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AGRICULTURAL RESEARCH THROUGH A 'NEW PRODUCT DEVELOPMENT' LENS

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SUMMARY

In this paper, we present the case for making better use of the theory, concepts, language and experience from the field of industrial and commercial 'new product development' within agricultural research. The argument is that by conceptualizing, organizing and managing applied and adaptive research activities as new product development, agricultural research will be better able to respond to enlarging agendas, increased expectations of impact and declining budgets. The role of the design function in innovation development is highlighted, and the major implications of a new product development stance for the organization and management of agricultural research are identified.

INTRODUCTION

Is it reasonable to expect agricultural researchers to be effective developers of innovative technology for poor farmers? At first glance, this would appear to be a nonsense question: of course it is reasonable, that is what they are paid to do! Upon reflection, however, the question becomes more troubling, particularly in light of the fact that in other sectors, research is only one of several inputs to the innovation process.

Reasonable or not, in recent years agricultural research in Africa has been much maligned for its apparent inability to provide useful outputs – innovations – for poor, small-scale producers. A wide range of factors has been identified to explain this inability to deliver: for example, it has been claimed that research is elitist and out-of-touch with rural realities; focused on high potential not marginal areas; commodity not system- or livelihood-oriented; positivist not constructivist; reductionist not holistic; focused on productivity not sustainability, and so on. While the basic claim of limited research benefits to poor farmers is contested (e.g. Maredia *et al.* 2000; Thirtle *et al.* 2003), there is no dispute around the fact that research is under increasing pressure to better serve this particular constituency.[1]

Over the last two decades there have been numerous attempts to address this problem. Farming systems research, on-farm research, farmer participatory research,

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[1] See Anderson (1998), Byerlee (1998) and Chema *et al*. (2003) for reviews of recent trends and developments in, and efforts to reform, agricultural research in the developing world.

participatory technology development, participatory plant breeding (and variety selection), strengthened links between research and extension, reorganization and reform of research institutions, farmer empowerment and farmer financing of research have all been promoted as means for making agricultural innovation more client- or demand-driven. Yet the fact remains that throughout most of Africa, the primary responsibility for innovation and technology development still rests with agricultural researchers: plant breeders, agronomists, economists, engineers and the like. As indicated above this is worthy of note because in most other sectors of the economy, the innovation process is neither solely dependent upon nor necessarily even driven by the research function. When the extra difficulties of trying to serve poor, small-scale farmers in Africa, such as high levels of bio-physical and socio-economic diversity, poor articulation of demand, and their highly diversified livelihoods, are taken into account the absence of the other competences that normally form part of a new product development team – particularly design and marketing – should be all the more striking.

The theory, concepts, language and experience that inform the discussion of innovation and new product development[2] are rooted primarily in the industrial and commercial sectors of competitive, capitalist economies. In such contexts, successful innovation development can be very much a matter of survival. While agricultural research and technology development in Africa remain, in large part, a public-sector monopoly, when faced with both declining resources and persistent calls for greater impact, agricultural research might do well to learn the broader lessons of successful new product development, regardless of their sectors of origin. Thus the point of this paper is to reformulate the problem of agricultural research and technology development for small-scale farmers in Africa using the concepts and language of the systems of innovation[3] and the new product development literature. Our objective is to determine whether through the use of these concepts, insights can be developed that might help re-orient the innovation process so that it can better contribute to the goal of rural poverty alleviation. This is an initial analysis, and the value of these insights is yet to be tested in practice.

The paper proceeds as follows. The next section introduces a number of concepts from the systems of innovations and new product development literature, with particular emphasis on the notion of a 'market' for innovation, and the nature of the demand side in such a market. The following section looks specifically at the role that the design function could or should play in agricultural technology development, with a focus on design specification and information design. The last section explores the implications of this analysis for the organization and management of agricultural research.

[2] Krishnan and Ulrich (2001:1) define new product development as 'the transformation of a market opportunity and a set of assumptions about product technology into a product available for sale'.

[3] For a general introduction to the systems of innovation literature see Carlsson *et al*. (2002), Edquist and Hommen (1999) and Lundvall (1998). See Clark (2002), Hall *et al*. (2001) and Hall *et al*. (2000) for examples of the use of systems of innovations thinking in relation to agricultural research in the developing world.

CONCEPTS

Innovation and technology

Following Niosi *et al.* (1993) we will consider innovations as 'new and improved products and processes, new organizational forms, the application of existing technology to new fields, the discovery of new resources, and the opening of new markets'. It is clear from this definition that an innovation may involve either technical or social (including organizational and institutional) change, and often both. A number of schemes have been proposed for classifying innovations: for example, in order of increasing novelty, Tidd (2001) identified continuous/incremental, complex, radical and disruptive innovation. These different degrees of innovation have implications for the organization and management of the innovation development process itself (Veryzer, 1998), and subsequently, for the integration of an innovation within a production system.

