives”, *World Development*, Vol. 26, No. 6, pp. 1057-1071.

Alston, J.M, P.G. Pardey and V.H. Smith (1998b), “Financing Agricultural R&D in Rich Countries: What is Happening?”, *The Australian Journal of Agricultural and Resources Economics*, Vol. 41, No. 1, pp. 51-82.

Anderson, J.R. (1998), “Selected Policy Issues in International Agricultural Research: On Striving for International Public Goods in an Era of Donor Fatigue”, *World Development*, Vol. 26, No. 6, pp. 1149-1162.

Ballenger, N. (2001), “The Roles of Government and Multilateral, Scientific, and Private Institutions” in: N. Ballenger, K.D. Wiebe, P. Pinstrup-Andersen (eds.), *Who Will Be Fed in the 21st Century? : Challenges for Science and Policy*, Washington, D.C. : International Food Policy Research Institute with the Economic Research Service, U.S. Dept. of Agriculture, American Agricultural Economics Association.

Beye, G. (2002), *Impact of Foreign Assistance on Institutional Development of National Agricultural Research Systems in Sub-Saharan Africa*. FAO, Rome.

Biggs, S. (1995), “Farming Systems Research and Rural Poverty: Relationships between Context and Content”, *Agricultural Systems*, Vol. 47, pp. 161-174.

Binenbaum, E., P.G. Parday and B.D. Wright (2001), “Public-Private Research Relationships: The Consultative Group in International Agricultural Research”, *American Journal or Agricultural Economics*, Vol. 83, No. 3, pp. 748-753.

Binswanger, H., and V.W. Ruttan (1978), *Induced Innovation: Technology, Institutions and Development.* Johns Hopkins University Press, Baltimore.

Brennan, J.P. and M.C.S. Bantilan (2003), “Price and Yield Effects of Spill-Overs in International Agricultural Research: Evidence from ICRISAT and Australia”, *Agricultural Economics*, Vol. 28, pp. 87–97.

Brenner, C. (1992), *Biotechnology and the Changing Public-Private Sector Balance: Developments in Rice and Cocoa*, OECD, Paris.

Brenner, C. (1997), *Biotechnology Policy for Developing Country Agriculture*, Policy Brief No. 4, OECD, Paris.

Brenner, C. and J. Komen (1994), *International Initiatives in Biotechnology for Developing Country Agriculture: Promises and Problems*, Technical paper No. 100, OECD, Paris.

Bull, D. (1982), *A Growing Problem: Pesticides and the Third World Poor*, Oxfam, Oxford.

Byerlee D. and G. Traxler (1994), *National and International Research on Crop Improvement in the Post-Green Revolution Period: Still a Good Investment?* Draft paper, CIMMYT, Mexico D.F.

Byerlee, D. (1998), “The Search for a New Paradigm for the Development of National Agricultural Research Systems”, *World Development*, Vol. 26, pp. 1049-1055.

Byerlee, D. and K. Fischer (2002), “Accessing Modern Science: Policy and Institutional Options for Agricultural Biotechnology in Developing Countries”, *World Development*, Vol. 30, pp. 931-941.

Byerlee, D. and P. Moya (1993). *Impacts of International Wheat Breeding Research in the Developing World, 1966-90*, CIMMYT, Mexico, D.F.

CGIAR (1995), *Annual Report 1994-1995*, CGIAR, Washington, D.C.

CGIAR (2002), *Stakeholder meeting: Agenda Item 7.a. Regional Priority Setting (GFAR and iSC)*, CGIAR Annual General Meeting 2002, Manila, Philippines (October 30-31).

CGIAR (2004). Consultative Group on International Agricultural Research. www.cgiar.org

Chambers, R. (1994), “The Origins and Practice of Participatory Rural Appraisal”, *World Development*, Vol. 22, pp. 953-969.

