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Re-Innovated and Accepted: An Approach for More Effective Management of Engineering for Small-Holder Farmers

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Abstract

The paper argues that lack of impact, and some very visible failures, are the main reasons for the decline in public sector agricultural engineering for small-holder agriculture seen in the Consultative Group on International Agricultural Research (CGIAR) system and elsewhere, since the mid-1980s. A literature survey establishes that a possible cause of engineering's problems is the linear, sequential, and one-way conceptualization of the research, development and transfer process which is adopted by much of the research establishment. The paper reviews the case study of a mechanical harvester developed by the International Rice Research Institute (IRRI) in the early 1990s. It finds that the harvester innovation process did not, and could not have occurred linearly. The linear conceptualization embedded in the project planning constrained the participation of the R&D team in further improvement of the technology after it had been released to manufacturers. It also resulted in much of the innovative potential of the first-adopter farmers being squandered. An evolutionary model of the innovation process is found to give a better match with reality. The evolutionary conceptualization suggests research managers should create organizational structures which foster the active participation of the stakeholders in the process, and the free flow of information between them. This nurtures the evolution of new technology by creating ideal conditions for local adaptations – generally regarded as essential with new agricultural technology – and the selection between them. The paper finds that an evolutionary model embodies the characteristics of a new methodology identified in the literature criticizing the linear conceptualization of the research, development and transfer process.

Introduction

International public sector agricultural engineering for the small-farm sector in developing countries has been in decline since the mid-1980s. Agricultural engineering in the CGIAR (Consultative Group on International Agricultural Research) system has almost ceased to exist. The International Rice Research Institute (IRRI) is the only CGIAR centre to have a separate engineering component, but staffing levels have fallen from 9 internationally recruited engineers and 17 nationally recruited engineers in 1984 (IRRI, 1985) to 2.5 internationally recruited engineers and 5 nationally recruited engineers today. The Overseas Division at Silsoe Research Institute in the UK ceased to exist as a separate entity in 1996 when it became part of another division. Bill Stout (1997), the president of International Commission of Agricultural Engineering (CIGR) wrote:

"Just about every agricultural engineering research and education program that I have visited around the world has had recent budget cuts". It is now virtually impossible to find a donor to fund a mechanization project. Funding cuts appear to have happened because donors' views on the desirability of funding agricultural engineering research and development (R&D) have changed.

Why has this happened? One reason is that equipment technology is generally viewed as "labour-saving"—it represents a substitution of capital for labour and hence may be inappropriate in areas of high underemployment. Secondly, in most cases equipment is manufactured by the private sector and sold for profit, and hence donors consider R&D costs should be borne by the private sector. Reinforcing this is the fact that public sector intervention in equipment innovation has had some spectacular and very visible failures. Paul Starkey's book "Perfected yet Rejected" (1986) did damage to the agricultural engineering profession by cataloging how about $40 million was invested in developing animal-drawn tool bars for thirty years without any sustainable adoption by farmers anywhere. If the profession had learned some of the negative lessons from the book then perhaps the decline could have been reversed. Unfortunately similar piles of scrap metal continue to be generated as 1000 virtually unused stripper gatherer (SG) harvesters in Myanmar, and 1500 flash dryers in the Philippines bear testament. The value of these machines alone, without engines (which can be used for other purposes so are not a complete write-off), is more than $1 million and $4.5 million, respectively.

The paper concerns itself with this lack of impact perception. It is the most serious problem because labour shortage is becoming a real issue in large areas of Southeast Asia and elsewhere, and a strong argument can be made for public sector intervention to support the small- and medium-scale firms supplying the more marginal farm sectors (Douthwaite, 1996). A group of key people in international agricultural engineering generally agreed that lack of impact was the main cause of the decline (Douthwaite and Bell, 1998). Donors simply do not want to fund an activity that has demonstrated little or no impact on the target groups.

The main contention of this paper is that the failure of public sector agricultural engineering stems from a failure to manage innovation properly. Poor management of innovation comes from a failure to understand the process as essentially iterative and evolutionary (Mokyr, 1990; Nelson and Winters 1982; Clark et al., 1996). Instead, according to the literature, the public sector agricultural research adopts a linear and top-down conceptualization of the technology development and transfer process (Clarke, 1994; Chambers and Jiggins, 1986; Biggs, 1989), irrespective of the type of technology (Kiamowitz et al., 1989). This conceptualization sees knowledge flowing through a pipeline that has basic research activities at one end and knowledge embodied as useful products at the other. Innovations are seen to flow sequentially down the pipe-line <u>with different participants responsible for different parts of the process</u>. Chambers and Jiggins (1986) called this conceptualization the Transfer-of-Technology (ToT) model.

