U-impact pathway for diagnosis and impact assessment of crop improvement

J. DIXON1*, J. HELLIN1, O. ERENSTEIN2 AND P. KOSINA1
1 International Maize and Wheat Improvement Center (CIMMYT), El Batán, Mexico
2 (CIMMYT), New Delhi, India
(Revised MS received 3 January 2007)

SUMMARY
Agricultural research has contributed enormously to poverty reduction and increased food security worldwide. Wheat crop improvement is a good example of this contribution. Public investments in wheat research from the Green Revolution onwards led to significant productivity increases: following the widespread adoption of semi-dwarf varieties, annual yield growth rates peaked at 2.75% p.a. in the 1980s. Since then, public and private investments in crop (including wheat) research have been modest despite the potential of such research to contribute substantially to the first Millennium Development Goal (MDG) of halving hunger and poverty by 2015. Drawing on a wide spectrum of recent literature, the present paper broadens the usual frame of reference for diagnosing the adoption of improved technology and measuring impact. The adoption of improved varieties and management practices is influenced on the supply side by the nature and performance of the input delivery pathway from research to the farm (input value chains), and on the demand side by the characteristics of the farm household system and the marketing or value-adding chains from the farm to the consumer (output value chains). These three elements (input value chains, farm household system characteristics, and output value chains) can be viewed as a U-impact pathway. This pathway determines the rate and extent of adoption of improved varieties and practices, the magnitude of direct and indirect impacts, and the potential for feedback loops leading to improved functioning of the input and output value chains. The U-impact pathway provides a framework to identify an expanded set of beneficiaries from crop improvement which extend beyond the common focus on producers and final consumers; conventional surplus analysis can then be used to estimate the wider benefits to crop improvement. Additional metrics may be needed to estimate impact related to non-economic benefits, such as poverty, health and social capital. The implication of this fuller accounting of impacts is that the benefits accruing to agricultural research may be greater, and more widely distributed across the economy, than previously recognized by research managers and policy-makers. This strengthens the case for maintained or increased public and private sector investment in crop improvement.

INTRODUCTION
There is ample evidence that agricultural research has contributed enormously to poverty reduction and increased food security worldwide (Evenson & Gollin 2003; World Bank 2005; Stirling et al. 2006; Pingali & Kelley, in press). Crop improvement involving enhanced germplasm and crop management is a good example of the potential contribution of agricultural research to poverty reduction. Of the total cereal area of 447.2 million ha in the developing world, wheat accounts for 100.7 million ha, maize 98.1 million ha and rice 150.0 million ha (FAO 2006). Following...
substantial public investments in wheat improvement research from the inception of the Green Revolution in the mid-1960s, wheat productivity increased significantly, especially in developing countries. Following widespread adoption of semi-dwarf varieties, the annual yield growth rate peaked at 2.75% p.a. in the 1980s. Since then, yield growth has slowed in part because varietal replacement is now more widespread than initial adoption, and also because of environmental factors (Heisey 2002; Wichelns 2004). Increased physical productivity has also been partially offset by an increase in input prices and a steady decline in grain prices. Nevertheless, wheat crop improvement continues to contribute to improved food security and reduced poverty and, hence, to the achievement of the first Millennium Development Goal (MDG) of halving hunger and poverty by 2015.

Despite the contribution of wheat research to poverty reduction, investments in wheat research have been mixed and uneven over the last 20 years. The contribution of the private sector to wheat breeding efforts, for example, varies across type of wheat and regions. Outside of countries in the Organisation for Economic Co-operation and Development (OECD), private sector releases were most significant in Eastern Europe and the former Soviet Union, East and Southern Africa, Latin America, and to a lesser extent in the Central and West Asia and North Africa (CWANA) region. Elsewhere, the private sector accounted for very few varietal releases (Lantican et al. 2005). Under these circumstances, continued support to national and international public sector crop improvement programmes and their partnerships with private sector is required (Heisey 2002; Delmer 2005). This was realized more than four decades ago: it was the Nobel Laureate T. W. Shultz who emphasized, during the 1960s, the importance of the provision of improved crop (and livestock) technologies as public goods to stimulate smallholder development (Schultz 1964).

The challenge of maintaining or increasing the level of investment in international crop research is accentuated by the difficulty researchers and development professionals face in diagnosing the constraints to adoption of crop improvement technologies and accurately assessing the impacts of research (Dixon et al. 2006). The present paper introduces the U-impact pathway as a value-chain-based conceptual framework to address this difficulty (see Fig. 1). Kaplinsky & Morris (2000) describe a value chain as the ‘full range of activities which are required to bring a product or service from conception, through the different phases of production (involving a combination of physical transformation and the input of various producer services), delivery to final customers, and final disposal after use’. The present authors propose that the U-impact pathway be viewed as an expanded value chain comprising the full range of actors from genebanks and molecular biologists on the input side to millers, retailers and consumers on the output side.