Technology is 'technical knowledge about the production of goods and services' (Niosi *et al.*, 1993). It follows that technology development is the process of transforming new or existing knowledge into new ways of producing goods and services. Two forms of such knowledge can be identified: research outputs are formal knowledge generated through systematic inquiry, while experience and know-how represent informal and generally uncodified knowledge. This highlights the idea that formal knowledge is one important element feeding technology development and innovation more generally. In later sections some other key elements feeding innovation, including design, will be discussed.

Combining these two definitions we see that a 'technical innovation' is a new or improved product or process that is based on new (or a reinterpretation of existing) technical knowledge about the production of goods or services. So far in this scheme we have identified knowledge, technologies, processes, innovations and production systems. The relationships between these are illustrated in a simplified way in Figure 1. It should be clear that there are critical transformational steps between knowledge and technology on the one hand, and between technology and technical innovation on the other. It is not necessarily either a simple or direct route between knowledge (either research-generated or uncodified know-how) and technical innovation.

With this base we can also conceptualize a technical innovation (or any technology for that matter) as a bundle comprised of the benefits that are expected to accrue to a user and the physical and management resources required to make use of it. The value of any particular technology or technical innovation will therefore depend on how well these benefits and resource requirements match the interests and available resources of potential users.

A 'market' for innovation

Here we start with the rather obvious idea that farming requires decisions about what to do, and when and how to do it. Put another way, farmers must decide what technology or combinations of technology to use, how they will mobilize and organize the required labour, when and where they will market their produce, and so

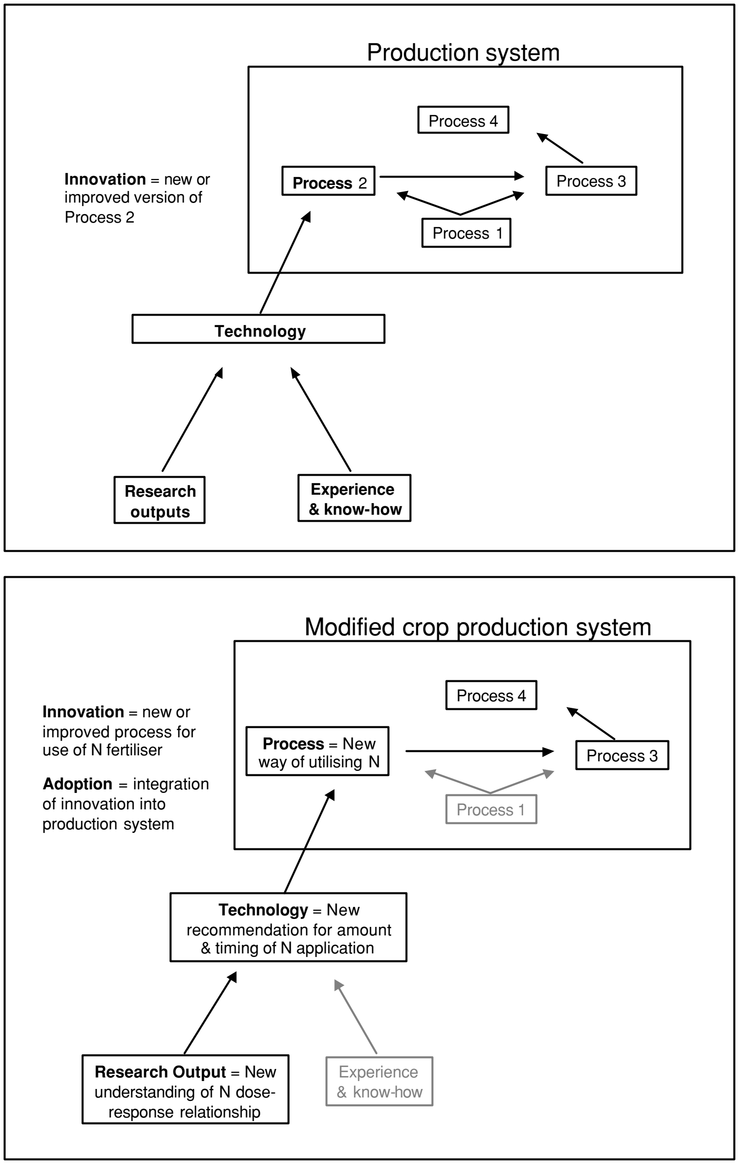

Figure 1. Key concepts (top half is the general case; bottom half is a specific crop production example).

on. Neo-classical economic theory tells us they will make these decisions in order to maximise utility or welfare. But more practically, a crop farmer's decisions will reflect, for example, a particular interest in a minimum but stable harvest, or producing more or better quality products, or producing them more efficiently, or meeting a particular market window. These decisions may be more or less explicit: Gladwin and Murtaugh (1980) suggested that farmers' decisions can be seen as either 'attentive' or 'pre-attentive', depending on whether they require attention (attentive) or essentially reflect

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information processing based on repetitive practise and acquired expertise (pre-attentive). In either case, decisions will be informed by the interplay of a wide range of factors including tradition, experience, differential access to information and other resources, livelihood structure, personal likes and dislikes, and individual management skills.

