TECHNOLOGY AND ITS CONTRIBUTION TO PRO-POOR AGRICULTURAL DEVELOPMENT

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1. Executive Summary

Given that improving the efficiency of agricultural production is a key to pro-poor economic growth, improvements in agricultural technology are the principal means of doing this.

Agricultural technology can affect smallholder income, labour opportunities for the poor, food prices, environmental sustainability, and linkages with the rest of the rural economy:

- Agricultural technology has been a primary factor contributing to increases in farm productivity in developing countries over the past half-century. Although there is still widespread food insecurity, the situation without current technology development would have been unimaginable.
- New technology can provide additional rural employment, but there are always countervailing pressures to reduce labour input and lower its costs.
- Food prices are demonstrably lower because of technology, but the distribution of benefits between consumers and producers depends on the nature of the local economy and trade patterns.

The adoption of technology requires adequate incentives for producers. Investments in labour or cash will not be made unless there are adequate returns. One of the most important supporting factors is the adequacy of markets for outputs and inputs.

Although there is much academic debate regarding the nature and impact of technological change, the important issues for development assistance agencies are related to other uncertainties. These include:

- identifying the most effective planning procedures for directing agricultural technology to poverty reduction;
- establishing the role of agriculture in national development strategies;
- deciding the degree to which agricultural investments are appropriate for marginal areas;
- identifying the correct mix of public, private and civil society support to agricultural technology generation;
- and identifying the types of technology that warrant support.

Because agricultural technology addresses multiple, and at times conflicting, objectives, there is a need for careful planning. But there is a trade-off between investment in micro-level technology screening, on the one hand, and support to basic institutional capacities and political responsiveness, on the other. The rhetoric of technological revolutions should be eschewed in favour of consistent attention to building technological capacity in response to changes in the rural economy. One of the most difficult choices is that facing the appropriate level of (agricultural) support for poverty reduction in marginal areas.

An important challenge is marshalling sufficient (and coherent) support for public research and extension in the face of severe constraints in development budgets. Private sector technology generation (and technology delivery) is of growing relevance to poverty reduction strategies, but it is probably unreasonable to place high expectations on vastly expanded formal public-private partnerships. Support to

NGOs in agricultural technology generation should focus on their role in building local institutions and capacities; a strong rural civil society is essential for articulating technology demand.

There are no easy rules for guiding investments in particular types of technology, and pragmatic, case-by-case analysis and follow-up is required. Much current rhetoric (e.g. related to biotechnology or low external input agriculture) does little to promote responsible policies.

Among the most important **policy challenges** related to support for agricultural technology are:

- the identification of an effective investment portfolio of technologies;
- structuring interchange among producers, consumers, public institutes (national and international), civil society and the private sector to elicit effective pro-poor demand;
- structuring assistance to recognise the long-term, incremental nature of technology generation;
- locating technology policies in a wider policy arena; and
- setting and articulating clear policy goals that relate technology generation to food price, labour, trade, and regional development.

There are a number of implications for the way that donor assistance to agricultural technology is structured. The agencies need to develop in-house capacity to monitor the processes and outcomes of agricultural technology generation. This implies a commitment to developing institutional memory and to coordinating central syntheses and guidance with country-level experience. Policies in support of agricultural technology generation should place strong emphasis on local institution building and should see that agriculture is addressed in a coherent fashion in poverty planning. An understanding of the multiple impacts and second-order effects of technology should inform the policy process. Finally, donor agencies need to increase their collaboration and co-ordination in support of technology generation.

2. *What is the issue?*

In many parts of the world – particularly South and East Asia – growth in agricultural productivity has been rapid, largely as a result of the extensive adoption of new agricultural technologies. For millions of poor people, particularly in Asia, the technological advances of the Green Revolution (complemented by a massive increase in irrigation) provided a route out of poverty through: directly increasing producer incomes and wages; lowering the price of food; and generating new livelihood opportunities as success in agriculture provided the basis for economic diversification. Asian industrialisation was in essence agriculturally led (Timmer, 1988).

The picture is not, though, one of universal success. Despite decades of investment in new agricultural technology, hunger and poverty continue to plague large areas of the developing world. The problem is particularly acute in areas of the world dependent upon rain-fed agriculture, in particular sub-Saharan Africa, where the impact of new technologies has been less apparent and agricultural productivity has at best stagnated, and may even have fallen in some areas.

Achieving the Millennium Development Goal of halving the proportion of people living in absolute poverty by 2015 will require agriculture to play a major role. Increasing agricultural productivity remains perhaps the single most important determinant of economic growth and poverty reduction, and hence provides the key to achieving the MDGs. This fact is not lost on developing countries and their development agency partners, who are seeking ways to stimulate agricultural development, in particular to increase productivity, as a corner stone of their growth and poverty reduction process.

But questions remain about technology's role in agricultural development, and debate continues in a number of areas, specifically:

- can technological development be pro-poor and, if so, how can it be more so?
- how can the poor benefit from the rapid improvements in knowledge and technology being achieved in the private sector?
- what role is there for bio-technology
- if, as many accept, agricultural research has an important public good implication, are we spending enough on it, and are we spending in the right places?