The U-impact pathway provides a framework for analyzing the integrated effects of agricultural input systems, farmer decision making in relation to improved technologies and output marketing systems. It facilitates the identification of the economic benefits of agricultural research in terms of producer and consumer surplus, value-added, employment and wealth creation. By so doing it can strengthen the argument for continued investment in agricultural research by demonstrating that the benefits accruing to this research may be greater than previously recognized.

The next section examines the role of seed-embedded technologies, knowledge and other service providers that represent the input value chain segment of the U-impact pathway (see Fig. 1). This is followed by a section on the drivers of farmer decision making on the adoption, and increasingly replacement, of improved technologies along with the consequential impacts on farm systems and household income and livelihoods. This represents the second segment of the U-impact pathway. The last section discusses the third segment, the output value chains, which also serve to transfer the signals on consumer preferences back along the pathway to farmers and, ultimately, breeders and agronomists. The U-impact pathway is illustrated with examples of wheat varietal adoption in the Yaqui Valley of Mexico and conservation agriculture (CA) in the Indo-Gangetic Plains (IGP), leading to a discussion of the implications for the diagnosis and assessment of impact along the full length of the U-impact pathway.

**INPUT AND SERVICE VALUE CHAINS**

The adoption of improved crop varieties and management practices is influenced on the supply side by

---

**INPUT AND SERVICE VALUE CHAINS**

<table>
<thead>
<tr>
<th>Input value chains</th>
<th>Output value chains</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop breeders</td>
<td>Consumers</td>
</tr>
<tr>
<td>Seed companies</td>
<td>Retailers</td>
</tr>
<tr>
<td>Extension agents</td>
<td>Traders</td>
</tr>
<tr>
<td>Credit providers</td>
<td>Transporters</td>
</tr>
<tr>
<td>Fertilizer providers</td>
<td>Feed millers</td>
</tr>
<tr>
<td>Equipment providers</td>
<td>Flour millers</td>
</tr>
<tr>
<td>Pesticides providers</td>
<td>Agro-processors</td>
</tr>
</tbody>
</table>

![Fig. 1. U-impact pathway.](image-url)
the nature and performance of the input value chains that deliver inputs and services (e.g. improved seed, technology and information) from researchers to the farm gate. These input value chains constitute the first segment of the U-impact pathway which comprises germplasm, knowledge and service providers including biotechnologists, breeders, seed multiplication and distribution entities, extension agents (both formal and informal, e.g. farmer-to-farmer) and, often, providers of complementary inputs such as credit and fertilizer. The availability of seed, agricultural information and, where available, credit and other services generally influences the rate of technology adoption and level of intensification. Hence, the adoption of an improved crop technology can be substantially reduced if key service providers are absent or weak. de Janvry & Kassam (2004) refer to the lack of such essential services as institutional gaps. For example, promising new crop varieties not infrequently fail to reach farmers because of inefficiencies and shortcomings in the multiplication and distribution of appropriate planting material (Kremer & Zwane 2005).

The fundamental resource for cereal improvement is the genetic variation housed in gene banks and in the multitude of advanced lines developed and shared among breeders. Existing genetic variation of wheat is now being enhanced by so-called synthetics (re-synthesized hexaploid wheats), which re-create the original ancestor species crosses (Coghlan 2006). This expands the available variation in valuable traits such as drought resistance, heat tolerance or increased mineral content (e.g. Fe or Zn). Public sector research, of which the partnership between the International Maize and Wheat Improvement Center (CIMMYT) and the National Agricultural Research Systems (NARS) is a significant component, has been particularly important for wheat improvement worldwide (Dixon et al. 2006). Whilst CIMMYT distributes more than 1000 advanced lines of wheat per year (Reynolds & Borlaug 2006a,b), NARS in developing countries released about 3000 wheat varieties between 1966 and 2005 and presently release approximately 100 new varieties per year (Lantican et al. 2005), or roughly one variety for every ten lines distributed.

Advanced lines from CIMMYT are used in different ways by NARS: weaker NARS often multiply seeds of well performing advanced lines and release them directly as new varieties without further crossing. Strong NARS use advanced lines from CIMMYT as parents in their own breeding programmes. It can take up to 8 years or more before a new local variety based on CIMMYT material is released. Several studies have shown that CIMMYT-related germplasm has made an important contribution to international wheat breeding efforts (Byerlee & Moya 1993; Heisey et al. 2002; Evenson & Gollin 2003; Lantican et al. 2005; Brennan et al. 2007) and continues to be used by public wheat breeding programmes throughout the developing world.

Most high yielding cereal varieties released during the past four decades are input-responsive and their profitability and, therefore, incentive for adoption is generally increased by the application of fertilizers. Suitable pesticides and equipment also need to be provided by service providers. Whilst a rapid concentration of agricultural input providers has been observed in OECD countries, service provision is still fragmented and small scale in many developing countries. Many smallholder farmers lack cash to finance input purchases and many studies show that farmers with access to credit, whether as part of a production inputs package or separately, have a higher probability of adopting modern crop varieties than those with no access (see Kotu et al. 2000; Murgai et al. 2001; Nagarajan 2005).