The model sees CGIAR centres and other advanced research centres at the beginning of the pipeline carrying out basic and strategic research that results in new technology building blocks and new concept prototypes. In the next stage of the process these prototypes are passed on to the research components of NARS for local verification and refinement. The technology is then transferred to the extension component of the NARS who extend it to manufacturers and farmers. Ruthenberg (1985) describes the conventional view of extension:

"The starting point is a technical innovation (the message) that has become available and that has been tested under conditions as similar as possible to those of the small-holder. The task then is spreading the message to achieve diffusion and adoption of the innovation by as many small holders as possible."

This paper presents the case of the research, development and transfer of the IRRI stripper gatherer (SG) harvester in the Philippines to determine:

- the degree to which the actual innovation process fits a linear or iterative model;
- mistakes made in the management of the process, and the degree to which these might be attributable to the ToT model assumed;
- how the process could be better managed and how an evolutionary conceptualization can help.

Case Study of the SG Harvester in the Philippines

The SG harvester (Figure 1) is a walk-behind harvester with a capacity of about 4 tonnes of paddy rice per day in good conditions. It costs about $1700 with an 11 hp engine. It was designed to work in small fields, unsuitable for larger combine harvesters with higher work rates. The machine consists simply 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, and some straw, into a collection container. When full, two people change the container and empty it. This material is then rethreshed and cleaned in a separate operation using a stationary thresher with cleaner (Douthwaite et al., 1993).

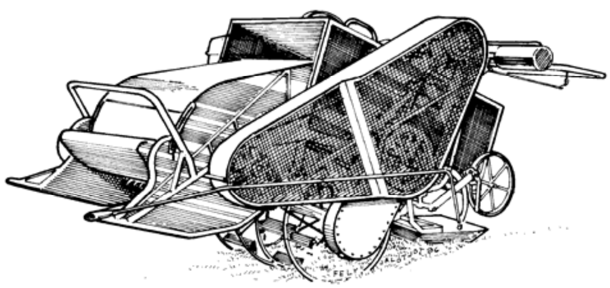

Figure 1. The stripper gatherer (SG) harvester

IRRI began developing the SG harvester in 1990, based on the successful Silsoe stripper rotor, used on combine harvesters in Europe. The competition to the SG harvester was the mechanical reaper which had been introduced into the Philippines from China and Japan in 1983, with only limited success. Lack of widespread adoption was attributed to high labour demand to pick up the windrowed crop left by the machine, poor performance in wet, weedy and lodged crop, inability to harvest in deeply flooded fields and frequent mechanical breakdown of the cutterbar front (Juarez et al., 1988). The SG harvester was developed after tests of the stripper rotor in rice had shown that the rotor could work at acceptable loss levels in a wider range of crop conditions, and was intrinsically simpler and more robust than the cutterbar.

The SG harvester was first released to manufacturers in the Philippines in 1993 and the first unit was sold to a farmer in the same year. IRRI has released three sets of drawings of the machine: - Mark I ver. 1, Mark I ver. 2, and Mark II. Since 1993, 36 other farmers have bought units with private funding, and 11 cooperatives have acquired units with soft government financing, without any down payment. A survey of 19 farmer-owners and 9 cooperatives was carried out by the author between April and August 1997. The survey found that the farmers had adopted the SG harvester to reduce the cost of harvesting, and because they were having problems finding manual harvesters to work in their fields, particularly during peak harvesting. Cooperatives on the other hand adopted the SG harvester because it was available cheaply from the government. None of the cooperatives have made any attempt to start repaying the loan.

The farmer-adopters were well educated – nearly one third had had at least three years of college level engineering.

Table 1 shows the average annual usage rate for all adopters which is calculated by dividing the total area harvested by the SG harvester since purchase, by the number of years since purchase.