A better understanding of the impact of new agricultural technology on the lives and livelihoods of the poor will help us find out at least some of the answers to these questions.

The paper examines the evidence concerning the impact of technology change on agriculture and poverty and highlights remaining areas of uncertainty, specifically issues related to the role of agricultural technology in pro-poor development.

Although this paper does not attempt to be comprehensive, it assumes a broad definition of agricultural technology. This includes: the products of plant and animal breeding (including biotechnology); the introduction of new crops; improved management practices relating to crops, livestock and fisheries; mechanisation; infrastructure development; external inputs (including chemicals, biocontrol products and veterinary products) and local inputs (soil amendments, mulches, etc). It also considers the dissemination of agricultural technology as a key aspect of an effective system.

3. The current evidence

3.1 Increasing agricultural productivity is central to reducing poverty – Technology's Role

Agriculture plays a unique role in reducing poverty. Partly this reflects the sheer numbers of poor people engaged in it. Around 75% of those surviving on less than US$1 a day - the internationally agreed definition of absolute poverty – live in rural areas (IFAD, 2001) and agriculture is an important livelihood source. It is estimated that 70% of sub-Saharan Africa's labour force and 67% of South Asia's, works in agriculture (Maxwell, 2001).

But the argument in favour of agriculture as *the* poverty-alleviating sector *par excellence* rests on more than population statistics. Improvements in agricultural productivity have a powerful knock-on effect to the rest of the economy by: creating jobs in neighbouring sectors such as food processing and input supply as well as directly in farming; increasing the supply of affordable food; and stimulating and supporting wider economic growth and development.

To the extent that technology raises agricultural productivity, it should be the major factor in creating these positive effects. Thirtle *et al* (2003) explored the relationship between agricultural productivity and poverty. They drew on observations between 1985 and 1993 in 48 developing countries and found that a 1% improvement in crop yields reduced the proportion of people living on less than US$1 per day by between 0.6 and 1.2%.

No other sector has demonstrated such a comparably high impact on poverty. Thus, Lipton (2001) argues that no other sector than agriculture offers the same possibilities to create employment and lift people out of poverty. Indeed, the adoption of new technologies and subsequent increases in agricultural productivity in different parts of the world explain, in large part, the regional differences in the reduction of poverty over the last few decades. Nkamleu *et al.* (2003) calculate changes in agricultural productivity in 10 countries in sub-Saharan African countries between 1972 and 1999. In contrast with significant progress in Asia, Nkamleu *et al* found that, on average, total factor productivity decreased in that period by 0.2% annually. They suggest that, whilst efficiency was constant, technological change was the main cause of the failure of total factor productivity to increase.

3.2 How widespread has the adoption of new technology been?

Technological change in agriculture began at least 10,000 years ago, when the first cultivators selected wild plants and experimented with different growing environments. From those early beginnings, the technical performance of agriculture in the great civilizations remained roughly equivalent for centuries until the middle of the nineteenth century, where, principally in Europe and North America, the introduction of new machinery and sources of power (Grigg, 1974), the rediscovery of Mendel's experiments leading to the development of scientific plant breeding, and the development of artificial fertilisers, resulted in rapid increases in agriculture's productivity.

Rapid technological change – leading to marked productivity increases - has clearly occurred in parts of the developing world, primarily over the last half century. This was particularly apparent during the **Green Revolution** - a term originally applied to the spread of short-straw, fertiliser-efficient new varieties of rice and wheat, primarily, though not exclusively, in Asia.

Throughout the developing world, average cereal yields increased by 2.7% per annum between 1966 and 1982 (IFAD, 2001). Performance in South Asia was especially impressive, where, between the mid-1960s and the mid-1980s, wheat yields increased by 240% and those of rice by 160% (Kerr and Kolavalli, 1999). Gains from new technology have also occurred in other crops and regions, thanks in large measure to investments in agricultural research and extension.

Since the mid 1980s progress in the rates of productivity increases achieved has slowed - the annual rate of increase in developing country cereal yields falling to an average of 1.7% (IFAD, 2001). While some commentators point to reductions in external assistance to developing country agriculture as a cause of this (Pinstrup-Andersen et al., 1997), a slow-down in productivity gains is almost certainly attributable - in part at least - to the Green Revolution 'running out of steam,' having achieved the easy gains under relatively favourable conditions in its early phases.

The spread of new technologies has been impressive, particularly improved "modern varieties" (MVs) of grains. By 1990 MVs represented an estimated 74% of rice, 70% of wheat and 57% of the maize grown in the developing world (Byerlee, 1994). Although these figures reflected in part the Green Revolution package of seed, fertiliser and irrigation, a substantial proportion of these MVs are grown with low or no external inputs (Byerlee and Lopez-Pereira, 1994).

But the story is not just confined to cereals, or to the development of yield maximising varieties. New technologies have also been developed for non-cereals, and many MVs have been developed principally for their resistance to pests and diseases. For example, improved cassava varieties have spread rapidly in parts of West Africa (Nweke *et al.*, 2002) and research undertaken in Nigeria in the 1970s was fundamental to the development of cassava resistant to mosaic virus in Uganda nearly two decades later (Otim-Nape et al., 2000). New disease-resistant bean varieties have been extensively adopted by most small-scale farmers in western Kenya (David et al., 2002). New varieties of potato, sweet potato, pearl millet, sorghum, groundnut, pigeon pea, soybean, chickpea, lentil, durum wheat and barley have also increased the yields, particularly of resource-poor farmers.

