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Why promising technologies fail: the neglected role of user innovation during adoption[☆]

B. Douthwaite[a,*], J.D.H. Keatinge[b], J.R. Park[a]

[a] *Department of Agriculture, University of Reading, Earley Gate, P.O. Box 236, Reading RG6 6AT, UK*
[b] *International Institute for Tropical Agriculture (IITA), Oyo Road, PMB 5320, Ibadan, Nigeria*

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Abstract

The paper analyses innovation histories of two agro-mechanical and two seed-based technologies with high and low technological complexity, introduced into simple and complex farming systems in Asia. The main conclusion, which may be seen as a hypothesis for further testing, is that, as technology and system complexity increase so does the need for interaction between the originating R&D team and the key stakeholders (those who will directly gain and lose from the innovation) when the latter first replicate and use the new technology. This is because a successful technology represents a synthesis of the researcher and key stakeholder knowledge sets, and creating this synthesis requires more iteration and negotiation as complexity increases. Instead of assuming a new technology is 'finished' when it leaves the research institute, a more effective way of developing complex technologies is for the R&D team to release them as soon as the key stakeholders will adopt, and then nurture the technology's continued development in partnership with the key stakeholders. © 2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

In October 1998, the third CGIAR[1] System Review concluded that: "Investment in the CGIAR has been the most effective use of official development assistance (ODA), bar none. There can be no long-term agenda for eradicating poverty, ending hunger, and ensuring sustainable food security without the CGIAR" (CGIAR System Review Secretariat, 1998, p. 1). The impact that the CGIAR system has achieved since its inception in 1971 has largely been the result of breeding modern crop varieties that respond better to fertiliser and allow higher yields. In rice, high yielding varieties (HYVs) developed by the International Rice Research Institute (IRRI) started the Green Revolution in Asia.

Despite the huge impact of the Green Revolution the Chairman of the CGIAR System has said that the research and development (R&D) approach that developed and disseminated HYVs needs to be adapted to better deliver technologies that are adopted by smallholder farmers in complex farming systems (CGIAR Secretariat, 1997). The Chairman has said that it is not

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[*] Corresponding author.

E-mail address: b.douthwaite@cgiar.org (B. Douthwaite).

[1] Consultative Group on International Agricultural Research.

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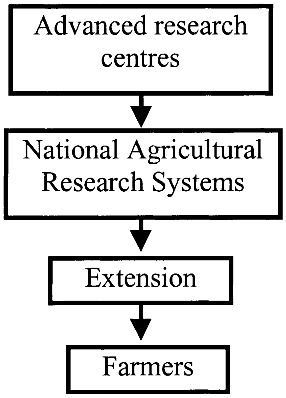
enough for CGIAR centres to do their own research, they must also develop and transfer new technology generation and diffusion models. The CGIAR system review concluded that: “no institution, however, successful can base its future purely on past performance. Progress and relevance come from building on past strengths and grappling with past weaknesses”. CGIAR System Review Secretariat, 1998, p. 1).

Both of these views reflect concerns of the donor community over lack of demonstrated CGIAR system impact on poor smallholder households. These concerns have grown as the priority of the international community has moved from food security to poverty eradication. This change of focus led in 1996 to the Organisation for Economic Co-operation and Development (OECD) issuing internationally agreed development targets, the main one being the eradication of 50% of world poverty by the year 2015 (ODI, 1997). Poverty eradication is now a central part of the CGIAR system’s mission statement (CGIAR Secretariat, 1999).

The lack of CGIAR impact on the ‘poorest of the poor’ has been attributed to the cognitive view of R&D and technology transfer that many agricultural scientists assumed and used to plan and manage the innovation process (Chambers and Jiggins, 1986; Biggs, 1989; Horton and Prain, 1989; Clark, 1995). Clark (1995) said that the approach is based on the view of the technology that sees knowledge flowing through a pipe-line that has basic research activities at one end and knowledge embodied as useful products at the other. The research institute at the beginning of the pipeline is seen as the single source of innovation (Biggs, 1989). The innovation is then seen to flow sequentially down the pipeline, without significant further innovation, with different participants responsible for different parts of the process (Chambers and Jiggins, 1986; Biggs, 1989; Horton and Prain, 1989; Clark, 1995). Farmers are seen to either passively adopt or not adopt but not significantly adapt the new technology themselves (Rogers, 1995). The job of extension workers is, therefore, seen as ‘spreading the message’ about a ‘finished’ product (Ruthenberg, 1985), not as co-development of new technology. Research is seen as separate from extension. This cognitive picture has been called the ‘central source of innovation’ model (Biggs, 1989) and the transfer of technology (TOT) approach (Chambers and Jiggins, 1986) summarised in Fig. 1. Interestingly, this view has a direct parallel in the commercial sector where it has been assumed that product managers develop product innovations and users passively adopt (Von Hippel, 1988). Von Hippel found that the assumption that product managers develop new product innovations is often wrong and other stakeholders-users and suppliers-can be major sources of innovation. He concluded that understanding this can help the management of innovation.



Adapted from Chambers and Jiggins, 1986

Fig. 1. The transfer of technology (TOT) model showing the traditional mental map of how knowledge in the form of technology is developed and is transferred to farmers.

A year later, Biggs (1989) said very much the same thing in the context of agriculture when he published a paper describing the ‘multiple source of innovation’ model. The model explicitly recognises that: “Instead of simply accepting or rejecting an innovation as a fixed idea (as the central model assumes), potential adopters on many occasions are active *participants* in the adoption process, struggling to give their own unique meaning to the innovation as it is applied in their local context” (Rogers, 1995). Resource poor farmers (RPFs), upon which the CGIAR is being encouraged to show greater impact, generally have more complex and diverse farming systems than those found in more favourable areas (Chambers and Jiggins, 1986), requiring more local adaptation to make new technologies work. The ‘multiple source of innovation model’ is, therefore, better at describing the technology generation and adoption process amongst RPFs in unfavourable production environments.

In rural development, R&D and extension approaches that are implicitly or explicitly based upon the recognition of multiple sources of innovation are often called participatory. There has been a rapid growth in participatory approaches over the last decade. IDB (1996) reviewed participatory approaches used by seven key international organisations, including the Canadian International Development Agency (CIDA), the Organisation of Economic Co-operation and Development (OECD), the United Nations Development Program (UNDP) and US Agency for International Development (USAID). The review found that the participation as a principle was important in all organisations and all had developed their own definitions and types of participatory approach (IDB, 1996). IDB's own definition of participation is:

"Participation in development can be defined in broad terms as the PROCESS through which people with a legitimate interest (stakeholders) influence and share control over development initiatives, and the decisions and resources which affect them" (IDB, 1996, p. 2).

The CGIAR system will have to be much more active in developing participatory R&D development approaches if it is to answer donor concerns about lack of impact in poor farmers' fields. Thus, the purpose of this paper is to facilitate the methodological development process by clarifying where traditional R&D approaches are likely to achieve greater impact, and why, and where participatory approaches, or a mixture of both, are likely to be more appropriate.