CIMMYT (1996), *CIMMYT 1995/96 World Wheat Facts and Trends: Understanding Global Trends in the Use of Wheat Diversity and International Flows of Wheat Genetic Resources*, CIMMYT, Mexico D.F.

Clarke B.R. (2002), “Transfer to Africa of the Resources and Rewards from Biotechnology: The Need for a Participatory Approach”, *Journal of Commercial Biotechnology*, Vol. 9, September, 31-39.

Cohen, J. I., C. Falconi, J. Komen, S. Salazar, and M. Blakeney (1999), “Managing Proprietary Science and Institutional Inventories for Agricultural Biotechnology”, in J. I. Cohen (Ed.), *Managing Agricultural Biotechnology: Addressing Research Program Needs and Policy Implications*, Biotechnology in Agriculture Series No. 23. ISAAA, Wallingford, UK.

Conway, G. (1998), *The Doubly Green Revolution: Food for All in the 21st Century*. Cornell University Press, Ithaca, NY.

Conway, G. (2000), *Crop Biotechnology: Benefits, Risks and Ownership*, Foundation News 03062000, Rockefeller Foundation, New York.

Conway, G.R. and J.N. Pretty (1991), *Unwelcome Harvest: Agriculture and Pollution*, Earthscan, London.

Davies, G. (1989), Effective Agricultural Research: NARS in Sub-Saharan Africa, *Food Policy*, August.

Echeverria, R.G. (1989), “Assessing the Impact of Agricultural Research”, in ISNAR, *Methods for Diagnosing Research System Constraints and Assessing the Impact of Agricultural Research*. Vol II, *Assessing the Impact of Agricultural Research*, International Service for National Agricultural Research, The Hague.

Eicher, C.K. (1990), “Building African Scientific Capacity for Agricultural Development”, *Agricultural Economics*, Vol. 4, pp. 117-143.

Eicher, C.K., and M. Rukuni (2003). *The CGIAR in Africa: Past, Present, and Future*, The CGIAR at 31: An Independent Meta-Evaluation of the Consultative Group on International Agricultural Research: Thematic Working Paper, World Bank’s Operations Evaluation Department, Washington D.C.

Falcon, W.P. (2001), “Globalizing Germ Plasm: Barriers, Benefits and Boundaries”, in: Peters, G. H. and P.L. Pingali (eds). *Tomorrow's agriculture: institutions, infrastructure and innovations*, Proceedings of the 24th International Conference of Agricultural Economists held in Berlin, Germany 13-18 August 2000.

Falcon, W.P. and C. Fowler (2002), “Carving up the Commons – Emergence of a new International Regime of Germplasms Development and Transfer”, *Food Policy* Vol. 27, pp. 197-222.

FAO (1998), *The State of the World Plant Genetic Resources for Food and Agriculture*, FAO, Rome.

Forsyth, T. (1999), *International Investment and Climate Change: Energy Technologies for Developing Countries*. Earthscan, London.

Fox, J. and D. Brown (eds) (1998), *The Struggle for Accountability*: *The World Bank, NGOs, and Grassroots Movements*, MIT Press.

Frison, E.A., W.W. Collins, and S.L. Sharrock (1997), *Global Programs: A New Vision in Agricultural Research*, CGIAR, Issues in Agriculture 12. CGIAR, Washington D.C.

Gardner, B. (2003). *Global Public Goods from the CGIAR: Impact Assessment,* The CGIAR at 31: An Independent Meta-Evaluation of the Consultative Group on International Agricultural Research: Thematic Working Paper. World Bank’s Operations Evaluation Department, Washington D.C.

Hall, A. and N. Clark (1995), “Coping with Change, Complexity, and Diversity in Agriculture – The Case of Rhizobium Inoculants in Thailand”, *World* Development, Vol. 23, No. 9, pp. 1601-1604.