Advances in crop management technology have also occurred but these are often less visible and tend to be under-reported compared to the spread of new varieties, but these too have made significant contributions to increased agricultural productivity. For example, agroforestry research has led to the widespread adoption of improved fallows in eastern Zambia, making an important contribution to soil fertility and increased yields (Franzel et al., 2002). The adoption of reduced-tillage practices in Brazil has increased productivity on more than 500,000 hectares (Landers, 2001). Significant advances have also been made in the management of tillage, crop establishment and weed control in many areas of Asia (Hobbs et al., 2000).

3.3 What influences the adoption of new technology by farmers?

A range of factors appears to have been critical in determining the rate at which farmers have innovated new ideas and so been able to raise productivity for the benefit of growth and the pace of poverty reduction.

Secure output markets

Farmers will innovate to increase subsistence production, but as innovation generally implies some type of investment (in cash, labour or learning) the chances of farmers investing and innovating are greatly enhanced by the existence of secure markets. As the evidence shows, it is difficult to overestimate the importance of reliable output markets as an incentive to new technology adoption.

Dorward et al. (2004) argue that a key feature of many successful early Green Revolution environments was government's role in stabilising output prices, a function which has been progressively dismantled in Africa where innovation has been limited. Wiggins' (2000) survey of African case studies found a number of success stories that contradict the general pessimism about African agriculture, but virtually every one was associated with well functioning output markets. In Malawi, Orr and Orr (2002) argue that unreliable maize markets lock many farmers into inefficiently producing as much of their own grain needs as possible, rather than innovating with new crops in which they may well have a comparative advantage.

Effective input supply systems, including credit

While there is danger in relying too heavily on "technology on the shelf", effective input supply systems are essential, particularly when technological change or advance depends on purchased inputs. Inadequate formal seed supply systems have been shown to dampen, or even preclude the diffusion of new crop varieties (Tripp, 2001). Increasing fertiliser use has long been plagued by difficulties in providing the right products in affordable pack sizes (Omamo and Mose, 2001).

Establishing the systems to provide those inputs is, however, one of the major challenges for many technologies, and not merely the conventional seed-and-chemical technologies. Delivery of tissue culture banana plantlets in Africa requires the development of a network of intermediary nurseries (Wambugu and Kiome, 2001). Nurseries are also crucial for the spread of many agroforestry technologies, and efforts at encouraging farmer groups to take on this role have largely failed (Bohringer and Ayuk, 2003). The delivery of veterinary technologies depends largely on the delivery role of the private sector (Leonard, 1993).

But an operational system of input provision is often ineffective in the absence of effective credit systems. Previous experiences with state-subsidised credit provision have received much justified criticism (Adams and Vogel, 1990) and new approaches are being considered, including linking input supply and output procurement (Dorward *et al.*, 1998).

Supporting infrastructure – particularly irrigation

The presence of supporting infrastructure is fundamental to effective innovation on new technology and was a major factor in Asia's successful Green Revolution. Roads are critical to supporting input and output marketing (Dorward et al., 2004), but the expansion of irrigation probably constituted the most important element of supportive investment.

The expansion of irrigation in developing countries has been greatest where attaining increasing agricultural output through land expansion has been difficult and so gains are made by intensification. Thus, both South and East Asia have a much higher use of irrigated land use compared to Africa (Table 1). By 2030, it is projected that about 80% of future production gains will be made from intensification (in part dependent on irrigation) with a much smaller proportion through land expansion (de Haen *et al.*, 2003).

Table 1: Irrigation in Africa and Asia, 1961/1963 – 1997/1999

	Irrigated Land in Use (million ha)		
	1961/1963	1979/1981	1997/1999
East Asia	40	59	71
South Asia	37	56	81
Sub-Saharan Africa	3	4	5

Source: FAO (2003)

Risk and vulnerability

The relationship between risk and technology use is a perennial theme. It can work in two directions. First, the adoption of agricultural technology can make a limited contribution to reducing the vulnerability of the poorest. Examples include the adoption of drought resistant varieties that **reduce the risk** of crop failure because of drought. The use of irrigation can enable double cropping and lengthen the growing season, thereby smoothing production and consumption, and **mitigating** against the impact of price volatility.

Second, there can be trade offs between growth through agricultural technologies and risk since taking up new agricultural technology is, in itself, risky. Whilst improved productivity through agricultural technology can lead to increased incomes, adoption is associated with capital and transactions costs that poor people may not be able to afford. Furthermore, poor farmers struggle to control production uncertainties. Whilst there are some instances of very poor people investing in quite risky technology (e.g. cotton farming in much of South India), on the whole, because **poor people are risk averse**, they tend to benefit less than others from agricultural technologies and stick with low risk, low return activities.

3.4 But have the poor benefited from new agricultural technology?

For many the key question remains: to what extent, and in what circumstances, have poor people benefited from new agricultural technologies or have the benefits been confined to the better off? Assessing this “distributional” impact of new technology is difficult, not least as the uptake of innovations is inevitably skewed with the better-off usually being “early adopters.” Propositions regarding distributional impact should therefore be carefully specified, and any assessment of ultimate impact should not be based on the adoption pattern seen in the early years after technology release. (Rogers, 1994).