Table 1. Annual usage rate since purchase by adopter status

	Adopter status		
Annual usage rate, ha	Coop	Farmer	Totals
<2 ha	6	6	12
2-6 ha	1	7	8
>6 ha	1	6	7
Totals	8	19	27
Average, ha	1.6	5	

Table 1 shows that the average annual usage rate of cooperatives was less than one third that of private owners, in spite of cooperatives having a much larger area potentially available to them to harvest. Nevertheless, the average annual usage rates of the farmers of 5 hectares per year were only half of the break-even hectarage of 10 hectares per year (Douthwaite et al., 1996). One reason for low usage rates was that, as Table 2 shows, almost half of the farmers had stopped using the technology because they found it did not meet their requirements.

The SG harvester was helping farmers reduce their harvesting costs – farmers were paying manual labour an average 7.8% of the value of the dry crop, and only 1.5% to the operators of the SG harvester. In spite of this, farmers stopped using the machine, or used it less than they might have, because they found that they were not able to rely on the SG harvester to harvest their fields in all conditions. They found the machine bogged down in wet field conditions, common in the wet season harvest, and frequently broke down. One farmer had to return his machine to the manufacturer five times. When the SG harvester failed, farmers then had problems finding workers to hand harvest their fields because no prior arrangement had been made. Several owners said the job was doubly difficult because harvest labour took the attitude that if the farmer wanted to try to replace them with a machine, then the farmer had gotten what he or she deserved and they were not going to help.

Table 2. Trend in usage rate by adopter status

	Adopter status		
Trend in usage rate	Coop	Farmer	Totals
Rejected	3	8	11
Trying out	3	0	3
Stable usage rates	0	11	11
Not used	2	0	2
Totals	8	19	27

Cooperative usage rate was much lower because two out of eight cooperatives had not used it at all, and three had stopped after harvesting only very small areas. One cooperative said this was because the mayor of the town had borrowed the engine pulley and they had not bought a replacement, even though it cost only $6. A second cooperative, who had owned three SG harvesters for 2 seasons, said they had not used the machines because no one from the Department of Agriculture (DA) had been to commission the machines, even though the brother of the Cooperative Secretary was DA Regional Director, and one telephone call could have solved the problem. In contrast all the farmer owners made a serious attempt to use the machine at the first opportunity after purchase, even if afterwards they stopped using it. The cooperatives that had stopped using the machine, did so after harvesting an average of only 0.27 ha, compared to the farmers who had stopped after an average of 6.25 ha. Farmer owners had made four times as many modifications to their machines to get them working as had cooperatives.

In spite of the problems farmers had with the harvester, one third managed to harvest more than 3 hectares per season, or about 6 hectares per year. Two farmers have placed orders for another machine. Two of the most successful were retired engineers who are now farming and trying to mechanize so they can farm without having to hire casual labour. The SG harvester has allowed both men to harvest all their crop with their own resources.

Whether a farmer was successful with the SG harvester was not correlated with why some farmers have been able to use the machine, and others not? One might expect a correlation between success and education level, or farm size, or severity of labour shortage in their area. None exists, however. The factor that seems to explain the difference is the motivation of the machine operators. Table 3 shows that the farmers who paid their operators a piece rate (i.e., in proportion to the amount they harvested) enjoyed a higher seasonal usage rate than those who paid none. The one farmer who had a low usage rate in this category paid his labourers a piece rate of only $3.18 per tonne, less than half the average $6.97 of the other farmers paying a piece rate.

Table 3. Level of harvester usage by incentive for SG operators

	Incentive for SG operators			
Annual usage rate, ha	Piece rate	Daily wage	None	Totals
>6	5	1	0	6
2-6	1	3	3	7
<2	1	0	4	5
Totals	7	4	7	18

Manufacturers were aware of problems such as unreliability and bogging down. Ropali replaced the ground drive transmissions on most of the first machines it sold, but this created a new set of problems because the new transmission was much bigger and heavier. The extra weight made the machine more likely to bog down, and it stuck out into the unharvested crop on the side of the machine, knocking some crop over which is then lost. Also when Ropali fitted the new transmission they did not realize it had a different reduction ratio, with the result that the machine needed to be operated at a run if the stripper rotor is to rotate at the right speed. Most operators, not surprisingly, chose not to run behind the machine, but rather to slow engine and hence the rotor speed. One farmer stopped using his machine after the new transmission was fitted he noticed losses were unacceptably high. The farmer blamed the variety which he said was highly shattering, but low rotor speed probably contributed.