2. Methodology

The Green Revolution has demonstrated that the top-down, centrally-controlled TOT approach to innovation has been successful for technology generation and transfer in relatively simple favourable production environments (FPEs). However, agricultural researchers have not repeated the success of HYVs with other types of technology that have been introduced into the same systems, for example, crop and resource management technologies (Byerlee and Pingali, 1994). This would suggest that different types of technology require different research management approaches even within the same farming system. But, Kaimowitz et al. (1989) state that CGIAR centres have used the TOT approach irrespective of the type of technology transferred.

There is a widely held view that technology can be usefully thought about in terms of knowledge, and innovation thought of as a learning process (Rosenberg, 1982; Mokyr, 1990; Clark, 1995). From this perspective the TOT approach can be seen as one that assumes the researchers can learn enough about a farming system and then embed this knowledge in a new technology (hardware) and operating instructions (software) that is then sufficiently 'finished' to require little or no subsequent local adaptation. Participatory 'multiple source of innovation' approaches recognise that the *key stakeholders* — those who put the innovation into practice and continue with it — also develop new technology by embedding their knowledge in it through the adaptations they make. Therefore, the attribute of the technology that is most likely to affect the choice between participatory or top-down approach is the amount of local adaptation expected by the key stakeholders — the people who are going to produce, supply and use the new technology. Local adaptation is part of the "struggling to give their own unique meaning to the innovation as it is applied in their local context" that Rogers talks about. It is not easy. Therefore, the amount of local adaptation expected is linked to Rogers (1995) concept of technological complexity — the degree to which an innovation is perceived as relatively difficult to understand and use.

The discussion above suggests the following hypotheses:

1. Technologies that require *key stakeholders* to change little to make the technology work (i.e. easy to understand and use technologies introduced into simple farming systems) will have the fastest impact using a top-down approach.
2. If either the new knowledge requirement or the system complexity is high then participatory approaches will be most effective.

Case studies can provide an understanding of the complex processes that lead to adoption and impact (GAO, 1987; Yin, 1989; Sechrest et al., 1996). Here, four case studies are used to describe each of the four combinations of high and low system complexity and technology complexity. The case studies are outlined in Table 1.

Table 1
Case studies

Knowledge complexity of technology	Complexity of system into which technology is introduced	
	Low	High
Low ‘easy-to-employ’	Modern rice varieties (MV) in a favourable production environment (FPE)	MVs in unfavourable production environment (UPE)
High ‘hard-to-employ’	‘Very low cost’ SRR dryer used to substitute for family labour	Stripper harvester used to substitute for hired labour

Seed-based technologies, in the form of modern varieties (MV) of rice, provide the two ‘easy-to-employ’ technology case studies. MVs are simple technologies because nearly all the new knowledge associated with them is embedded in the seed itself. Farmers need to learn little to take advantage of MVs because they can generally be reproduced and grown in similar ways to traditional varieties. Favourable production environments (FPEs) generally contain simpler farming systems compared to less favourable production environments (LFPEs).

The two ‘hard-to-employ’ technologies are equipment technologies designed for smallholders. Equipment technologies are complex compared to seed-based technology because they require manufacturers to learn how to build the machine, and users often need to acquire new skills to operate the technology effectively. Moreover, there is large scope to modify the knowledge embedded in a machine, while there is no scope for farmers to purposefully change the genetic make-up of MVs (unless they are trained in how to do cross-hybridisation).

The two equipment technologies chosen are the stripper gatherer (SG) harvester adopted in the Philippines and the ‘very low cost’ SRR dryer adopted in Vietnam. The SG harvester operates in a socio-economic context made complicated by traditional labour arrangements designed to redistribute crop to those without sufficient land to support their own families. The SRR dryer, on the other hand, operates in a relatively simple system because it replaces family labour, not hired labour (Douthwaite, 1999).

Data for both the equipment technology case studies is reported elsewhere (Douthwaite, 1999) and is based on actual fieldwork by the first author. The data for the seed technology case studies comes from published literature and is as a result more general. The case studies are constructed and examined to determine:

- the degree to which the invention and innovation occurred in a traditional or participatory way;
- the amount, quality and sources of innovation that occurred after first adoption to assess stakeholder motivations and ability to innovate, and the degree to which the actual innovation process better fitted a central- or multiple-source-of-innovation model;
- the degree to which inappropriate choice of innovation models may have affected impact.

Fig. 2 proposes a number of stages in the innovation process (adapted from personal communication with R. Yin, 1995). The studies focused on the *adaptation* phase, when the key stakeholders first begin to adopt the technology because, according to Rogers (1995), this is when most user (as opposed to researcher) innovation occurs. The case studies describe the degree of modification and assess its impact on the ‘fitness’ of the technology. The concept of fitness is borrowed from evolutionary biology and provides an indication of the degree to which the attributes of a technology favour its adoption and use. Rogers (1995) identified five attributes that explain 49–89% of variation in adoption rate. One of these attributes is technological complexity, already discussed. The other four are:

1. *Relative advantage* is the degree to which an innovation is perceived as being better than the technique it supersedes. *Relative advantage* is probably the most important of the five attributes in explaining adoption rate.
2. *Observability* is the degree to which the results of an innovation are visible to others.
3. *Trialability* is the degree to which an innovation may be experimented with on a limited basis.
4. *Compatibility* is the degree to which an innovation is perceived as consistent with the existing values, past experiences, and needs of potential adopters.

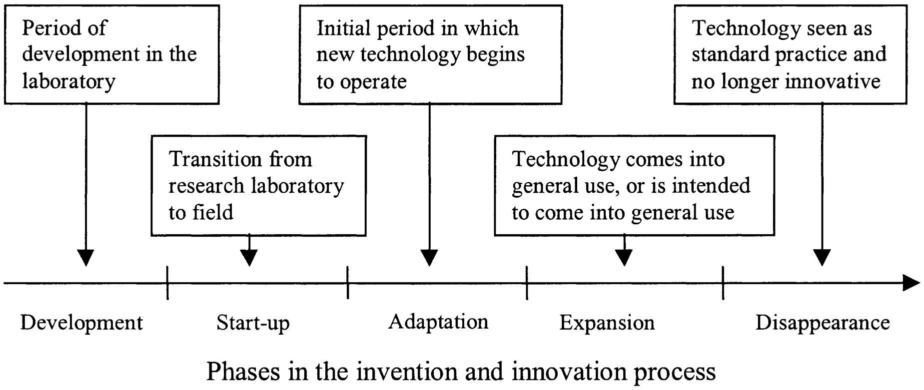


Fig. 2. Stages in the innovation process.

Fitness is therefore an average measure of these attributes.

3. Case studies

3.1. Modern rice varieties in favourable production environments (simple technology, simple system)

From its foundation in 1962 IRRI was primarily a rice-breeding institute with the goal of increasing rice yields with little or no consideration of other characteristics that rice farmers and consumers might find important, for example, eating quality. IRRI's first major success was with the semi-dwarf variety IR8, released in 1966 (Holden et al., 1993). This was followed by a number of 'finished' varieties including IR20, IR26 and IR36. The high yields and rapid farmer adoption of the new grain varieties helped trigger the Green Revolution.