Extension activity (or its modern surrogate) provides farmers with information and technologies and plays an important role in the adoption of improved varieties and production practices. In a review of East African adoption studies in largely rain-fed semi-commercial wheat farming systems, Doss et al. (2003) show that farmers’ exposure to extension demonstrations of varieties and good production practices can increase adoption rates of new maize and wheat varieties. This is the case even in remote rain-fed farming systems (Kotu et al. 2000). Conversely, the adoption of improved varieties can also be inhibited by the manner of presentation of the technology, including the behaviour of extension agents, the content of the extension message and the language used to convey the message (Bellon et al. 2003a).

**FARM HOUSEHOLD SYSTEM DECISION MAKING, DIVERSIFICATION AND LIVELIHOODS**

The availability of the full range of modern seed, inputs and services ‘at the farm gate’ does not ensure adoption: farmers do not behave as passive recipients of new technologies but rather as social actors whose conscious strategies, decisions and interactions, framed within the limits of available information and resources, determine development outcomes (Long 2001). Accordingly, farm household decisions on technology adoption depend on the assessments of the expected changes in marginal costs, benefits and riskiness (both direct and indirect, as well as in cash and kind) in the specific farm system. Thus adoption decisions are not simple and may vary from farm to farm: there can be different trade-offs between yield and variability, home consumption preferences and the quality demands of the market, on-farm production and off-farm employment, or between the improved wheat production and competing crops or livestock. Moreover, most technology is not
immutable: the reality is that once the new technology reaches the farm, it often becomes subject to a process of adaptation, e.g. the incorporation of maize breeders’ germplasm into local creolized varieties (Bellon et al. 2003), the adaptation of equipment for CA, or the adaptation of soil conservation technologies (Hettin & Schrader 2003). Hall & Khan (2003) consider that farmer technology adoption decisions are driven by the balance between short-term transition costs of adoption and successive adaptation (including notably the costs of learning) and the long-term benefits which flow from adoption. In this sense, farmers’ private discount rates are a key determinant of technology adoption and adaptation decisions.

Typical lags from the release of modern wheat varieties until full adoption (usually defined as 0.95 of the potential coverage) average 4–5 years in developed countries compared with almost 7 years in developing countries (Brennan & Byerlee 1991). In developing countries, improved wheat varieties were sown on 0.83 of irrigated and high rainfall land by the late 1970s and on practically all high crop potential land worldwide by 1990.

The differing rates of adoption (and adaptation) of wheat technologies between regions and farming systems can be explained by a variety of factors including agricultural input services, farm household asset levels and characteristics, and market opportunities. Common farm household assets that determine adoption are farm size, access to irrigation and education levels. Empirical studies have shown that farm size is positively correlated with adoption rates of modern wheat. This may also be attributed to the fact that large farmers are likely to have more opportunities to learn about modern varieties, and have adequate risk-bearing capacity. Studies demonstrate a positive correlation between the level of education of the farm household head and the probability of adopting modern seed varieties (Villaume 1977; Mussei et al. 2001; Gamba et al. 2003).

Adoption rates are not solely correlated with formal education but with informal knowledge levels, which could stem from advice from neighbouring farmers or radio programmes (Heisey et al. 1990; Kotu et al. 2000; Mussei et al. 2001). Another source of information on new varieties is farmers’ membership in groups and local networks, often informally organized, which have been shown to have a positive influence on adoption rates through the sharing of techniques and information on potential benefits and risks (Demir 1976; Zegeye et al. 2001).

Empirical evidence shows that farmers do not always adopt improved cultivars even when all the supporting inputs and services are available. Ruttan (2003), in a wide review of institutional drivers of agricultural development, noted that when small farmers fail to adopt recommended practices, it is often the rationality of the ‘experts’ rather than that of the farmers that may be questioned: in fact, there is a substantial body of evidence supporting the notion of rational decision making by small farmers (Schultz 1964; Chambers 1997).

The choice of livelihood strategies has a great bearing on technology adoption decisions. As noted in Dixon et al. (2001), there are five main livelihood improvement strategies employed by smallholders who seek to escape poverty: intensification of existing production patterns; diversification of livelihoods (on-farm, including value adding); expanded farm or herd size; increased off-farm income (local versus distant); and exit from agriculture (including permanent migration). The relative importance of these livelihood improvement strategies varies between farming systems.

Adoption and improved productivity of crops is, therefore, only the first step towards livelihood improvement and wider impacts. Adoption of improved germplasm may lead to an intensification of existing production patterns—the first livelihood improvement strategy—that in turn releases resources that allow farmers to invest in other strategies, notably crop and livestock diversification. Jat et al. (2006) document the rapidity and extent of diversification to horticulture in the rice–wheat farming systems of the IGP. In the developing world, farming’s capacity to provide the sole means of survival for rural populations is diminishing fast. Whether because of declining crop prices, competition for land and access to markets, or declining productivity due to soil and land degradation, successful intensification and diversification may also lead to off-farm employment and even to a voluntary (cf. forced) exit from farming (Pingali & Kelley, in press). Farmers are increasingly moving into rural non-agricultural work. The definition of ‘non-agricultural’ excludes primary production, whether in agriculture, fisheries or livestock, but covers manufacturing (including agro-processing) as well as services such as transportation (Berdégué et al. 2000).