Among the most useful (but rarest) assessments of technology’s impact on poverty are those that follow farming communities’ experiences over a longer-term period (Lanjouw and Stern, 1998; Hazell and Ramasamy, 1991). These studies tend to show that the poor have benefited from new technologies, principally through increased employment opportunities and higher wage rates.

On the other side, a review by Freebairn (1995) of over 300 other studies related to the Green Revolution revealed a general increase in inequality **between regions** as a result of technology uptake. This conclusion however, requires qualification. First, it is inevitable that technological advance will lead to an adopting area becoming relatively better off compared with a non-adopting area. This simply underlines the importance of balancing investment in technology generation between marginal and favoured environments. Secondly, the review itself identified the difficulties in separating the impact of technological change from concomitant changes in population, policies or land tenure.

Rigg (1989), identified a similar issue: many negative assessments of the poverty impact of the early Green Revolution are examples of 'guilt by association' – the technology was seen as responsible for increasing inequality which was primarily the result of other factors including: farm concentration, urban migration, and so on, which accompanied technology dissemination.

Most of the evidence about the poverty reducing effect of agricultural technology comes from Asia. In Africa there are far fewer examples of where agricultural technology has benefited poor people. However, evidence from Zimbabwe reveals a post-independence Green Revolution amongst smallholders which had a very significant impact on poverty. This was achieved through the introduction of hybrid maize, expanded access to credit, guaranteed prices and marketing subsidies. The outcome was a doubling of maize production between 1980 and 1986 (Eicher, 1995).

3.5 How does new agricultural technology benefit the poor?

A number of factors influence the extent to which the poor benefit from changes in agricultural productivity through the adoption of new technology. These are discussed below, beginning with the two most important factors – impacts on employment and food prices.

The impact on employment

Employment on the farms of others is of critical importance to the livelihoods of the poor. This is not just true for the classically landless, employment is also a vitally important way for many farmers to supplement their incomes. The impact of new technology on labour markets – specifically its impact on the demand for labour and wage rates - is of great importance to the poor. Most evidence on this issue comes from the Asian Green Revolution experience and, while often technology-specific, a number of general principles emerge with respect to the impact of new technology on the demand for labour and wage rates.

In terms of the impact on the **demand for labour**:

- the adoption of high yielding rice and wheat varieties generally increased demand for labour due to the higher harvesting and threshing requirements associated with their greater yields
- the majority of additional labour used was hired rather than family labour (Lipton and Longhurst, 1989). This is particularly important for the poorest
- increased labour demand was greatest when new varieties were introduced into high potential areas and often associated with an increase in cropping intensity. The impact was less pronounced when in low potential areas. (David and Otsuka,1994; Lipton and Longhurst, 1989).

The impact on **wage rates** is more difficult to determine because there are numerous causal, and on occasion counteracting, factors. Some conclusions can be drawn though, including that:

- generally wages appear to have increased (IFPRI, 2002)
- labour saving technology has probably dampened the rate of wage increases, although this does not means that wages have fallen because of the adoption of new technology. Lipton and Longhurst (1989), show that while a doubling of yields increased wages by 40% early in the Green Revolution, a similar yield increase 20 years later resulted in only a 10-15% increase in wages due to mechanisation. Bautista (1997) describes disappointing increases in the demand for agricultural labour in the Philippines, explained in part by subsidised farm mechanisation
- in some cases, e.g. herbicide adoption in rice systems (Naylor, 1994), the introduction of labour-saving technology has been a response to rising rural wage rates caused by growth in non-farm wage rates
- even where wage increases have been modest, the adoption of new technology has frequently increased the number of employment days, and on occasion, facilitated the introduction of contracts for casual labourers (Leaf, 1983).

Food prices

For the poor, the price of food is critically important given the relatively larger proportion of their income generally spent on it. A relative lowering of food prices – particularly of staples - allows the poor to eat more and possibly better which has a positive impact on nutrition, health and food security. But cheaper food also releases income which can be spent on other goods and services with immediate positive benefits to the poor such as improved shelter or access to key services such as health and education. This release of income also creates demand for goods and services which can have a powerful multiplier effect on the wider economy.

In many developing countries - and for the developing world as a whole - increases in the production of staple foods have comfortably outstripped population growth since the mid-1960s when the Green Revolution began to be adopted widely. Only in Sub-Saharan Africa have food supplies grown slower than population during the last thirty years.

Given this significant increase in per capita supply, and the relatively low elasticity of demand for basic foods, the real world market prices of the major traded grains have steadily fallen since the early 1950s. At the individual country level, increased production of food grains can have a dramatic effect on prices. This is of great benefit to the poor, both in urban and rural areas, where many people buy, as well as grow their own food. (De Janvry and Sadoulet, 2002; Jayne *et al.*, 1999).