Eng. Boy Campillian of ARC Engineering recounts how he had as good as sold a SG harvester during a demonstration until the farmer asked him to harvest some crop in a muddy field. The machine bogged down and the sale was lost. As a result of this experience, Boy developed a new wheel design to solve the problem. IRRI took the development of the ARC-wheel further, and it can now harvest in softer mud. An important added advantage is that the ARC-wheel can be adjusted to work in both wet and dry conditions. On the Mark I SG harvester, failure by farmers to change the star-wheel for rubber wheels in dry conditions contributed to failure of the wheel axle, transmission and skid, because used in hard field conditions the star-wheel, which is star shaped and not round, caused a great deal of machine vibration and shock loading.

Eng. Lawrence Morallo and his father had to refund a farmer who bought a Mark II SG harvester that bogged down. The Morallos then redesigned the machine to solve the problem and built a harvester that it is 25% lighter, and built to a higher quality and reliability specification than other manufacturers. The Morallos started building the SG harvester in 1995. They benefited from a number of improvements to the design made by manufacturers who began building the Mark I versions, because IRRI had included these changes, and some of its own in the Mark II design. The modifications though had caused the weight of the SG harvester to creep up from 230 kg, without engine, to 280 kg. Morallo reduced the weight of the machine to 213 kg, below that of the original Mark I design, while keeping strength in the crucial area of the ground drive transmission and drive shaft. The main way Morallo did this was by reducing the size of the collection container. The disadvantage of this, and the reason why IRRI had not considered it, is that a smaller container fills up more quickly and potentially slow harvesting by requiring the machine to stop more often to change containers. IRRI kept the big container as their original specification was for a machine aimed primarily at contractors, for whom high field capacity is vitally important. Morallo, though, realized that their initial market was individual farmers who were more concerned with being able to use the machine in a wide range of conditions. As well as reducing the weight, going for a smaller container enabled the Morallos to move the engine and transmission closer of the centre of the machine which improved the balance and reduced the amount of crop knocked over by the side of the machine.

In September 1997, IRRI, PhilRice (Philippine Rice Research Institute, IRRI's counterpart institute in the Philippines) and Morallo tested the lightweight Morallo machine with the improved ARC wheel at two sites. The audience, which included the Ropali production manager, two other manufacturers, and farmer-owners, concluded that the improvements extended the range of field conditions that the SG harvester can work in, and made the machine much easier to handle. IRRI, with the permission of Morallo and ARC, is now producing drawings of the next generation SG harvester, based on their designs.

Was the innovation process linear?
Should it have been?

The case study shows clearly that the innovation process for the SG harvester was not linear. The SG harvester was not "perfected" when it was first commercialized, and since commercialization it has been extensively modified, or re-innovated, by manufacturers, farmers and the R&D team at IRRI.

Defenders of the linear model might claim that these modifications have only happened because IRRI did not do its job properly in the first place, and released the machine too early. The critique would say that IRRI should have carried out more farmer field tests and released the machine to manufacturers only when it could work adequately in soft fields, and could work without breakdown. Then, according to the ToT approach, IRRI should have handed the technology over to the relevant Philippine national agency (in this case PhilRice) who would first satisfy themselves that it worked, perhaps further refined it before releasing it to manufacturers. Once released to manufacturers, PhilRice would have handed over the extension of the technology to the relevant agencies, and begun working on the next technology coming though the pipeline. Extension agencies would then police manufacturers to make sure they built the machine to specification, and train farmers in how to use it. In other words, after commercialization, the work would be to prevent modifications that would "corrupt" the "perfect" message.

This approach has worked for modern rice varieties, and might work for a simple mechanical technology being introduced into a simple system, where IRRI and PhilRice could have closely replicated reality on-station and in farmer field trials, and correct operation procedures could be condensed into a simple set of heuristics. The case study shows why a linear approach would not have worked for a technology as complicated as the SG harvester being introduced into the culturally most important, and arguably the most complex portion of the rice cropping calendar. In the case study the improvements were made mainly by farmers and manufacturers, and not by IRRI or PhilRice. The modifications were made based on the unique knowledge and experience of the manufacturers and farmers, which IRRI and PhilRice did not have.