OUTPUT VALUE CHAINS, MILLERS, RETAILERS AND RURAL ECONOMIC GROWTH

Farmers need access to markets to dispose of surplus produce at a reasonable price. Access to produce markets is often a critical determinant of adoption of agricultural technology. Such access is important not just to farmers, but to the wider rural economy: empirical studies show that every additional US$ 1 of farm production can generate another US$ 3 of growth in the rural economy (Watkins & Von Braun 2003). Until the 1980s effective function of value chains from producer to consumer often depended on the public sector, but during structural adjustment
associated with the *Washington Consensus* during the 1980s and 1990s, many developing countries dismantled the state marketing boards that had previously exerted monopoly control over domestic trade and prices for agricultural commodities (FAO 2004).

Thus, the role of the private sector in value chains has grown in importance. The change from public to greater private sector engagement in value chains has occurred at the same time that food value chains are being transformed rapidly as a result of the growth and significant changes in consumer demand from expanding urban populations with increasing per capita income. As a result, food systems can no longer be viewed simply as a way of supplying basic staple foodstuffs from farms to local consumers. Now, smallholder farmers often supply long and sophisticated value chains that deliver processed and branded products to mainly urban consumers (Barghouti et al. 2004). This is particularly the case with the growth and increasing concentration of supermarkets and associated private standards for quality, reliability, and timeliness (Reardon et al. 2003; Pingali et al. 2005; Reardon 2005; Traill 2006).

Agriculture today, therefore, requires improved linkages with input supply systems, agricultural processing chains, and systems for the distribution of fresh and processed products. The application of the U-impact pathway (see below) enables researchers, development practitioners and value chain actors to identify the opportunities, constraints and interventions that are needed to make the chains work more efficiently and effectively, bringing greater benefits to producers, consumers and other actors along the value chains.

As part of the livelihood strategies mentioned above, farmers are also able to increase total income as well as offset the effects of fluctuations in income flows during the year by engaging in off-farm work. The contribution of non-farm work to rural people’s livelihoods should not be underestimated. In Latin America and the Caribbean, for example, it has been calculated that on average rural non-agricultural income accounts for over 0.4 of total rural income (Reardon et al. 2003; Pingali et al. 2005; Reardon 2005; Traill 2006).

Table 1. *Replacement of bread wheat by durum wheat in the Yaqui Valley, Mexico (Source: CIMMYT data)*

<table>
<thead>
<tr>
<th>Year</th>
<th>Area harvested (000 ha)</th>
<th>Durum wheat (proportion of area)</th>
<th>Bread wheat (proportion of area)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1970/71</td>
<td>89.8</td>
<td>0</td>
<td>1.0</td>
</tr>
<tr>
<td>1980/81</td>
<td>121.9</td>
<td>0.18</td>
<td>0.82</td>
</tr>
<tr>
<td>1990/91</td>
<td>101.4</td>
<td>0.21</td>
<td>0.79</td>
</tr>
<tr>
<td>1994/95</td>
<td>118.3</td>
<td>0.59</td>
<td>0.41</td>
</tr>
<tr>
<td>2000/01</td>
<td>134.6</td>
<td>0.85</td>
<td>0.15</td>
</tr>
</tbody>
</table>

Two descriptions follow of contrasting crop technology adoption experiences. The first example concerns crop germplasm and briefly outlines the key determinants of the switch from bread wheat to durum wheat in the Yaqui Valley in north-western Mexico. The second example concerns the adoption of CA in the IGP of South Asia, and is intrinsically more complex.

ILLUSTRATIONS OF THE U-IMPACT PATHWAY

Two descriptions follow of contrasting crop technology adoption experiences. The first example concerns crop germplasm and briefly outlines the key determinants of the switch from bread wheat to durum wheat in the Yaqui Valley in north-western Mexico. The second example concerns the adoption of CA in the IGP of South Asia, and is intrinsically more complex.

From bread wheat to durum wheat in the Yaqui Valley, Mexico

The Yaqui Valley, located in the State of Sonora in the north-west of Mexico, is one of a series of highly productive irrigated valleys. The replacement of bread wheat by durum wheat is well exemplified in the Yaqui Valley, as a response to new market opportunities and emerging pest problems. As shown in Table 1, from 1970 to 1980 bread wheat dominated wheat production, occupying over 0.8 of the land area sown to wheat. Only a relatively small proportion was sown to durum wheat through the 1980s and early 1990s. However, from 1994/95 the popularity of durum wheat surged and the area of durum exceeded that of bread wheat. Since the mid-1990s, durum wheat has dominated the Yaqui Valley.