But increasing production can also be a double-edged sword if it reduces prices to the extent that producer incomes fall. However, where productivity increases due to technology match or even outpace the corresponding fall in prices, both net consumers and net producers can benefit. Bangladesh provides an excellent example of this. Between 1980 and 2000, production of rice and wheat increased from below 15 to over 25.7 million tonnes, increasing per capita availability over the same period from 425 to 510 grams per day, despite population increasing over the same period from 90 to 191 million people. Real wholesale prices in Dhaka markets of rice and wheat have consequently fallen dramatically, with the price of rice falling from just over Taka 20 to around Taka 11 per kg in two decades.

But despite declining market prices, farmers have successfully increased their production, yields and incomes - rice yields have risen from an average of 2 tonnes to over 3.4 tonnes per hectare by the early 2000s – through the use of new varieties, fertiliser and, above all an expansion of irrigation. These improvements have allowed farmers to cut their unit costs of production and so offset the impact of falling prices on their incomes. It also appears that smaller farmers have not been excluded from this technology.

Nutrition and food utilisation

There are numerous examples of how agricultural technology has benefited the nutritional status of poor households. These include:

- improved varieties with increased vitamin content that contribute to the reduction of human disease;
- post-harvest fortification of crops to reduce vitamin deficiencies;
- longer cropping seasons to regulate food supply and reduce the number of months that households go hungry; and
- improved storage and processing to extend the shelf-life of food and reduce waste.

Access to land and other resources

The extent to which agricultural technology can benefit poor people clearly relates to existing inequalities in land and access to other resources. There are various explanations of why poor people stay poor that are couched in terms of the allocation of land and other resources.

There is concern that technologies may exasperate inequality in access to productive resources. One major criticism of the early Green Revolution was the fact that early adopters tended to be larger (richer) farmers. (Indeed, a large proportion of subsidies for Indian farmers continue to go to richer farmers (Gulati & Narayanan, 2003)). These farmers were able to take greater risks and gain economies of scale from applying new technologies to larger land holdings. Evidence suggests that, subsequently, smaller farmers caught up and, in some cases, took better advantage of the new technology (Lanjouw and Stern, 1998; Hazell and Ramasamy, 1991). Nevertheless, it is widely accepted that, initially at least, technology is an unlikely way to overcome major inequalities in access to basic resources, especially land.

Gender issues

Gender-related effects of technology change are often important in determining the impact of adoption on poverty. Technology generation has tended to favour crops traditionally grown by men, who frequently have greater access to labour, markets, credit and other inputs than women to a degree that may impact negatively on the intra-household distribution of income and consumption (Doss, 2001).

Addressing these challenges goes well beyond technology design, as male-dominated societal rules and norms, and a complex household environment of ‘joint decisions, multiple objectives and mutual dependence' (Bonnard and Scherr, 1994) make it difficult to target, or predict the gender-related outcomes of technology development. Simply targeting technology to women's crops is not necessarily the answer. (von Braun and Webb, 1989).

3.6 Sustainability issues

Whilst new technologies are important for poverty reduction, if not carefully managed, they can create additional demand on resources which may simply not be sustainable in the future. The most obvious example of this is water, for example the lowering of water tables and loss of aquifer water, but other resources, including biodiversity and chemicals, are also discussed here.

Irrigation and water resources

The area of irrigated farmland has tripled since 1950 (Smil, 2000). As Table 1 shows (above), the expansion has not be evenly distributed, with much greater increases in irrigation in South and East Asia. Irrigation has, undoubtedly, been a central component in poverty-reducing agricultural growth. But poorly managed irrigation has led to falling water tables, salinisation and other problems.

Salinisation

Rosegrant *et al.* (2002) review evidence of salinisation. They argue that on a global scale there are about 20-30 million hectares of irrigated land that are severely affected by salinity. Furthermore, an additional 60-80 million hectares are affected to some extent by waterlogging and salinity. Some salinisation would have happened even without new technology but some has been encouraged by unsustainable subsidisation of irrigation.

Chemicals

The indiscriminate use of chemicals has also caused problems; Rola and Pingali (1993) showed that pesticide use on rice in the Philippines results in negative economic benefits if human health costs are included in the analysis.

Biodiversity

Technological advance is often blamed for the loss of biodiversity, but the issues here are complex. Agricultural expansion generally has caused habitat destruction and, at the local level, productivity increases can attract new farmers to the agricultural frontier by making farming more profitable. But yield increases achieved through new technology have curbed deforestation and the cultivation of marginal lands. If world crop yields had remained at their 1960 levels, another 800 million hectares of land (equivalent to the Amazon River basin) would have had to be brought into cultivation to meet current demand (Ausbel, 1996).

Modern crop varieties have frequently displaced many local varieties. But the relationship of these changes to overall genetic diversity is difficult to unravel. Recent work shows that the uptake of wheat MVs has not lowered genetic diversity (Smale, 1997) as farmers often adopt a new crop variety and grow it alongside their traditional varieties.

4. Emerging issues in technology development

Few would disagree that continued technological progress is critical to fulfilling agriculture's potential role in growth and poverty reduction. This point accepted, agricultural technology continues to attract considerable controversy and debate. This next section outlines some of the more significant of these debates.

4.1 Can we really match technology development to fit agriculture's future role in growth and poverty reduction?

The focus of technology development will, at its most fundamental level, need to be guided by an understanding of the future direction of agriculture in the developing world and an appreciation of the (changing) ways in which it will contribute to growth and poverty reduction. While small-farm agriculture focusing on increasing yields of basic grains provided the script for technology development in the Green Revolution, this may not remain the case in the future.