Hall, A., G. Bockett, S. Taylor, M.V.K. Sivamohan, and N. Clark (2001), “Why Research Partnerships Really Matter: Innovation Theory, Institutional Arrangements and Implications for Developing New Technology for the Poor”, *World* Development, Vol. 29, pp. 783-797.

Hall, A., N. Clark, R. Sulaiman V, M.V.K. Sivamohan, and B. Yoganand (2000), “New Agendas for Agricultural Research in Developing Countries: Policy Analysis and Institutional Implications, *Knowledge, Technology and Institutions*, Vol. 13, No. 1, pp. 70-91.

IPCC (2002), *Methodological and Technological Issues in Technology Transfer, A Special Report of WG III*, Cambridge University Press.

Keck, M.E. and K. Sikkink (1998), *Activists Beyond Borders: Advocacy Networks in International Politics*, Cornell University Press.

Kerr, J. and S. Kolavalli (1999), *Impact of Agricultural Research on Poverty Alleviation: Conceptual Framework with Illustration from the Literature*, EPTD discussion paper No. 56, IFPRI, Washington D.C.

KFPE (2001), *Enhancing Research Capacity in Developing and Transition Countries: Experiences, Discussions, Strategies, and Tools for Building Research Capacity and Strengthening Institutions in View of Promoting Research for Sustainable Development,* Swiss Commission for Research Partnerships with Developing Countries (KFPE), Berne.

Krattiger A. (2002), “Public-Private Partnerships for Efficient Proprietary Biotech Management and Transfer, and Increased Private Sector Investments”, *IP Strategy Today* No. 4, *Bio*-Developments LLC and Swift.

Krattiger A. (2004), "Financing the Bioindustry and Facilitating Biotechnology Transfer". *IP Strategy Today* No. 8, *Bio*-Developments LLC and Swift.

Leys, C. (1996), *The rise and fall of development theory*, Currey, London.

Lipton, M. and R. Longhurst (1989), *New Seeds and Poor People*, Unwin Hyman, London.

Maredia, M.K. and C.K. Eicher (1995), "The Economics of Wheat Research in Developing Countries: The One Hundred Million Dollar Puzzle", *World Development*, Vol. 23, pp. 401-412.

Mathy, S. (2002), *L'intégration des PED – Pays en Développement – Dans les Politiques Climatiques: Entre Recherche d'Efficacité Économique et Opportunités de Développement Propre* (Integrating Development Countries in Climate Policy: Between Economic Efficiency and Development Opportunities) *Économies et Sociétés*, Hors-Série, HS, No. 38, pp. 915-944.

Morris, M., and B. Ekasingh (2001), "Plant breeding research in developing countries: what roles for the public and private sectors", in: Byerlee, D., R. Echeverria (eds.). *Agricultural Research Policy in an Era of Privatization: Experiences from the Developing World*. CABI, Wallingford, UK.

Nottenburg, C., P.G. Pardey, and B.D. Wright (2002), "Accessing Other People's Technology for Non-Profit Research", *Australian Agricultural and Resource Economics Society*, Vol. 48, pp. 389-416.

OECD (2002), *Impact Assessments and Agricultural Biotechnology – Research Methodologies for Developing, Emerging and Transition Economies*. Global Forum on Knowledge Economy – Biotechnology, OECD, Paris.

OED (2003a), *The CGIAR at 31: A Meta-Evaluation of the Consultative Group on International Agricultural Research; Volume 1: Overview Report*. Operations Evaluation Department, World Bank, Washington D.C.

OED (2003b), *The CGIAR at 31: A Meta-Evaluation of the Consultative Group on International Agricultural Research; Volume 2: Technical Report*. Operations Evaluation Department, World Bank, Washington D.C.

Parayil, G. (1992), "The Green Revolution in India: a Case Study of Technological Change", *Technology and Culture*, Vol. 33, No. 4, pp. 737–756.

Parayil, G. (2003), "Mapping Technological Trajectories of the Green Revolution and the Gene Revolution from Modernization to Globalization", *Research Policy*, Vol. 32, pp. 971-990.