With the signing of the North American Free Trade Agreement (NAFTA) in 1994, the popularity of bread wheat declined because of the radical change in the output value chains for wheat, i.e. the third segment of the U-impact pathway. Prior to 1994, there was a ‘guaranteed’ market for bread wheat in the
form of the Mexican flour-maker GAMEZA. In addition, grain pricing policy had been another key feature of the output value chain, viz., the state trading agency Compañía Nacional de Subsistencias Populares (CONASUPO) that established the wheat prices paid to farmers and also fixed consumer flour prices at a low, subsidized, level. Prior to 1994, the major market for durum wheat was the animal production industry, as feed for the piggeries. However, from the mid-1990s Mexican durum wheat found a ready market in North Africa and Italy. Additional external markets for durum wheat were identified by the Asociación de Organismos de Agricultores del Sur de Sonora (AOASS) and the Mexican credit unions. The shift from bread to durum wheat had economic and livelihood implications in the non-farm economy. The milling industry shifted to imported bread wheat. Some modest additional economic activity and employment emerged in the handling and transportation of the export durum wheat. Some, lower quality, durum wheat continued to be supplied to the pig feed industry.

The transformation of the output value chains had major consequences at the farm household system level, i.e. the second segment of the U-impact pathway. Farmers have a long tradition of commercial production and, given their relatively advanced farm management capabilities, are responsive to shifts in the output (and input) value chains – perhaps more quickly than in some other areas of Mexico. As a consequence of NAFTA, the farm profitability of bread wheat production reduced substantially. Moreover, the most popular bread wheat variety had become susceptible to rust, which further reduced profitability of bread wheat production. The ‘drivers’ of the switch from bread wheat to durum wheat also continued to have an impact on the types of durum wheat grown by Yaqui farmers. Between 1992/93 and 2002/03, Altar was the durum wheat variety that covered the most area in Yaqui. Between 2003/04 and 2006/07, Jupare became the dominant variety because Altar became susceptible to leaf rust. There is evidence that farmers are now replacing Jupare with Banmichi because of the latter’s greater resistance to leaf rust, as well as better grain quality for the export markets. Whilst profitability and household income increased with the switch to durum wheat, other features of the farm system changed little.

Several features of the input value chains that facilitated the switch from bread to durum wheat deserve mention. The Valley is relatively small in extent and the farmers are well organized. They are well serviced by a range of commercial input providers, and in addition the farmers’ organization, Patronato, hosts an active and responsive crop improvement research programme. Thus, the Yaqui Valley wheat production input value chains are remarkably short and well-coordinated. Whilst there was a reduction in the demand for fungicides, other changes in the organization, margins or employment in the input chains were limited.

Whilst the ultimate driver of change was the transformation of the output value chains as a consequence of NAFTA, the combination of responsive local institutions, both public and private, and farmers’ sound management capability created the conditions for a remarkably rapid change of wheat varieties. This is not new: Brennan & Byerlee (1991) estimated a wheat varietal adoption time lag of only 1.8 years for coverage of 0.95 of the potential area, in this case the whole Yaqui Valley. Table 1 shows that the capacity for rapid adoption has been sustained during the 1990s and into the current decade: the lessons which could be drawn from a study of the characteristics of the U-impact pathway of Yaqui Valley wheat, notably its efficiency and sustainability, might be of great value in other wheat growing regions of the world.

**Conservation agriculture in the Indo-Gangetic Plain**

The Green Revolution transformed the Northwestern IGP into both the breadbasket and rice-bowl of South Asia. The technological packaging of improved wheat and rice seed, chemical fertilizer and irrigation in an overall supportive environment for agricultural transformation led to rapid productivity growth. The intensification of the rice–wheat system thereby has, however, become a victim of its own success, with the degradation of the natural resource base widely seen as the root cause for the recent stagnation. CA is increasingly perceived by the research and development community as the way forward (Gupta & Sayre 2007; Hobbs 2007). Conservation agriculture is the term used for a diverse array of crop management practices that involve three components: (i) minimal disturbance of the soil, (ii) retention of residue mulch on the soil surface and (iii) use of crop rotations (Harrington & Erenstein 2005; Hobbs 2007).

The first segment of the U-impact pathway comprises the input value chains of CA. In contrast to seed-embedded technology, CA is not an embodied tangible technology. Instead, it is a basket of interlinked cultural practices that imply the need for diverse complementary supporting component technologies and knowledge. To date the component technology in rice–wheat systems in the IGP that has been most successful is the zero tillage drill (ZTD): a mechanical tractor-mounted seed drill that can sow wheat into an untilled rice field. Zero and reduced tillage wheat have spread rapidly since the turn of the century to an estimated 1.6 million ha in 2004/05 in India (Laxmi et al. 2006). A recent study confirmed widespread adoption of ZTD wheat (0.345) in the rice–wheat belt of Haryana State in northern India.
Developing adequate input value chains for ZTDs, from factory to farmer fields, proved crucial to the success of reducing tillage in India (Seth et al. 2003). The private sector recognized that zero tillage offered a substantial market opportunity and local manufacturing capacity was developed to produce, adapt and deliver ZTD to farmers at a competitive cost. By 2004, 92 ZTD manufacturers were known to operate in the Indian IGP with location of manufacturing capacity closely associated with diffusion and aggregate sales increasing to approximately 7000 ZTD p.a. in 2003 (Erenstein et al., in press). Although detailed figures are not available, the expansion of the ZTD manufacturing and servicing sub-sector will have created substantial new additional income for industry workers.