Part of the reason for the rapid adoption of IRRI's high yielding varieties (HYVs) was the extension system IRRI developed. It was based on the American agricultural extension model, which is the oldest diffusion model in the US, and the most successful public sector one (Rogers, 1995). This model consists of three components: researchers at universities; extension specialists based at the same universities; and extension agents working with farmers at the local level. These three levels correspond to the transfer of technology (TOT) model described by Chambers and Jiggins (1986), shown in Fig. 1.

The TOT model used by IRRI and later by the CGIAR system differs from the US model in one critical aspect — researchers and extension specialists do not work at the same institutes and do not have the same status. In the CGIAR system research scientists work at the CGIAR centres not at the NARS institutes who are responsible for extension. Also CGIAR scientists are generally better qualified and higher status — 'internationally' recruited rather than 'nationally' recruited. The most important role that the CGIAR system has played is to set the tone for the NARS (Horton, 1997). The tone the CGIAR system has set has biased the NARS towards research, not extension, and this is now reflected in national agricultural research centres that have modelled themselves on CGIAR centres (e.g. the Philippine Rice Research Institute, the Cuu Long Rice Research Institute in Vietnam and the Chinese National Rice Research Institute that are all modelled on IRRI).

Despite this shortcoming, the TOT model worked well for the dissemination of HYVs, partly because of the unusually favourable nature of the technology has meant that adoption has occurred without there needing to be good links between research and extension. The attributes of the HYV technology that made its dissemination so easy were:

- very high relative advantage, giving much higher yields than traditional varieties in FPEs;
- the requirement for little or no new knowledge to make it work, and the fact that the seed could be easily and cheaply reproduced and transported.

Scientists in national programs used the IRRI breeding lines to generate hundreds of semi-dwarf varieties more suited to local conditions. Feedback about susceptibility to diseases and pests reached IRRI. For example, it was found that IR8, the first widely adopted modern variety, was vulnerable to seven major pests and diseases. IR8 was followed by a succession of varieties that overcame these problems and in 1982 11 million hectares was planted to IR36, the most widely planted rice variety in history (Holden et al., 1993). Average rice yields in South and Southeast Asia in 1991–1993 were 83% higher than those in 1964–1966, the 3 years immediately preceding the introduction of IR8. Total production rose by 120% while the land planted to rice increased by only 21% (IRRI, 1993). IRRI and the TOT methodology of working with NARS undoubtedly was the key factor in this remarkable increase in rice production. A second major factor was that, contrary to some opinion, farmers are very quick to adopt new ideas and technologies that are of clear immediate benefit to them (Scott, 1998).

3.2. Modern varieties in less favourable production environments (simple technology, complex system)

TOT approaches, or ‘classical breeding’ methods as they are also called, have led to very high adoption rates of HYVs in the relatively homogenous irrigated ecosystem. Irrigation helps control growing conditions to suit the uniform needs of these pure lines. The TOT approach has largely failed to deliver benefits to farmers in less favourable production environments (LFPEs), or marginal areas, where agro-climatic conditions are far more varied and far less controllable. LFPEs include areas that are rainfed, have salty soils, are flood or drought prone, and areas where rice is grown as an ‘upland’ crop — like wheat or barley without flooding and ponding of water to control weeds. In such areas farmers’ priorities tend to be subsistence in nature, that is, their objective is to guarantee sufficient food each year for their families rather than grow large surpluses for sale, as farmers in FPEs. Subsistence farmers tend to be poorer in monetary terms than their commercially-orientated counterparts. Hence, the concern that CGIAR centre efforts are not contributing sufficiently to poverty eradication.

Farmers in LFPEs have developed intricate risk management strategies to ensure they grow sufficient food and can save seed each year. Since farming began over 10,000 years ago farmers have been selecting landraces that are suited to the ecological niches they farm (Holden et al., 1993). This has created a huge diversity evident in the estimated 100,000 varieties of rice that existed in Asia. Farmers select and choose to plant varieties based on a large number of factors other than yield. For example, a farmer might choose to plant a drought resistant variety that competes well with weeds in their higher fields, and a higher yielding variety in lower ones where water supply is more assured. Moreover, the landraces they plant have greater genetic variability than the ‘pure’ cultivars produced by IRRI and national breeding programs. This means that while some plants may be susceptible to a certain pest attack, others, with a different genetic make-up are likely to be resistant. This makes less likely catastrophic loss due to the whole, genetically pure, crop failing.

Faced with the realisation that few farmers in marginal areas had adopted modern varieties researchers began looking for alternative breeding and dissemination approaches to the TOT approach. Two approaches have emerged: participatory varietal selection (PVS) and participatory plant breeding (PPB), both of which acknowledge that farmers have rich local knowledge that makes them better able to select varieties suitable to their complex and changeable farming systems than breeders in research stations (Sperling et al., 1993; Witcombe et al., 1996). In PVS farmers are allowed to choose finished, or near finished, products of a conventional plant-breeding program to evaluate in their own fields. Sperling et al. (1993) reported that in Rwanda the selections made by bean farmers involved in PVS outperformed breeders’ choices in farmers’ fields. In PPB farmers themselves are involved in the breeding process. In one method of PPB reported by Salazar (1992) the breeder gives F3 or F4 material to farmers who carry out all further selection. At F7 or F8 breeders monitor diversity and select best material for conventional trials.

3.3. The SRR dryer (complex technology, simple system)

The SRR dryer is one of the cheapest and simplest mechanical grain dryers ever built. It consists of 3 components — a two-stage axial fan powered by an

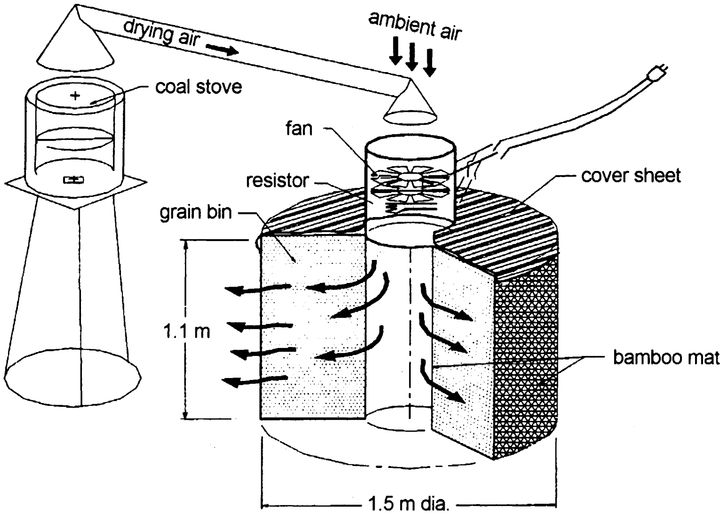


Fig. 3. The 'very low cost' SRR dryer.

electric motor; a heater which can either be an electric element or a coal stove; and a bamboo mat drying bin. It was designed to be used by small-area (<1 ha) Vietnamese farmers growing rice in urban areas or in rural areas with a good rural electricity supply. The basic SRR dryer model, shown in Fig. 3, can dry 1 t in 66 h and cost $90 as of March 1998.