Proponents of the ToT approach would argue that IRRI could have tapped into the farmer and manufacturer knowledge sets through sufficiently thorough surveys. However, even with this knowledge, it is unlikely that IRRI engineers could then have come up by themselves with the innovations that have improved the technology. What we see in the case study is manufacturers and farmers "learning by using". Rosenberg (1982) defines "learning by using" as gains that are generated as a result of using a new product after commercialization. Rosenberg identifies "learning by using" as an extremely important source of incremental improvements to new technology <u>in complex systems</u>, which when taken together can amount to major improvements in the attributes of the technology.

Proponents of the ToT approach would also argue that IRRI could have obtained manufacturer and farmer input to the innovation before commercialization, through on-farm field testing, of locally-manufactured prototypes commissioned by IRRI. However, in these types of arrangements the manufacturers and farmers involved have little or no equity in the process. A manufacturer commissioned by IRRI to build a machine prior to commercialization does not feel he will gain from investing his own time and resources in improving the technology. And even if he did, he has limited experience and knowledge of the technology to make sensible changes. The modifications the manufacturer makes under this arrangement are modifications largely to reduce his production and material costs. Once, however, a manufacturer has something to gain and lose, and has experience and knowledge of the technology, he is far more motivated and able to make improvements. The case study demonstrates this – ARC and Morallo made their important modifications after they had lost sales to potential customers, more than one year after they built their first machine. With the owners, the case study showed that cooperatives, which had invested none of their own capital in buying a SG harvester, were far less successful in making the SG harvester work and made far fewer modifications.

The improved SG harvester did not evolve purely from the efforts of farmers and manufacturers. IRRI played a crucial role in filtering out modifications that detracted from the performance, and improving on and promulgating beneficial changes. Again this runs contrary to the ToT approach which separates R&D from transfer and extension. However, IRRI was the only stake holder who could to do this for some time after commercialization, because, having designed the machine in the first place, IRRI had the motivation and technical know-how. Now, four years after commercialization, that knowledge and motivation has been transferred to PhilRice, but it did not happen over night, and could not have done.

What mistakes were made, and was a linear conceptualization of the innovation process to blame?

Clearly mistakes were made in the innovation process of the SG harvester. The main mistake was that the manufacturers and farmers were not recognized by IRRI as partners in an ongoing research, development and dissemination continuum. In this way the resource that the farmer-adopters represented was to a large extent wasted. Firstly, it was not recognized what a resource this group represented – one third of them were engineers or had college-level engineering training – and when they first adopted the technology they were keen to invest a lot of time and effort to get the technology to work. This enthusiasm was dissipated, and with it the likelihood that they would demonstrate the technology favourably to other farmers and provide informal training. Much of their enthusiasm evaporated because they were left to sort out their problems in isolation, without proper technical support and advice.

This support should have come from IRRI and/or PhilRice and the manufacturer. In the case study, Ropali did more than other manufacturers in upgrading machines. Unfortunately, the larger transmission it fitted caused a new set of problems, which could have been avoided with closer collaboration between Ropali and IRRI/PhilRice. Also IRRI/PhilRice should have worked much more closely with the manufacturers to filter out modifications and lapses in quality that detracted from machine performance and reliability, and to ensure customers received adequate training.

Towards a New Conceptualization and a New Management Model

"The importance of understanding innovation as a process is that this understanding shapes the way we try and manage it". (Tidd et al., 1997). If public sector agricultural engineering R&D is to have greater impact on technology change in the future, particularly with relatively more complex machinery introduced into complex systems, then clearly we need to apply a conceptualization of the innovation process that better matches reality. The same conclusion has been reached by a number of writers including Chambers and Jiggins (1986), Biggs, (1988) and Clarke, 1994. Common themes that emerge from the literature criticizing the ToT approach adopted by public sector agricultural engineering research in general are that:

- The way that research is carried out needs to take into account the nature of the process of technology change and become more iterative and flexible;
- Resource-poor areas, in particular, need a more flexible and iterative approach because they tend to be more complex and diverse than more favourable areas;
- The need for iteration and two way flows of information means research needs to be integrated with technology diffusion over time. For agricultural machinery development this means links are needed between "upstream" research that takes place at the beginning of the product development cycle, and the "downstream" local adaptation that occurs during the technology transfer and diffusion stages.
- Innovation and knowledge have equal importance wherever they arise.