The involvement of several manufacturers ensured competitive prices, good quality equipment and easy access to drills by farmers along with the availability of facilities for repairs and servicing. Close linkages of scientists and farmers with the private manufacturers, including the provision of machines to villages for farmer experimentation, allowed rapid feedback on, and refinement of, the implements. Strong support from State and local government officials helped with dissemination, including the provision of a subsidy to lower the investment cost. The Rice–Wheat Consortium (RWC) for the IGP (Seth et al. 2003) played a catalytic role in promoting the public–private partnership, nurtured it through its formative stages and facilitated technology transfer from international and national sources. Accessibility to the ZTD was greatly enhanced by ZTD service providers, with the majority (0.6) of ZTD adopters still dependent on their services (Erenstein et al., in press). Service providers have the added advantage of having hands-on experience and having a clear incentive for promoting the technology. The concerted efforts from a range of stakeholders, thus, proved crucial in developing the input value chains of ZTD to the farmer.

So far, ZTD has primarily been adopted for the wheat crop in rice–wheat systems. For the full potential environmental impact of CA to materialize, reduced tillage needs to be extended to the rice crop (Gupta & Sayre 2007). This presents additional challenges, although such an initiative could benefit from the existing machinery and information value chains (Erenstein, in press). The impact of CA will be further enhanced when other components of the input value chains re-orient towards CA. For instance, most crop breeding efforts have traditionally selected germplasm under intensive tillage conditions (Erenstein, in press). For CA to achieve its full impact the two other CA components – mulching and crop rotation – need to be addressed. This has yet further implications for the input value chains, particularly in terms of ensuring access to relevant knowledge (e.g. crop residue management and rotation practices) and necessary crop technologies (e.g. seed, chemical inputs, machinery adapted to the presence of loose crop residues). Developing the input value chains of the component technologies is a necessary but still insufficient condition for the adoption of CA. Indeed, often significant constraints to the adoption of CA also lie in the subsequent legs of the U-impact pathway.

Whereas in the past CA has largely been promoted from a natural resource management perspective, these considerations are often secondary in farmers’ adoption and adaptation decisions. The main driver behind the rapid spread and widespread acceptance of ZTD is the combination of a significant continuing ‘yield effect’ and a substantial ‘cost saving effect’ which ensure the immediate profitability of adoption (Erenstein et al., in press). The resource base and livelihood strategy of the farm household also prove particularly influential: ZTD adoption is closely associated with farm size, asset base and with specialization in the rice–wheat system (Erenstein et al., in press). The significant wheat area of ZTD adopters implies larger annual benefits, lower relative learning costs and earlier payback to ZTD investment. As in other parts of the world, CA adoption is associated with the reduction of risk and vulnerability and tends to foster the diversification of crops. While farmers increasingly accept ZTD for wheat, reducing tillage for the subsequent rice crop is still problematic. Meanwhile, the main bottleneck for the second CA component – retention of soil cover – primarily lies at the farm household level. Prevailing crop residue management practices are largely incompatible with residue retention, not least due to the widespread use of wheat residues for feed purposes and burning of rice residues (Erenstein et al. 2005).

With respect to the third segment of the U-impact pathway, the output value chains in the north-west IGP are characterized by widespread public intervention, particularly assured produce prices and marketing channels for rice and wheat grain. Although these foster intensification, they represent a major obstacle to the third component of CA – the practice of crop rotation. The combination of secure produce markets and irrigation means that rice and wheat production is a low risk activity that had proven difficult to displace until recently. However, the rapidly evolving domestic market in India implies promising new opportunities for diversification of rice–wheat systems with selected vegetables, legumes, feed/fodder crops and livestock products (Gulati et al., 2007).

There are additional non-pecuniary features of the output value chains. CA has significant positive environmental benefits for consumers and the wider economy – particularly in terms of reducing pressure.
on over-exploited water resources and reducing air pollution. Although these remain to be accurately valued, clearly consumers are major beneficiaries of CA. Indeed, an analysis of the impact of ZTD in India based on the yield gains and cost savings alone, revealed that 0.65 of the discounted economic surplus of US$ 94 million benefited consumers (Laxmi et al. 2006).

The CA case eloquently illustrates some of the advantages of the broad view inherent in the U-impact pathway, whilst also eliciting some of the complexities inherent in the impact assessment of complex crop improvement technologies. The U-impact pathway thereby provides a useful conceptual framework for diagnosis and assessment – particularly in terms of identifying secondary constraints and wider opportunities to enhance the impact of agricultural research and development.