About 665 units had been sold in the Mekong Delta in the 2.5 years since the first commercial unit was made in October 1995. One manufacturer, who was also the main researcher on the SRR dryer development project, has manufactured 85% of these. The main benefit of the SRR dryer found in a July 1997 survey (Douthwaite, 1999) was to reduce the amount of family labour needed to dry farm production to one quarter. Children were found to spend this time studying, and men and women spent the time either in money-earning activities or other farm or household work. Adopters were using the dryers to dry 75% of their wet season output. This percentage was significantly higher for poorer farmers with small farm size.

The research that led to the development of the SRR dryer by the University of Agriculture and Fisheries (UAF) began in a traditional way. UAF started working on in-bin, low temperature drying, the technique on which the SRR dryer is based, because GTZ funded a project to do this work. This GTZ project 'Postharvest Technologies for Rice in the Humid Tropics' (GTZ Project) began largely as the result of the success of a similar GTZ-funded dryer project in Korea. It was expert driven. UAF had a strong dryer group and lobbied GTZ to be included in the GTZ Project. The GTZ Project provided them funds to evaluate and develop low-temperature dryers, not to conduct the type of R&D that UAF felt would have most impact on Vietnamese farmers.

The invention of the SRR dryer was largely the work of one UAF researcher, Mr. L.V. Bahn. He was a rice farmer when growing up and by the time he began working on in-bin drying also owned a small manufacturing business. His background enabled him to develop a first prototype of the SRR dryer that generated a great deal of interest amongst farmers when first tested at a rice mill in July 1995. This interest led to a demonstration in a farmer's house in September 1995 carried out together with the Binh Chanh extension office. This farmer, and three others, ordered SRR dryers. This prompted the decision to commercialise the technology in October 1995. The extension officer helped make a radio program about the dryer that resulted in another 20 orders in 1995. Mr. Bahn built all the first machines. Other members of the UAF dryer group also benefited financially from these sales through a profit sharing scheme linked to Mr. Bahn's business.

UAF's extension approach was to carry out 'demo-sales' for farmers interested enough in the SRR dryer to come to UAF to find out more information. Farmers heard about it from the radio program and other media coverage. If the farmer was interested in buying a unit, UAF staff transported the dryer to the farmer's house. Transport was relatively easy because the dryer could be loaded onto the back of a motorbike. UAF staff installed the dryer and stayed for up to four days to dry the first batch, during which time they trained the farmer. If the farmer was satisfied then he or she paid the full cost of the dryer. If not, UAF took the dryer back.

The 'demo-sales' gave Mr. Bahn and the UAF dryer team important feedback about the performance of the early SRR dryers. They quickly realised that the main constraint to adoption was the requirement for adopters to have a good electricity supply that could run the 1 kW heater as well as the 0.5 kW electric blower. Within 1 year they were supplying coal stoves to replace the electric heater. The survey of dryer adopters found that Mr. Bahn had made seven other non-trivial changes to the SRR dryer to allow use in areas with poor electricity; or to increase dryer capacity; or to make the dryer cheaper to build.

In 1996 an owner of an electrical repair shop in Long An Province, Muoi Dinh, began copying the SRR dryer and by July 1997 had built about 100 units while Bahn had built about 560. The same survey found Dinh had made six modifications, four to allow use of the dryer in areas with poor electricity supply, reflecting the conditions in Long An; and two to make the dryer cheaper to build. All modifications were rated on a scale of +5 to –5 to reflect their effect on the 'fitness' of the technology. A modification would be given the highest rating of +5 if it was judged to be a major improvement to machine fitness. The net total of Bahn's modifications were +21, showing his innovative activity was highly beneficial, while Dinh's score was −5 showing his changes had reduced the fitness of the technology.

The same survey found that users had made 13 significant changes to the operating instructions provided by UAF. UAF, in designing the operating instructions, had tried to minimise fuel costs by recommending the heater was turned off during the day, at the expense of long drying times. Most farmers, however, had more than one batch (1 t) to dry at a time and so reducing drying time was their main priority. Hence, more than two-thirds ignored the UAF recommendation and kept the heater on all, or nearly all, the time. Even if they did turn the heater off, hardly any used the UAF-recommended drying strategy, choosing instead to devise versions of their own, matched to their electrical supply, the initial moisture content of paddy to be dried, and personal preference. In adopting a strategy to minimise drying time, owners were able to reduce the drying time by 39%, or by 42 h for a 22% increase in energy costs if coal was used, or 37% increase if an electric heater was used.

While the R&D that led to the SRR dryer was 'traditional' in approach as evident in UAF being tied to evaluate one drying technique that 'outside' experts had deemed appropriate, the subsequent development and promotion of the SRR dryer can be described as participatory for a number of reasons:

- the fact that Mr. Bahn was the researcher, manufacturer and came from a farming background made seamless the integration between research, manufacturer and end-user needs;
- farmer opinion was sought very soon after the first prototype was built;
- extension services were included and contributed from the time of testing the first prototype;
- profit motivation meant the researchers were very well motivated to improve the technology and receptive to innovations to the machine and its operation that improved 'fitness', whether they developed them or not.

3.4. The SG harvester (complex technology, complex system)

The SG harvester, shown in Fig. 4, consists of a stripper rotor that spins in the crop as the machine moves forward and combs, or strips, the grain from the plants. The rotor throws grain, with some straw, into a collection container. When full, two people change the containers and empty the full one. The machine is operated by a third person, who walks behind the machine. The mixture of grain and straw emptied from the container is then threshed and cleaned by the TC800 thresher/cleaner, or any other available thresher. The latest version of the SG800, the Mark III, costs $2000.

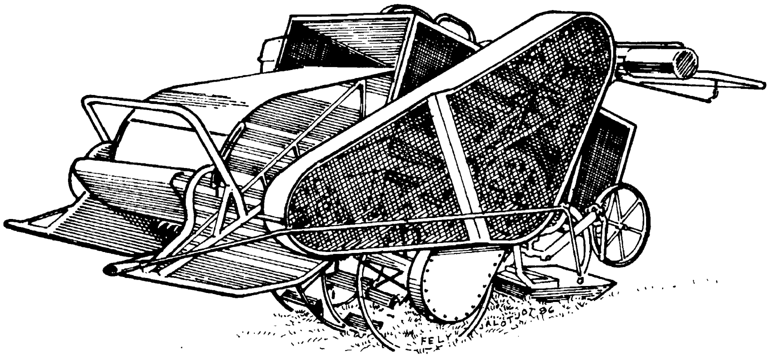


Fig. 4. The stripper gatherer (SG) harvester.

Together the SG harvester, TC800 thresher/cleaner and seven people can harvest 4 t paddy in 1 day.

About 130 SG harvesters have been sold in the Philippines in 5 years since the first commercial sale. Most of the farmers who have bought the machine did so to reduce the costs and risks associated with organising, paying and depending on teams of hired harvest labourers. Most owners use the machine only on their own farms, which are large (14.4 ha) compared to the Philippine average (2.17 ha (IRRI, 1995a,b)). Some owners have begun offering contract-hiring services using the machines but this has yet to become commonplace.