An important body of literature draws an analogy between the process of technical change and biological evolution (Nelson and Winter, 1982; Mokyr, 1990; Clark et al., 1995). Mokyr (1990) makes the analogy between the technology or technique, and the species. An evolutionary system needs three components: "novelty generators" which generate modifications, a mechanism to select the beneficial modifications and discard the rest (Nelson, 1987), and something that forces the whole process – the "evolutionary drive" (Clarke et al., 1995). The "evolutionary drive" is a function of the perceived potential attributes of the new technology and the difference between perception and reality. Evolutionary drive also comes from the R&D team who wants to see the technology adopted for reasons of institutional kudos, professional recognition, etc.

What management strategies does an evolutionary analogy suggest for public sector engineering? If we see the development of a technology like the SG harvester in evolutionary terms, then we see that the technology is never "perfected", i.e., it never stops being modified to better fit local conditions. This is because we see the technology in a system that is dynamic, and so to be competitive the technology must evolve. This contradicts the ToT dictate that it is the job of R&D to develop a "perfect" machine which is then transmitted unchanged to manufacturers and farmers. Instead we see that the role of public sector R&D is to develop the best "first approximation". This "first approximation" is then commercialized at a pilot level to ensure the active participation of manufacturers and farmers. To evolve further the "first approximation" needs modification generators and selectors. In the SG harvester case study we saw the stakeholders – the R&D team, the manufacturers and the farmers – play both roles. Once the technology has evolved to a point where it has become sustainably adopted, i.e., the technology "*has become an institutionalized and regularized part of the adopters ongoing observations*" (Rogers, 1995), then the R&D team can withdraw. Other organizations can then "seed" the new technology in other areas. The sustainably adopted technology in the pilot area becomes the "first approximation" in the new areas. If the new areas are identical to the pilot area, then the extension activity will be the conventional transmission of a message. If not then extension agencies will also have to be participants in an evolutionary process.

The value of the stakeholders' contribution to the process depends on their level of equity and knowledge, and the quality of interactions they have with the other stakeholders. Viewed in this way, we see that a linear conceptualization hinders the innovation process because it prevents innovator-adopter farmers and manufacturers becoming equal partners in the process, and it hinders knowledge flows. For example, the expectation that a technology is "perfect" when initially commercialized can cause manufacturers to initially build large numbers to be first on the market (Douthwaite, 1996), which they then find they cannot sell without major modifications. These resources would be much better employed working with the R&D team and innovator-adopter farmers to improve the machine. Also the "perfection expectation" can lead the R&D team to be defensive and blame subsequent problems and lack of adoption on manufacturers for not following specifications and on farmers for being "backward" in their attitude to new technology.

The evolutionary conceptualization suggests public sector managers should attempt to create conditions in which the twin evolutionary processes – the generation of modifications and the selection between them – can occur as efficiently as possible. This suggests creating institutional structures which foster close links between researchers, extension, manufacturers and farmers at all stages in the innovation process. Information should be able to flow freely. Measures should be taken to ensure that all the stakeholders participate as actively as possible, by ensuring they have equity in the project. Farmer and manufacturer equity can be secured, as we have seen, by pilot commercialization of the technology. One way of ensuring involvement of public sector workers might be to allow them to earn some royalty on their work, for example. Evolutionary drive should be further ensured by fostering a "product champion" – someone with sufficient interest and authority to push the new technology through the innovation process and overcomes obstacles (Peters and Waterman, 1982).

If public sector managers are able to create these sorts of institutional structure, then the themes that come out of the literature criticizing the ToT approach are met. Creating such structures is not impossible: - they already exist in the Faculty of Agricultural Engineering at the College of Agriculture in Ho Chi Minh City, Vietnam, and in the ATIAMI project in Indonesia.

The public sector may also have a role in encouraging and fostering manufacturers' and farmers' organizations. The Kondinin Group which is a unique farmers' organization in Australia, demonstrates what is possible, and may offer a model. The Group has the central theme of "farmers helping farmers" and promotes this mainly sharing information through a monthly magazine. The Group conducts opinion surveys, carries out product testing and encourages farmers to share the successful adaptations and innovations they have made to their equipment and work practices (Anon., 1993). Machinery manufactures use the information the Group gathers from its members to improve their equipment. The Group is funded by member subscriptions, magazine sales and partial public sector funding of some research projects.

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