DISCUSSION: IMPLICATIONS FOR DIAGNOSIS AND ASSESSMENT ALONG THE U-IMPACT PATHWAY

Diagnosis

It is the decisions of millions of farmers worldwide that ultimately will determine whether improved crop technologies are adopted and adapted, leading to increased productivity, improved livelihoods, other primary and secondary impacts, and reduced poverty. Agriculture can, therefore, be viewed as an integrated technical–social system in which farmers and service providers create solutions to production and livelihood problems, often taking advantage of new opportunities through the modification of technologies and existing farming systems (Hall et al. 2005). Consequently, agricultural and rural development is an immensely complex process characterized by a high degree of non-linearity.

The complex web of interactions of researchers, extension agents, equipment manufacturers, input suppliers, farmers, traders, processors, retailers and consumers, is sometimes considered as an innovation system (Ekboir et al. 2003; Hall et al. 2005). In order to target crop improvement more effectively, research organizations and their partners need a better understanding of the innovation systems and impact pathways and networks that link research outputs (germplasm and information) to institutional outcomes and farm-level impacts, notably improved household livelihoods (see Fig. 1). This approach implies a shift of focus from crops to people-centred livelihoods and from linear technology selection and transfer to a non-linear complex systems approach which explicitly recognizes feedback loops, farmer innovation and systems dynamics and evolution.

The adoption of the U-impact pathway concept facilitates the identification of constraints that hinder the realization of the impacts of crop improvement research and, subsequently, the identification of improvements in the organization and performance of the pathway. Beyond the direct food security benefits, welfare improvements derive from the improved distribution of benefits among different actors along both input and output value chains, including seed distributors, farmers, traders and consumers. Further benefits accrue to farmers from on-farm diversification, and to other rural poor through the jobs created in the input and output value chains, especially in the local non-farm economy.

The first step in implementing the U-impact pathway involves ‘value chain mapping’, analogous to market mapping. This is a diagnostic tool that facilitates the identification of the main actors along the chains – breeders and other input suppliers, farmers, millers, traders and consumers – along with the specification of opportunities, constraints and interventions to enhance impact. The key types and sources of data for impact assessment can be identified by the mapping of impact pathways, which also facilitates, in complex systems, the specification of attribution. Generally, impact pathway analysis provides plausible specification of the dominant links and critical roles of the key actors, leading to the adoption and better management of improved germplasm and knowledge on farmers’ fields. An understanding of these links and roles allows for feedback and subsequently for the adaptation of behaviour by actors in the chains to foster greater impact.

Approaches such as participatory value chain analysis (Hellin et al. 2005) that are more commonly used in the third segment of the U-impact pathway – output value chains – can be readily adapted and applied to analyse and improve the efficiency of the first two segments. Different actors in the three segments of the U-impact pathway can be brought together in a series of multi-stakeholder workshops to identify jointly bottlenecks and inefficiencies in the chains linking them, as well as required data to analyse and improve the system. The innovation pathway should, therefore, not be seen as one-way flow of information: in reality feedback loops operate along its length. The pathway can be envisaged as a mountain stream which appears, on the surface, to be running in one direction; below the surface, however, there are a series of turbulent, whirling, eddies. One can envisage these eddies as a series of feedback loops that provide different actors in the U-impact pathway with important information from actors further ‘up’ or ‘down’ the pathway.

Value chain mapping can generate considerable amounts of qualitative and quantitative data that are rarely available from more conventional data sources; examples include the number of seed providers and the value of seed as it passes down the input chains, or the number of ZTD manufacturers
supporting CA, their innovations and their agricultural extension activities. The joint problem-solving analysis can also help identify which actors are best placed to improve the functioning of the pathway, and how best to involve them. A current focus of interest is on creating a stronger market for services – either by increasing the demand (willingness to pay) or by improving the supply (range, price and quality of services) available from public and private service providers (Miehlbradt & McVay 2005).

A further step to improving the functioning of the impact pathway is the establishment of ‘learning platforms’ in order to scale up best practices. Based on Lundy et al. (2005), the process involves bringing together research organizations, donor and development agencies, policy-makers, input providers, breeders, private businesses and farmer organizations to share and adapt good practices. The learning platforms can establish clear objectives, define specific topics of interest, implement a learning cycle and share results with policy-makers, researchers, businessmen and farmers. The role of policy is often overlooked, or considered to be immutable, but in reality it is critical to establish an effective enabling environment for public–private-farmer partnerships for technology adoption and adaptation, knowledge exchange, and entrepreneurship. These factors are generated by structures (national and local authorities, and research agencies) and institutions (policies, regulations and practices) that are often beyond the direct control of actors in the value chains (Hellin et al. 2005).

**Impact assessment**

One of the classical challenges of impact assessment is the specification of attribution, especially in the complex network of actors characterized in the U-impact pathway. Participatory methods, especially if applied in a multi-stakeholder context, can be particularly useful for identifying causal relationships and attribution. Douthwaite et al. (2003) trace out the multiple impact pathways and associated attribution for maize technologies to combat *Striga* (a parasitic weed that severely reduces maize, millet, and sorghum in sub-Saharan Africa, especially under conditions of poor soil fertility).