Like the SRR dryer, the project that developed the SG harvester began in a traditional, supply-driven way. In 1986, Silsoe Research Institute (SRI) in the UK developed a stripper rotor (Klinner et al., 1987) that was quickly and successfully commercialised in the UK. The head of IRRI Agricultural Engineering Division and the head of the Overseas Division of SRI both saw potential for the technology in small Asian rice fields. The first concept prototype of the SG harvester was built in 1990 and subsequent versions were tested in farmers' fields. In 1992, the first order was placed for a unit which was supplied in 1993. The order was a result of a 1992 press release that led to newspaper and magazine articles in the Philippine and international press.

Ropali Trading Company, a large Philippine agricultural machinery manufacturer, negotiated with IRRI to begin production of the SG harvester in 1993. The manufacturer bought a prototype from another builder, tested it, and began building a first batch of 50 units in November 1993, reassured that the technology was 'mature'. Unfortunately there were 11 deviations from the original design that seriously reduced the 'fitness' of the SG harvester (see Fig. 4). These included the fitting of poor quality ground-drive transmissions that generally broke before harvesting 1 ha; unbalanced stripper rotors; and collection containers that did not fit properly and were made from poor quality, under specification plywood.

The manufacturer invested considerable resources in advertising and demonstrating the SG harvester. However, after selling 15 machines in 1994 serious problems began to emerge. These did not stop the manufacturer building another 20 in April 1994. By mid-1998 Ropali had sold only another 16 machines in spite of investing about $7500 in one promotion campaign alone. The company also spent money in replacing the faulty transmissions on the machines it sold and in warranty claims: one owner had his machine replaced five times.

In hindsight the company received less technical assistance and training than was necessary. Part of the reason for this was that the IRRI R&D team who had been working with the manufacturer stopped after responsibility for this 'extension' work was passed over to the Philippine Rice Research Institute (PhilRice). This transfer of responsibility exactly followed the TOT approach that draws a clear line between research and extension activities. It took time for the PhilRice team to learn about the SG harvester and during this transition period the manufacturer received little help.

In 1995 IRRI and the Philippine Rice Research Institute (PhilRice) released the Mark II drawings of

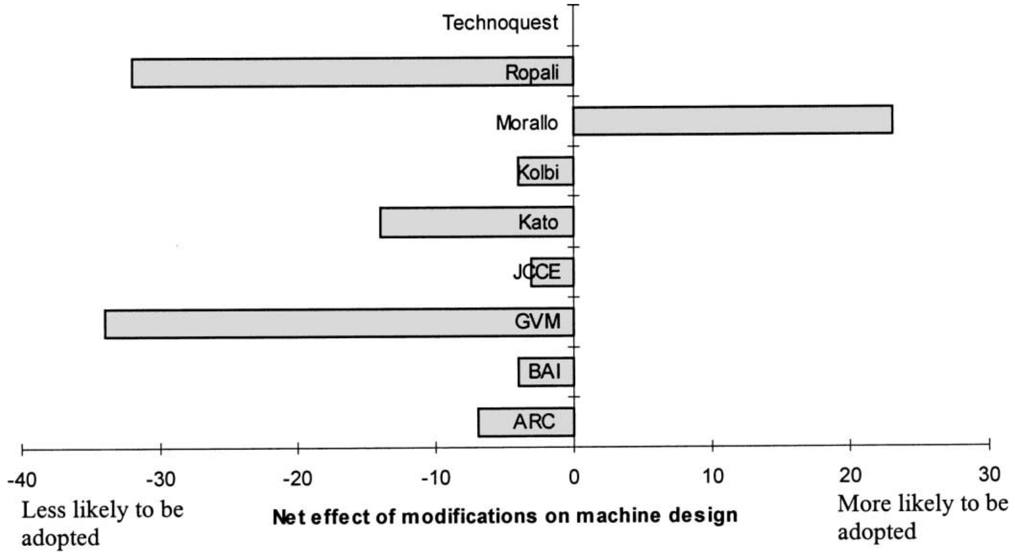


Fig. 5. Net effect of manufacturers' modifications on the fitness (likelihood of adoption) of the original IRRI design of the Mark II SG harvester.

the SG harvester. The design included 10 modifications designed to make the machine more reliable, robust,[2] better able to operate in muddy and soft field conditions, and easier to operate. Manufacturers first made several of these changes. The effect of the changes was to increase the weight of the machine by 31% which negated the changes made to improve handling and performance in difficult field conditions.

In 1996 and 1997, nine manufacturers were surveyed for the variations that their machines had from the Mark II design, which all were building. The same ranking system was used as with the SRR dryer described previously. Fig. 5 shows that only one manufacturer had actually improved the 'fitness' of the technology. Morallo Metal Industries developed their own version of the Mark II design that was almost as light as the Mark I version but far more reliable. Another manufacturer developed an idea for an improved wheel design that was further developed by IRRI and proved to give much better mobility in muddy field conditions. In 1997, IRRI released drawings of the Mark III SG harvester based on the Morallo SG harvester and incorporating the novel wheel.

As with the SRR dryer the development of the SG harvester was expert driven at the beginning but became participatory when manufacturers started building it and farmers started buying and using it. Unlike the SRR dryer, however, researchers were hindered from fully participating in the early adoption process.

4. Discussion

"The importance of understanding innovation as a process is that this understanding shapes the way we try and manage it" (Tidd et al., 1997). Our purpose in this paper is to assist the development and choice of approaches to catalyse and manage agricultural innovations that have a public sector source. Our contribution is to help understanding of the interactions between management approach, technology type and farming system type.

4.1. Knowledge and fitness changes in the case study technologies

Mokyr (1990) defined an invention as an incremental increase in the total knowledge set of a society.

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[2] The first design used relatively expensive Japanese-made bearings, chains and sprockets. Local manufacturers often substituted these for cheaper, lower quality, lower specification Chinese-made components. The size of some of the drive train components on the Mark II SG harvester were increased to give reasonable life with Chinese-made components.

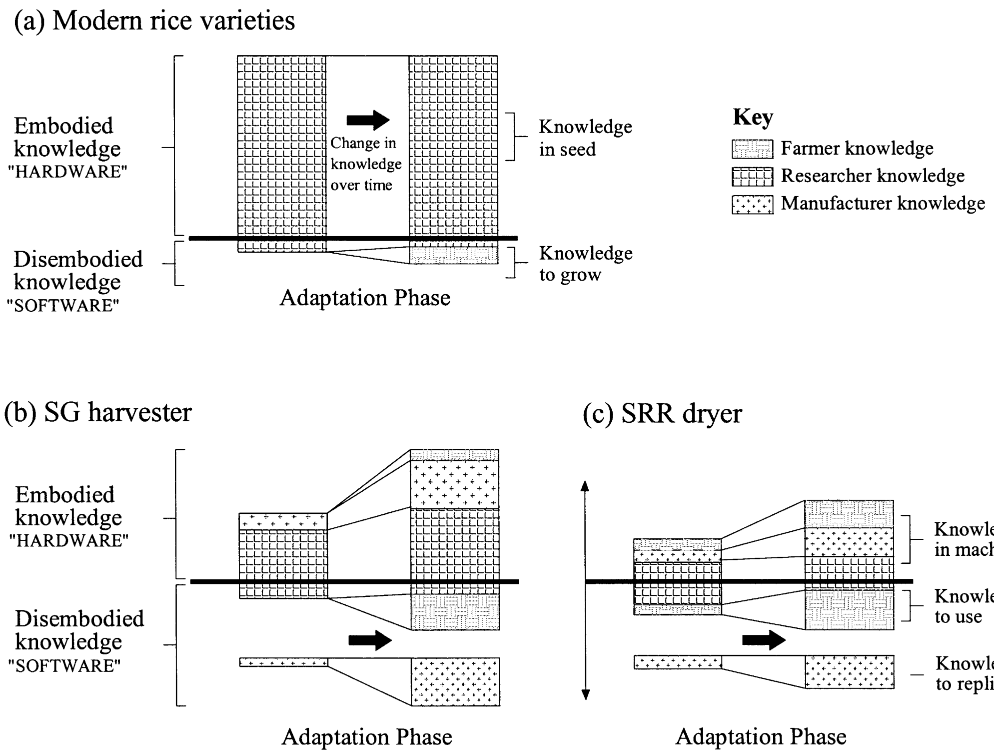

Fig. 6. Schematic representations of the change in the knowledge associated with three types of technology during the adaptation phase.