In order to set the general direction for coherent and inevitably long-term investments in research and technology for agricultural development, we need a vision of where agriculture will be in twenty years time. Is there agreement on where agriculture is heading or should head? The answer is probably no, and the debate about the future shape of agriculture and the ways in which it will impact upon the poor remain contested (Ashley and Maxwell, 2001). What is clear, however, is that many factors will influence and combine (possibly with counteracting effects) to "shape" agriculture in the future, and with it the demands and opportunities for technology development. Key amongst these include issues relating to:

- the future viability of smallholder agriculture as a means of generating growth and reducing poverty
- the implications of changes in diets – particularly the increased consumption of animal products in many large developing countries
- changes in international agricultural trade regimes which may have a major role in determining what parts of agriculture are profitable
- changes in the non-farm rural economy.

Hypothesising such a complex future is difficult. But can it be done? And will the results be worth having? Probably only time will tell, but one attempt (Hazell and Haddad, 2001) provides a matrix illustrating how different types of technology might be targeted to different regions, depending on: whether the country is middle or low income; has liberalised markets; has scarce or surplus labour; good or poor infrastructure, and high or low agricultural potential. Similarly, the World Bank has proposed an International Assessment of Agricultural Science and Technology for Development (IAASTD) to explore future technology needs. Given the broad range of perspectives on agricultural trajectories, it will be a significant challenge to establish a common view on research and technology priorities.

4.2 Can technology development be targeted to benefit the poor most?

Is it possible, or indeed wise to attempt to target investment in research in order to maximise poverty reduction? Some commentators, drawing on experiences from the past have raised precisely this question.

For instance, Lipton and Longhurst (1989) challenged support for public research on mechanical innovations and herbicides in Asia on the grounds that these would reduce the demand for labour in areas with large landless populations. Adams (1995) showed how analysis of the distribution of rural incomes could identify the priorities for investment in specific agricultural enterprises for the purposes of improving equity. Similar analytical approaches and techniques have been devised for research planning (e.g. Mills, 1998; Cox et al., 1998).

However, the multiple objectives involved in planning for the development and dissemination of agricultural technology are exceptionally challenging, and any new technology may set off a series of second-order adjustments - related to institutions, competing enterprises, labour markets, and so on - that are very difficult to predict. These factors lead to some sober warnings about the limitations of planning to maximise impact on the poor.

Alston et al. (1995) acknowledge that different technology development strategies can have profound and quite different effects on equity. They consequently urge that other policy instruments must be in place to correct for negative impacts, and conclude that it is unwise to rely solely on agricultural research as a primary instrument for the pursuit of objectives other than economic efficiency. Byerlee (2000) concludes that research in terms of improving broad-based efficiency will often produce greater benefits for the poor than those efforts which seek to specifically target poverty alleviation.

4.3 Is investing in technology development for marginal areas warranted?

"Marginal areas" are variously defined, but tend to be characterised by relatively low agricultural potential, poor infrastructure, weak integration with the rest of the economy and high levels of poverty. Inevitably, agricultural innovation is less common in these areas, but they have been and remain the focus of efforts to reorient agricultural technology generation and dissemination to suit their "special" needs. But how much effort should be given to developing new agricultural technology for these areas, or should resources be concentrated in areas of greater potential?

On the positive side, marginal areas offer significant opportunities for the design of agricultural technologies, often emphasising low-input solutions. But where agriculture in marginal areas becomes less important to poor people's livelihoods as they seek employment opportunities outside the sector, so the poverty impact of increasing agricultural productivity will decline. At the same time, and as history shows, the benefits of new technology development for the poor have occurred largely through the impact on wage employment and food prices of increasing productivity in areas where productive potential is greatest.

So where should limited resources for technology development be focussed? The issues involved need to carefully considered and evidence can be shown to support both views (Renkow, 2000; Fan et al., 2000). Perhaps the only conclusion here is that policy makers must present clear strategies based on an understanding of the impact of technology change and increasing agricultural productivity on poverty.

4.4 What future is there for public (national and international) agricultural research and extension services?

Much agricultural research and extension in developing countries can be seen as a public good and it is important to identify appropriate strategies for supporting it.

National systems of research are often poorly resourced and funded reflecting the tight fiscal reality of many developing countries. A major imperative for development agencies is to work towards better co-ordinated, long-term strategies for supporting public agricultural research in the developing world so that efforts become less competitive and greater predictability in support can be assured.

International public research remains centred principally around the Consultative Group on International Agricultural Research (CGIAR). Despite a difficult recent past, the CGIAR has emerged with a strong science council, active and productive standing panels and an effective secretariat. Funding for the CGIAR has held up well with more now being channelled into core funding. There is renewed conviction to work better with national agricultural research systems and farmers' groups.