Another common challenge for impact assessment is the source of data to estimate producer and consumer welfare changes. Agricultural and industry statistics are often relatively weak in their coverage of the input and output chains which, as has been seen above, create value added, employment and livelihoods for farmers and other rural poor. For this reason, advantage might be taken of participatory value chain mapping and analysis to generate requisite relevant data to supplement, at low cost, those statistics available from conventional sources. Such participatory methods can generate, relatively quickly and inexpensively, approximate data which are not readily available from other sources and which suffice for the estimation of the scope and scale of impacts.

The conventional measures of impact assessment such as surplus analysis can be applied across the full length and breadth of the U-impact pathway. The theoretical framework for agricultural research impact assessment is broad, as expounded by Davis et al. (1987) and Alston et al. (1995). The latter recognize that agricultural research generally serves multiple objectives of donors and policy-makers, e.g. metrics related to equity, health, nutrition, resource degradation, biodiversity, etc., and that agricultural research is often a poor mechanism for such ‘non-economic-efficiency’ goals. Nevertheless, in practice such wider goals are often set and there is a need to assess the degrees of achievement of those goals.

In addition to the broad theoretical framework, Alston et al. (1995) describe many additional contexts in which surplus analysis can be applied, including the differentiation of producers and consumers, multiple factor markets, factor substitution, multiple product markets, market distortions and environmental and other externalities. Such assessments could also identify areas where research and development could improve the technologies in input chains (e.g. breeding methodologies or seed multiplication), in production (the historical focus) and in output chains (e.g. milling).

Given appropriate theory and available methods, it is somewhat surprising that relatively few impact assessments incorporate, in addition to producers and final consumers, the wider set of beneficiaries along the input and output chains (see, for example, the review of Pingali 2001). For example, improved germplasm and production technologies generate incremental benefits in seed systems, farm input providers, millers, transportation services and other actors along the value chains which have implications for both the total benefits and the distribution of the benefits stemming from crop improvement. Equally surprising, given the prominence of the MDGs, relatively few impact assessments focus on accurate assessment of the level of poverty reduction. In principle this might be attributed to the implicit focus of impact assessments on economic efficiency; however, the emphasis of many donors on a wider range of outcomes and metrics such as reduced poverty, improved livelihoods and enhanced nutrition and health suggests the importance of incorporating these into conventional impact assessments. Another plausible explanation for the use of restricted metrics has been the lack of suitable data. However, some economists are now identifying sufficient surrogate data to estimate impact by socio-economic group or poverty class. Participatory value chain mapping is likely to document a variety of market distortions...
that are frequently ignored in impact assessments. Alston et al. (1995) outline appropriate approaches; and readers are referred to an insightful recent application of Kostandini et al. (2006) who incorporated market distortions into an impact assessment of bio-pharming.

CONCLUSIONS

The adoption of improved varieties and management practices is influenced on the demand side by the characteristics of the farm household system and the marketing or value-adding chains from the farm to the consumer; and on the supply side by the nature and performance of the input value chains from the breeders, agronomists and other researchers to the farm households. Together the three elements (input value chains, farm household system behaviour, and the output value chains) can be viewed as an integrated impact pathway, which is referred to here as the U-impact pathway. This pathway determines the rate and extent of adoption of improved varieties and production practices, the magnitude of direct and indirect impacts and the potential for feedback loops leading to improved functioning of the integrated pathway.

The U-impact pathway framework can be used in the diagnosis of constraints and opportunities, and in the assessment of consequences related to the direct and indirect impacts of improved crop germplasm and technologies. One great advantage of such mapping of the different actors and steps in the U-impact pathway is the clarity afforded to attribution, one of the two classical challenges of impact assessment.

Arguably, such detail renders the specification of a counter-factual somewhat more challenging. The extension of the impact pathway in this manner does not necessarily require new metrics for impact assessment, i.e. conventional surplus analysis can be used to estimate the individual and collective benefits to crop improvement. Additional metrics may, however, be estimated to supplement surplus analysis with measures of other impacts such as health, social capital and poverty reduction.

The U-impact pathway identifies the broad canvas of actors ranging from breeders at one end of the value chain to consumers at the other end. Participatory mapping of the entire input and output chains allows actors to recognize the context of their roles and the relative importance of the relationships with other actors. Where funding is limited and the impact pathways are complex, low-cost participatory mapping methods can be applied not only to identify constraints and interventions to improved pathway efficiency but also to estimate key performance and impact data on the input and output chains. The implication of this fuller accounting of impacts along the input and produce chains is that the benefits accruing to agricultural research may be even higher, and more widely distributed across the economy, than previously recognized by many policy-makers, researchers and development professionals.

We thank Roberto La Rovere, Matthew Reynolds, Dagoberto Flores and two anonymous reviewers for their invaluable ideas and comments on earlier versions of this paper.

REFERENCES


U-impact pathway