Fig. 6 uses this definition to show a schematic representation of the new knowledge, or existing knowledge used in a novel way, associated with the three case study technologies. The figure shows how the knowledge changes between the end of the *start-up* phase just before key stakeholder adoption begins, and the beginning of the *expansion* phase when widespread adoption of the technology occurs (see Fig. 2). The figure distinguishes between two types of knowledge:

- Embodied or hardware knowledge — knowledge that is embedded in the machine or seed itself. For example, the knowledge needed to build a blower that works efficiently and delivers the required volume of air at the necessary pressure, or the knowledge that a particular gene gives resistance to stem borer.
- Disembodied or software knowledge — knowledge that is not embedded and has to be socially constructed in situ by the people replicating and using the technology. Software knowledge has two parts:

  1. The knowledge required using or growing the technology.
  2. The knowledge required building or reproducing it.

Fig. 6 also shows the extent to which the researchers and the two *key stakeholders* (manufacturers and users) involved in the innovation process contributed to this knowledge over time.

Bar graph areas in Fig. 6 represent the sum of knowledge that is new to the system into which the technology was introduced, and existing knowledge used in a novel way. All technologies are founded on what went before so in terms of the total knowledge associated with a technology the knowledge shown is the tip of the iceberg. There is no easy way to quantify new knowledge and Fig. 6 does not attempt to do this. Rather the figure attempts to give a qualitative picture of knowledge changes in terms of ‘more’ or ‘less’, ‘increase’ or ‘decrease’. Estimates of the amount and sources of knowledge are based on data from the case studies indicating the extent of the cognitive contribution of the stakeholders in the innovation process.

Fig. 6 shows important knowledge differences between 'simple' modern seed varieties and the 'complex' agricultural machinery. Firstly, modern rice varieties, whether introduced into favourable or unfavourable production environments, have the largest amount of knowledge associated with them, but nearly all of this is embodied, and nearly all of this comes from research. For example, IR36, introduced in 1976, had at least partial resistance to seven of the most serious pest and diseases. Resistance to one disease — grassy stunt — required researchers to screen over 17,000 varieties for the resistance gene (Holden et al., 1993). The knowledge required to undertake this screening, as well as the ability to combine resistance genes in a single, high yielding variety, is part of the knowledge shown in Fig. 6(a). The fact that genes that gave this resistance were available to IRRI scientists to find was due to natural and farmer selection. This resistance can be thought of as existing knowledge. However, IRRI researchers discovered and applied it in novel ways so research is shown as the source of the innovation. Fig. 6(a) shows that this embodied knowledge does not change once the MV is released. This is because MVs breed pure — there is not genetic diversity in their progeny on which farmers can select, unlike with landraces.

In contrast, Fig. 6(b) and (c) shows that the embodied knowledge in equipment technologies had multiple sources of innovation and they changed a great deal after first release. These modifications represent experiential learning cycles carried out on the part of the farmers and manufacturers as they used and built the equipment. Increases in researcher innovation after the release of the technology are also the result of researchers learning more about the technology in actual usage. Fig. 6(b) and (c) show more of the hardware knowledge originating from researchers and manufacturers than from end-users reflecting the finding that manufacturers and researchers, not users, made the majority of modifications that were incorporated in design after commercialisation. Fig. 6(b) shows that when first commercialised the SG harvester, being a far more complex technology, contained a greater amount of knowledge than the SRR dryer. Most of this knowledge originated from research. In contrast the SRR dryer was developed by a research team that also had experience manufacturing dryers and had farming backgrounds, so a greater proportion of knowledge came from these sources, at least indirectly.

Compared to the 'easy to use' MVs, Fig. 6(b) and (c) show more 'software' knowledge associated with the 'hard to employ' technologies at the end of the *adaptation* phase, with more sources of innovation. This is because users needed to learn much more to use equipment technologies than grow MVs: operators needed to learn new skills to successfully operate the SG harvester and SRR dryer and farmers needed to reorganise their harvest and drying arrangements. In contrast farmers can profitably grow MVs in the same way they grew their traditional varieties and so have comparatively little to learn.

In Fig. 6(b), knowledge to operate the equipment technologies is shown as all researcher knowledge at the first release stage which was passed on to operators through training materials and first-hand instruction. Fig. 6(b) shows that this researcher knowledge actually decreased at the beginning of the successful adoption stage as a result of operators learning their own ways of better organising themselves and operating the machines in their conditions.

Equipment technology requires manufacturers to learn to build it resulting in an additional source of innovation that MVs do not have. Manufacturers needed to learn how to build the equipment technologies using their (often limited) workshop assets, set up quality control procedures, build jigs and fixtures, learn where the cheapest sources of non-standard raw materials exist, etc. This is represented in Fig. 6(b) and (c) as a large increase in manufacturer knowledge between the first-release and successful adoption stages. In contrast there is no new reproduction knowledge needed with MVs because farmers can grow and save seed of MVs in much the same way as they did with traditional varieties.

Fig. 7 shows the 'fitness' of the case study technologies and how this changed after first adoption. Fig. 7 identifies two fitness levels: (1) good enough to be adopted by innovative farmers; and (2) good enough for widespread adoption.