New conditions certainly require new strategies. Competitive research funds are one option. They help direct research towards well-defined targets; provide incentives for the participation of a wider range of technology providers (beyond the national research service) and encourage links between NGOs, farmer groups and research organisations (Reifschneider et al., 2000; Bingen and Brinkerhoff, 2000). But these funds also have certain limitations. It may be argued that they are simply another way of providing external support to research and do not resolve long-term issues of institutional strengthening. In some cases their transaction costs may outweigh any benefits from the delivery of new technology. In addition, they tend to be best at supporting short-term research and do not necessarily provide support to more strategic research objectives and capacities.

Public extension is also undergoing major change and pressures. The traditional notion of extension as a hierarchical organisation responsible for transferring technology to farmers, no longer seems viable. Various proposals for revitalising extension, often involving greater decentralisation, more accountability and diversified service provision, have been or are being considered. (Alex *et al.,* 2002). For instance, several countries (e.g. Uganda, Benin) are developing forms of demand-led extension.

However, a number of unresolved problems afflict even these initiatives. The move towards more decentralised, demand-led approaches, while sensible, is based on assumptions about the emergence of responsive decentralised government, the capacities for aggregating and articulating dispersed demand, and the degree to which such institutional changes will reduce the need for external financial support. Calls for extension to be more of a catalyst in support of diversifying rural economies, with extension offices providing a wide range of information services and links, are also increasing, but there is little evidence of where the necessary information and skills are going to come from, nor of how best to structure incentives for extension personnel to play such a brokerage role. Similarly, the hopes that a portion of extension services can successfully become a private activity are not backed by evidence.

4.5 How best to tap the growing importance of the private sector – what role for Public-Private-Partnerships?

One of the most notable changes in the structure of agricultural research in recent years is the growing importance of the private sector. Recent years have seen the increasing use of purchased inputs whose characteristics, combined with the increasing scope of intellectual property protection, make them 'appropriable' and subject to private investment. Compared to the public sector, the private sector has seemingly boundless financial resources. This emphasises the importance of directing public investment to those research areas not covered by the private sector, and of using public policy to guide private investment towards poverty reduction goals.

Recognising the importance of accessing technologies developed by the private sector, policy makers are demonstrating increasing interest in the concept of public-private-partnerships (PPPs). The idea is attractive, but there are relatively few instances where collaboration has benefited poor people (see Box 2 for one example).

Box 2: The CIAT-Papalotla Agreement: An example of public-private cooperation

Since 1987, CIAT has worked to improve the resistance of *Brachiaria* sp., a tropical grass upon which the pastoral-based livelihoods of millions of people in tropical America depend. A Bracheria network was established, based in Columbia but, following structural adjustment in Latin American countries, neither the public seed industry nor CIAT had the capacity to market the new cultivar.

To fill this gap CIAT formed a strategic alliance with Papalotla, a Mexican seed company that CIAT felt could do business at a multinational level and could guarantee a rapid and wide diffusion of the new hybrids.

Within two years, seed to plant more than 25,000 hectares was produced and marketed in several Latin American countries and livestock producers in tropical regions were starting to reap environmental and economic benefits from the new hybrid. Papalotla and CIAT are now carrying out trials in Thailand, the Philippines and Laos and there are plans for similar trials in Africa.

One recent review found few successful partnerships, and an even smaller number that contributed to poverty reduction (Spielman and von Grebmer, 2004). A review of Latin American cases of collaboration in agro-industrial initiatives found these to be mostly driven by public funds and rarely achieving sustainable partnerships (Hartwich *et al.,* 2003) and a review of over 200 transgenic crop varieties developed by public research shows that only a small percentage were the product of PPPs (Atanassov *et al.,* 2004).

Although there may be further possibilities, differences in incentives, concerns about transaction costs, and lack of information limit immediate development of PPPs (Spielman and von Grebmer, 2004). The need for attention to legal, regulatory and intellectual property concerns in PPPs justifies the existence of the recently created African Agricultural Technology Foundation (AATF).

Considerable hope is also being vested in the concept of private extension, but further examination of this is needed. One innovative aspect is the separation of provision of funding from service provider thus opening the way for public funds to be used by farmers to “buy” services provided by the private sector. While this opens the way for the more efficient delivery of a wider range of extension options, it does not obviate the need for public funding which remains perhaps the key constraint. The number of instances in which resource-poor farmers will be willing to pay the full cost of extension advice is very limited. When private extension is a possibility, it must rely either on effective decentralised government or robust farmer associations (Chapman and Tripp, 2003). The diversification of extension strategies is important, but there are probably fewer opportunities for relying on private provision than there are in agricultural research.

4.6 Defining a role for NGOs

A growing amount of internationally-funded agricultural research and extension is channelled through NGOs of various types. A recent review of research impact, found that NGOs tended to have a better reputation among farmers than government agencies, and were better at targeting the poor. However, there was considerable variation in competence, integrity and procedures (Meinzen-Dick et al., 2003).

Support to NGOs in agricultural technology development and dissemination needs to include some vision of long-term objectives. One common and important goal for NGO work is the development of strong farmer organisations, but these need to be sustainable and should not simply be a response to short-term project objectives. It may be argued that too much emphasis has often been given to the mere formation of local organisations and not enough to linking them to external agencies and other services.