Pardey, P.G. and N.M. Beintema (2001), *Slow Magic: Agricultural R&D a Century after Mendel*. International Food Policy Research Institute (IFPRI), Washington D.C.

Pardey, P.G., J. Roseboom and N.M. Beintema (1997), "Investments in African Agricultural Research", *World Development*, Vol. 25, pp. 409-423.

Pardey, P.G., J.M. Alston, J.E. Christian, and S. Fan (1996), *Hidden Harvest: U.S. Benefits from international Research Aid*. International Food Policy Research Institute (IFPRI) Food Policy Statement 23. Washington D.C.: IFPRI.

Philibert, C. (2003), *Technology Innovation, Development and Diffusion*, OECD/IEA Information Paper, Paris.

Philibert, C. (2004), *International Energy Technology Collaboration and Climate Change Mitigation,* OECD/IEA Information Paper, Paris.

Pingali P.L. and P. Heisey (1996), *Cereal Crop Productivity in Developing Countries: Past Trends and Future Prospects*, Presented at the conference Global Agricultural Science Policy for the Twenty-First Century, Melbourne, Australia, 26-28 August.

Pingali P.L., and G. Traxler (2002), "Changing Locus of Agricultural Research: Will the Poor Benefit from Biotechnology and Privatization Trends?", *Food Policy*, Vol. 27, pp. 223-238.

Pray, C.E. (2001), "Public-Private Sector Linkages in Research and Development: Biotechnology and the Seed Industry in Brazil, China, and India", *American Journal of Agricultural Economics*, Vol. 83, No. 3, pp. 742-747.

Pray, C.E. and D. Umali-Deininger (1998), "The Private Sector in Agricultural Research Systems: Will it Fill the Gap?", *World Development*, Vol. 26, pp. 1127-1148.

Pray, C.E. and K.O. Fuglie (2000), "The Private Sector and International Technology Transfer in Agriculture", in K.O. Fuglie and D.E. Schimmelpfennig (eds.), *Public-Private Collaboration in Agricultural Research: New Institutional Arrangements and Economic Implications*, Iowa State University Press.

Reece, J.D. and J. Sumberg (2003), "More Clients, Less Resources: Towards a New Conceptual Framework for Agricultural Research in Marginal Areas", *Technovation*, Vol. 23, pp. 409-421.

Shiva, V. (1991), *The Violence of the Green Revolution*. Zed Books, London.

Spielman, D. (2003), *International Agriculture Research and the Role of the Private Sector*, The CGIAR at 31: An Independent Meta-Evaluation of the Consultative Group on International Agricultural Research: Thematic Working Paper, World Bank's Operations Evaluation Department, Washington D.C.

Traxler, G. and Pingali, P.L. (1999), "International Collaboration in Crop Improvement Research, Current Status and Future Prospects", CIMMYT Economics Working Paper No. 11. CIMMYT, Mexico, D.F.

Tribe, D. (1994), *Feeding and Greening the World: The Role of International Agricultural Research*, CAB International, Wallingford.

Tripp, R. (2003), *Strengthening the Enabling Environment for Agricultural Technology Development in Sub-Saharan Africa*, Working Paper 212, Overseas Development Institute, London.

Wade R.H. (2003), *Governing the Environment: The World Bank and the Struggle to Redefine Development*. Unpublished manuscript.

Worrell, E. and M. Levine (2002), *Industry*, in IPCC, *Methodological and Technological Issues in Technology Transfer, a Special Report of WG III.* Cambridge University Press.

Wright, B.D. (1999), *IPR Challenges and International Research Collaborations in Agricultural Biotechnology,* Paper presented at the Conference "Agricultural Biotechnology in Developing Countries: Towards Optimizing the Benefits for the Poor", organized by ZEF and ISAAA in collaboration with AgrEvo and DSE in Bonn, November 15-16.