Fig. 7 shows that MVs introduced into FPEs are highly fit, which gives rise to high adoption rates. The attributes of the technology (fitness) improve slightly with time as farmers adapt crop management to their

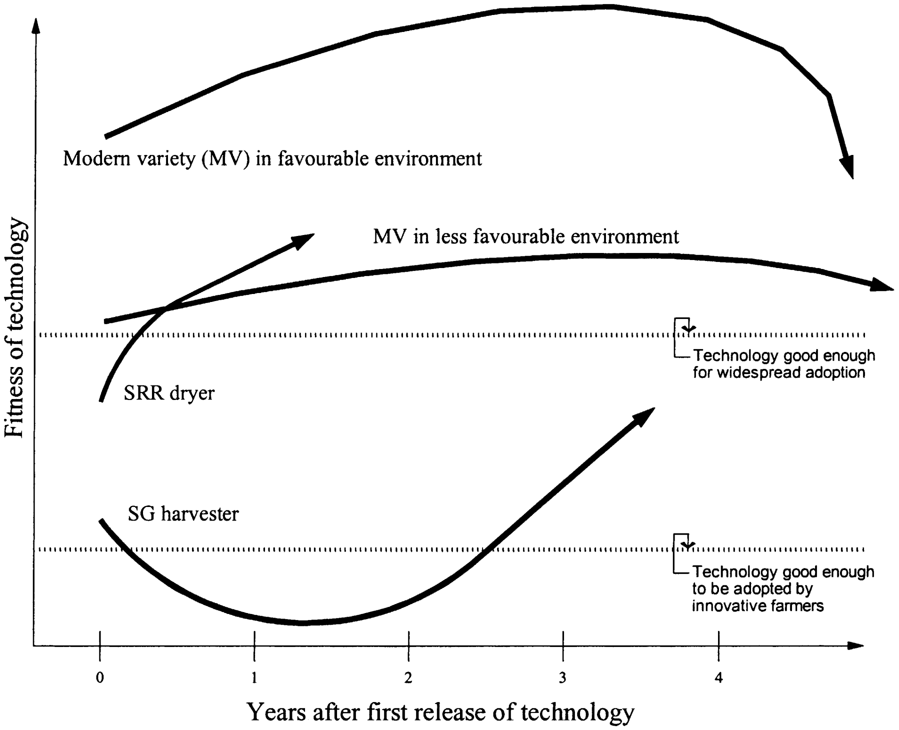

Fig. 7. 'Fitness' trajectory of case study technologies.

local conditions. The increase rate is small because the scope for learning and innovation is relatively little compared to the equipment technologies. Then, as pests and diseases evolve to by-pass the genetic resistance the fitness falls off and a new MV is needed to take its place. The situation is different with a MV introduced into a LFPE. Here, if a suitable variety is found at all (and few are) then Fig. 7 shows that the MV has lower fitness than in a FPE, reflecting the finding that farmers apply less fertiliser and so achieve a lower return in more marginal areas. However, lower fitness implies lower adoption rate which in turn means slower breakdown of resistance, hence much more prolonged fall-off in fitness.

The fitness trajectories of the complex technologies are very different to those of the simple ones. This reflects the much larger scope for innovation that existed for the complex technologies, and the result this innovation had on fitness, both beneficial and detrimental.

Fig. 7 shows that neither complex technology was suitable for widespread adoption when first released. Both technologies were initially bought by farmers who were drawn to adopt the technology after hearing about it in the media. These farmers' characteristics closely match Rogers (1995) definition of an innovative adopter, namely, people who are venturesome, are drawn by the technical challenges posed by new technology, are prepared to take the risk and have the resources to do so.

Fig. 7 shows that the SG harvester was less fit than the SRR dryer when it was first introduced. This was partly because the machine itself was much more complex.[3] This additional complexity also explains why the fitness of the technology fell when manufacturers began building it because there was more to learn and more scope to make mistakes. Also any changes they made to the design were more likely to cause unforeseen and detrimental results (see Fig. 5). The fitness of the SG harvester finally began increasing when Morallo Metal Industries developed their version of the machine, ARC Manufacturing developed

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[3] The SG harvester has four belt drives, two chain drives and five shafts while the SRR dryer has none.

an improved wheel and IRRI put both improvements together and promulgated them as the Mark III design. The SG harvester R&D team at IRRI speeded up the evolution of the technology by playing this selection and promulgation role and may have made the difference between success and failure. They were uniquely qualified to play the role through their knowledge of the technology and their motivation to see it succeed.

Low initial fitness of the SG harvester was also due to the higher complexity of the system in which the machine had to work, and the system clashes that resulted. One example of a system clash was the negative response of manual labourers who felt threatened by the introduction of the machine. Labourers threatened or took sanctions against farmers using the harvester which reduced the attraction of farmers using the machine. One sanction was to refuse to harvest when the SG harvester was unable due to difficult field or crop conditions. In contrast the SRR dryer was bought to reduce family labour, just like families in developed countries might buy washing machines. Such technologies cause less social conflict than those that displace hired labour.

In contrast to the SG harvester, Fig. 7 shows that the fitness of the SRR dryer increased after first commercialisation. A key reason for this was that the main researcher was also the manufacturer so there were no problems in transferring knowledge about the technology. UAF, in allowing a researcher to become a manufacturer, contributed to the success of the innovation. Unwittingly, UAF was following successful innovation management practice identified in industry in the 1960s. In the conclusions from a survey of factors affecting the success of ten key innovations in Europe and the USA, Layton et al. (1972) wrote: “Our studies showed that an important factor in successful innovation is the transfer of information from development to production; and here we found no substitute for the movement of people, including highly qualified ones” p. 3.

The increase in fitness of the SRR dryer came about when UAF staff, who were both researching and manufacturing the dryer, learned more about the performance of the technology in actual farm conditions and made modifications accordingly. Improvements also resulted from user innovations. Like IRRI, UAF played an important role in discovering and promulgating these.

Fig. 7 shows that the rate of increase in the fitness of the SRR dryer began to fall 1 year after first commercialisation. This was when the manufacturer in Long An Province started making and selling inferior quality machines that also did not work as well.

Another difference between the SRR dryer and the SG harvester is that the fitness of the former became good enough for widespread adoption 6 months after first commercialisation, once the innovation of using a coal stove instead of an electric heater was made. Although the knowledge associated with the SG harvester is greater than the SRR dryer 5 years after commercialisation, it is still not fit enough for widespread adoption. Further improvements to the performance of the machine, or demand-side changes, are required before sales of the technology will begin to increase substantially. These changes are likely to occur if economic growth continues in the Philippines and with it shortages of manual harvest labour continue to increase.

5. Testing the hypotheses

The hypotheses were set-up so that testing them would help achieve the purpose of the paper, namely, gaining a greater understanding of the interaction between management approach, technology type and the system into which the technology is introduced. The results of testing the hypotheses will give an indication of the most effective mix of top-down and participatory management approaches.

Hypothesis 1. Technologies that require key stakeholders to change little to make the technology work (i.e. easy to understand and use technologies introduced into simple farming systems) will have the fastest impact using a top-down approach.

The case study of the early MVs developed by IRRI supports the hypothesis. It shows that the top-down TOT approach developed by IRRI and the CGIAR system has been extremely effective at developing HYVs and transferring them to FPEs in many countries, who have then transferred them to farmers. The nature of the technology transfer system allowed impact to be achieved quickly because IRRI transferred breeding lines to many NARS who were able to adapt and extend the technology to their farmers. It is not true to say that the TOT approach was not participatory — the approach did engender the active participation of NARS plant breeders. It would be more accurate to describe it as not being farmer-participatory. In practice this meant neither CGIAR nor NARS scientists saw farmer learning and innovation as important in the extension and final impact of the technology. To a large extent they were probably right given the nature of MVs. Most of the knowledge associated with a MV is 'locked' into the seed and cannot be altered by farmers. Growing rice is not a new technology so there was very little farmer learning necessary to make MVs work. The only scope for farmer innovation with MVs is in crop management practices, and while this has certainly taken place, no references have been found of work that has looked for this innovation and assessed its impact on technology performance and adoption rate. Most impact studies carried out have simply looked at adoption or non-adoption of MVs, not farmer modifications to the technology package (personal communication with G. Castillo, 1999).