NGOs can and do fill in where public extension fails, but, if this is the rationale, attention should be given to finding long-term solutions. In addition, extension requires technical experience, and there are too many examples of NGO and community development projects taking on technical responsibilities that are beyond their competence. Haggblade and Tembo (2003) found that a number of NGOs dropped out of promoting conservation tillage with farmers in Zambia because of a lack of technical skills among staff. Development support for NGOs in agricultural technology development and dissemination needs to pay attention to long-term goals and capacity in specific fields.

4.7 Biotechnology

Biotechnology is probably the single, most controversial topic in contemporary agriculture. However, not all aspects of biotechnology engender strong debate. Techniques such as marker-assisted selection and DNA fingerprinting are widely-used without attracting criticism. But biotechnology also includes techniques for the transfer of genes between species and this is the source of considerable debate (Tripp, 1999). Concerns have essentially focussed on four issues.

First, environmental concerns relating principally to the possibility of out-crossing of transgenic traits to other varieties or related wild species. This concern varies greatly by crop, trait and environment and has been the cause of significant investment in biosafety regulation (McLean et al., 2002).

Second, food safety issues, although less well defined, and range from concerns about antibiotic resistant marker genes to the definition of organic produce. No evidence has yet been found to support concerns that genetically modified foods are dangerous for human health.

Third, concerns around the control and ownership of biotechnology. Most investment in biotechnology comes from the private sector and many of the relevant genes, key processes and tools are now patented. There is widespread concern that the benefits from transgenic crop development will be captured by a relatively small number of companies, and that potentially important technologies will not be available to resource-poor farmers.

The issue of access to intellectual property is far from being resolved, but initiatives are under way to promote its more effective sharing (Graff and Zilberman, 2001). Some commentators believe that in many cases developing country scientists can use 'protected' technologies with impunity because patent rights are assigned at the national level and most products in developing countries will not enter international trade (Nottenburg et al., 2001). Others note that patents expire, and some of the more important transgenes are near the end of their patent protection. In addition, seed companies can license the technology. For instance, at least a dozen private Indian seed companies now have legal access to one or another Bt gene for cotton.

Finally, and perhaps most fundamentally, debate continues about the relevance of biotechnology to developing countries and particularly to small, resource poor farmers. The decision to invest in biotechnology generally implies a considerable commitment of money and time that sceptics often believe small farmers are unable to make. But the evidence shows that demand for transgenic commercial crops, in particular Bt cotton by Chinese and Indian farmers, indicates strong demand because of the technology's clear advantages (in particular significantly reduced pesticide applications) for poor farmers. In comparison, similar evidence of small farmer demand for food crops is however, not yet apparent.

Looking to the future, if biotechnology is to make a difference to the poor, then it will require: supportive public polices; public acceptance of transgenics and some assurance that adequate regulation can be achieved at a reasonable cost. In addition, there are still questions to be answered about the delivery to farmers of new biotechnology products. This is especially the case where formal seed and planting material systems are not well developed. One recent survey uncovered an impressive inventory of 209 separate examples of publicly developed transgenic crops in developing countries, but a much less optimistic assessment of the likelihood of their being effectively delivered to farmers (Atanassov et al., 2004; Traxler, 2004).

4.8 The role and potential of low-external-input-agriculture

Although less controversial than biotechnology, low-external-input agriculture (LEIA) is also the subject of considerable disagreement. Debate on the relevance of these technologies is unfortunately often clouded by ideology, with the result that an array of potentially useful technologies find themselves hostage to arguments between those more interested in defining sustainability than in pragmatic technology development and the champions of ‘modern agriculture’ who dismiss indigenous or local resource-based innovations as primitive or hopelessly labour-intensive.

There are many examples where innovations such as agroforestry, cover crops or reduced tillage have been successfully adopted by significant numbers of farmers (Franzel et al., 2002; Versteeg et al., 1997; Bunch, 2002). Examples can also be found of the successful introduction of technologies that have reduced dependence on external inputs such as pesticides (Winarto, 2004).

On the other side however, there are many cases where these technologies have failed to gain acceptance either because of deficiencies in technical performance (Graves et al., 2004), or because farmers have been unable to acquire the skills required to implement them, or to meet the often additional labour demands of these technologies.

In terms of skills acquisition, by their nature these technologies are frequently championed by short-term projects or individuals. Often these initiatives lack the means to create the critical mass of information and support for farmers interested in learning the new techniques. While generalisation is risky, there are many cases in which the knowledge or skill-intensity of these techniques is as important a barrier to their adoption as the labour costs. This implies the need to support what Pretty (1995) calls the ‘transition costs’ of shifting to alternative practices. In many cases these barriers are not insurmountable, but the costs of overcoming them are often most easily met by better-resourced farmers. So although LEIA is often cited as being particularly appropriate for the resource-poor (and there is an inherent logic in this), present adoption patterns are usually not dissimilar to those for conventional technology.

In addition to the skills issue, labour requirements have also tended to skew adoption away from the poor. To the extent that LEIA techniques require extra labour, this tends to be met by hired rather than family labour. The idea that resource-poor farmers have spare labour to invest in their own farms is often false (and of course the crucial factor is the level of returns that can be expected from that labour). But the source of labour for some LEIA is a factor often overlooked by advocates who hope that these techniques will prove particularly useful for equitable growth, particularly in marginal areas (e.g. Hazell and Haddad, 2001).

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