While the TOT approach has been very effective with MVs in FPEs, it is conceivable that greater participation of farmers during breeding would have resulted in varieties with even higher fitness. For example, the early IR varieties would have been improved if they had tasted better.

Hypothesis 2. If either the new knowledge requirement or the system complexity is high then participatory approaches will be most effective.

The mechanical technology case studies showed the importance of the participation of the *key stakeholders* and researchers during the *adaptation* phase (early adoption). As Fig. 7 shows neither technology was fit enough for widespread adoption and only improved with *key stakeholder* and researcher learning and innovation. The assumption of the TOT approach in the development of the SG harvester restricted the participation of the original R&D team from facilitating the learning of the *key stakeholders*, and also restricted the R&D team learning more about the technology and further improving it. As a result, *key stakeholder* knowledge gaps lasted longer than they should have, more mistakes were made, and innovations to solve technical shortcomings took longer than they might. Together, these factors contributed to the fitness of the SG harvester deteriorating after release, and the length of time before it recovered.

The invention and subsequent development and diffusion of both the SG harvester and SRR dryer involved participatory and non-participatory approaches. By definition technologies that qualify as macro-inventions when first introduced require non-participatory 'expert driven' early R&D. Mokyr (1990) defined a macro-invention as a new technology without clear-cut parentage that represents a distinct break from previous technique in a given society. Mokyr also went on to say that macro-inventions represent a challenge to the status quo and an attack by an individual on a constraint that everyone else has taken for granted. Farmer-participatory approaches that make use of local knowledge rather than challenge it are more likely to be useful for micro-inventions. Micro-inventions are innovative changes to macro-inventions to get them to work better. Both the SG harvester and SRR dryer were macro-inventions with respect to the systems into which they were introduced. Therefore, one can predict that the participation of the key stakeholders was likely to be most useful when the concept had already been established. In practice this point represents the beginning of the *adaptation* phase when the *key stakeholders* gain a 'stake' in the technology by starting to build it and own it.

Modern varieties are not macro-inventions when first introduced into a farming system so one can predict that farmer participation can be of use from the beginning of the R&D process. This is borne out as seen previously by recent work in which farmers do most of the breeding (Salazar, 1992; Witcombe, 1996).

6. Implications for R&D planning and implementation

The tests of the hypotheses above suggests that effective management of invention and innovation requires a mix of top-down and participatory approaches whatever the complexity of the technology or system. The criteria for choosing the amount of R&D team participation in the early adoption process is the amount of *key stakeholder* learning that will be required in implementing the new technology, and the scope for innovation after adoption. The more learning necessary, and the greater the scope for innovation, then the more the R&D team should participate in the *adaptation* phase.

Key stakeholder participation will be of most help in the *development* phase if the new technology is a micro-invention rather than a macro-invention. *Key stakeholder* participation should be sought as soon as a workable prototype of a macro-invention has been developed. The R&D team should attempt to 'perfect' a new technology as much as possible before release to reduce the *key stakeholders*' risks of adoption. However, given the length of project cycles the R&D team will probably have no more than 3 years to demonstrate the viability of the innovation through actual farmer adoption. Early *key stakeholder* participation reduces the risk of the development of inappropriate technology and is more parsimonious (Chambers and Jiggins, 1986) because the *key stakeholders* embody the necessary local knowledge themselves instead of researchers trying to capture it through expensive surveys. Furthermore, early *key stakeholder* participation increases the potential sources of innovation and so increases the rate at which the fitness of the technology will increase, if the process is properly managed.

While the amount of *key stakeholder* learning and innovation expected during adoption determines the mix between researcher-driven and participatory approaches, the type of learning and innovation expected determines the actual type of participatory or non-participatory approach used. The case studies showed that participatory varietal selection (PVS) is not suitable for equipment technology. This is because farmers are not inventive in PVS, in that they do not invent the novelty that distinguishes one variety from another, rather they select novelty that is generated by crossing, genetic diversity, and from the interaction of genotype with the environment. In contrast, with equipment and most other types of technology beneficial novelties are usually the result of micro-inventions of the stakeholders. This means that managing participatory technology development (PTD) in other technologies is likely to be harder than managing PVS because the need for invention makes the process less predictable and requires people who are inventive as well as good at selection and promulgation.

Other characteristics of seed technology that makes management of the innovation process particularly easy are its high trialability and observability attributes. Farmers can easily experiment with new varieties because seed is cheap to produce, easily transported, can be given to farmers without instructions (Witcombe, 1996) and farmers can then grow their own seed and pass it on to their neighbours who have seen its benefits for themselves.

7. Conclusions

This paper has taken the view that an invention represents an increment in the total technological knowledge of a society or farming system. New knowledge associated with a new technology is embedded in the hardware (seed or machine) and the software, i.e. the knowledge to replicate and use the technology. The paper has shown that the adoption rate and impact of some new technologies depends upon the motivation and success of the people who directly benefit from an innovation — the *key stakeholders* — in learning about the technology and their ability to make it cheaper and more profitable to replicate and use. It also depends upon researchers — the group who developed the first prototype and who have scientific knowledge of the technology — working in partnership with the *key stakeholders* to help impart scientific knowledge, learn more about the performance of the technology in real conditions themselves, and to make improvements of their own. The importance of these learning and modification processes on adoption rate and eventual impact depends on the amount of new knowledge that needs to be learnt by the researchers and *key stakeholders*. In the past technology generation and transfer approaches in public sector agricultural research have been based on a model developed for the transfer of very simple technologies — high yielding crop varieties (HYVs) — into simple systems. Seed technology, particularly HYVs of closed pollinated species, is unusually simple because the knowledge embedded in the hardware (the seed) cannot be altered by the user. Furthermore, HYVs can be grown and reproduced in similar ways to farmers' traditional varieties. Taken together this means that farmers need to learn very little, and can modify very little, when adopting HYVs. Models for generating and transferring HYVs can, therefore, be simple. One resulting organisational simplification is the separation of research from extension. However, this simplification is not appropriate for the research and dissemination of more complex technologies where more learning and more adaptation is possible and required. This paper has shown that with some technologies, e.g. agricultural equipment, modifications made by the *key stakeholders* can result in rapid changes in the fitness of the technology that can be either beneficial or detrimental. Deterioration of fitness due to mistakes as a result of knowledge gaps of the researchers and *key stakeholders* are likely during the initial adoption phase. Research planners and managers need to be aware of this and act accordingly. When properly managed the early release of a new technology can be a parsimonious and rapid way to generate improvements resulting from a synthesis of scientific and local knowledge. These improvements in fitness make widespread adoption and impact more likely. However, if badly managed the result can be technology failure. Good management involves ensuring the R&D team participates in the early adoption process to facilitate *key stakeholder* learning while at the same time making innovative improvements themselves.

The stage at which *key stakeholder* participation can be effective depends upon the extent to which the technology is seen as an improvement of an existing technique (a micro-invention) or a new technique that challenges existing beliefs and cultural practices (a macro-invention). In the latter *key stakeholder* participation is likely to be effective only when a working prototype has been produced.

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