It is of course true that making a decision is only half of the story, as it still must be implemented in order for it to have the desired effect. Thus, following Reece and Sumberg (2003) we use the term 'farming precision' to indicate the degree to which farmers are generally able to implement successfully their decisions or plans. A farmer who has a relatively high degree of control over key resources (such as land and labour) is considered a 'high precision' farmer, and should be more able to implement consistently and successfully his/her decisions than a farmer with less control (a 'low precision' farmer). We would expect wealth to be an important factor accounting for variation in farming precision, as well as any other factors (e.g. age, gender) that affect access to and control over productive resources (including one's own time). We would also expect that farming precision will come into play during technology choice, as, for example, low precision farmers will likely be unable to meet the more stringent management requirements of some technologies. Farming precision as defined here has much in common with relative vulnerability to 'hazard' as described by Richards (1986) in relation to rainfed-rice farmers in Sierra Leone.

As indicated above, decisions relating to crop production are motivated by a combination of more or less explicit objectives: to produce more, better quality or different products, to increase efficiency or competitivity, and so on. Thus, it is fair to assume that there will be an underlying interest in knowing about, evaluating and potentially using innovations – new ways of doing things – in order to increase the likelihood of achieving these goals. It is on this basis that we can conceive of farmers as being 'in the market for' or as 'consumers of' innovation. In this view a farmer is like any other entrepreneur or business manager who seeks innovation to increase efficiency, market share, competitive advantage and range and quality of output.[4] This search for advantage within industry includes both 'product innovation' (change in the type, range or quality of products produced or services offered) and 'process innovation' (change in the way products or services are created or delivered) (Tidd, 2001). In the agricultural example, the introduction of a new crop would be a product innovation while a new variety of an existing crop, a new fertilizer regime or soil conservation measure would be considered a process innovation.

In addition to the presence of farmers as consumers, the 'market' for innovation may be supplied by a range of innovation providers. It is now widely recognized that in agriculture (Biggs and Clay, 1981; Biggs, 1990) as in industry (Niosi *et al.*, 1993; Malerba, 2002), innovation arises from multiple sources, including state-funded

[4] We are aware that the analogy between poor, small-scale farmers and business managers has its limitations. For example, Reenberg (2001) highlights the fact that while farmers may be rational, they 'do not run a business but rather manage a household'. Nevertheless, faced with economic and environmental change, even household managers must seek advantage through innovation.

and private-sector research, other public and private sector actors, and the users themselves. The critical point is that formal research is but one of these sources. The systems of innovation literature places much emphasis on the dynamic interplay amongst the various sources and users of innovation. Specifically, within what are essentially 'knowledge markets', learning is of critical importance, and takes place, in part, via the interaction of those involved in 'knowledge search' and those concerned with 'knowledge use' (Edquist and Hommen, 1999; Clark, 2002).[5]

The systems of innovation and new product development literature are rooted in the behaviour of private-sector firms and their links with state-funded research and state policy, in open, competitive economies. How does this relate to agricultural technology development in Africa? It is certainly true that over the last two decades there has been much written about the increasing role of the private sector in agricultural research in the developing world (Pingali and Traxler, 2002; Pray, 2002), driven principally by opportunities associated with new intellectual property regimes and developments in biotechnology. In Africa however, and particularly in relation to small-scale producers, staple crops and marginal areas, technology development remains essentially the domain of publicly-funded agricultural research (Pardey *et al.*, 1997). The various public agricultural research organizations are conventionally seen as part of either a national agricultural research system or the international research system.[6] It is important to note that these two groupings mask a very considerable degree of heterogeneity in terms of history, size, scope and depth, legal status, organizational model and financial stability. The research activities undertaken by these institutes have been classified in various ways, with a common scheme using the terms basic, strategic, applied and adaptive to indicate the range from 'blue sky' investigations to product development. This hierarchy of research has been described and depicted in various ways (e.g. Figure 2), and there have been attempts to use the notion of comparative advantage to identify the appropriate roles and responsibilities of the various actors within the national and international systems. This paper is particularly concerned with the applied and adaptive end of this hierarchy. It is our contention that activities here must be conceived, managed and evaluated differently from basic and strategic research; yet they are most often seen as part of a logical, seamless continuum, a view that blurs the essential differences between research and product development.

In effect, state-funded agricultural research remains, at least as far as formal innovation and technology development are concerned, a monopoly supplier to the market for innovations, and one that struggles to relate to its client base.[7] The main

[5] Although, as noted by Clark (2002), the distinction between knowledge search and knowledge use is not so clear, as 'recipient knowledge investment' is essential to understand fully externally acquired knowledge: 'paradoxically technology transfer in general only works well where the recipient carries out its own related RandD programme' (p. 362).

[6] Referring primarily to the centres supported by the Consultative Group for International Agriculture Research (CGIAR), a funding mechanism through which 50 members channel funds to 16 international agriculture research centres (IARCs); as well as the handful of other IARCs active in Africa that are not funded through the CGIAR.

[7] The point here is not so much the usual argument about under-investment in public goods research due to market failures (Barnes, 2001), but rather the poor use of the resources that are invested because of the monopoly position and ethos of the public-sector provider.

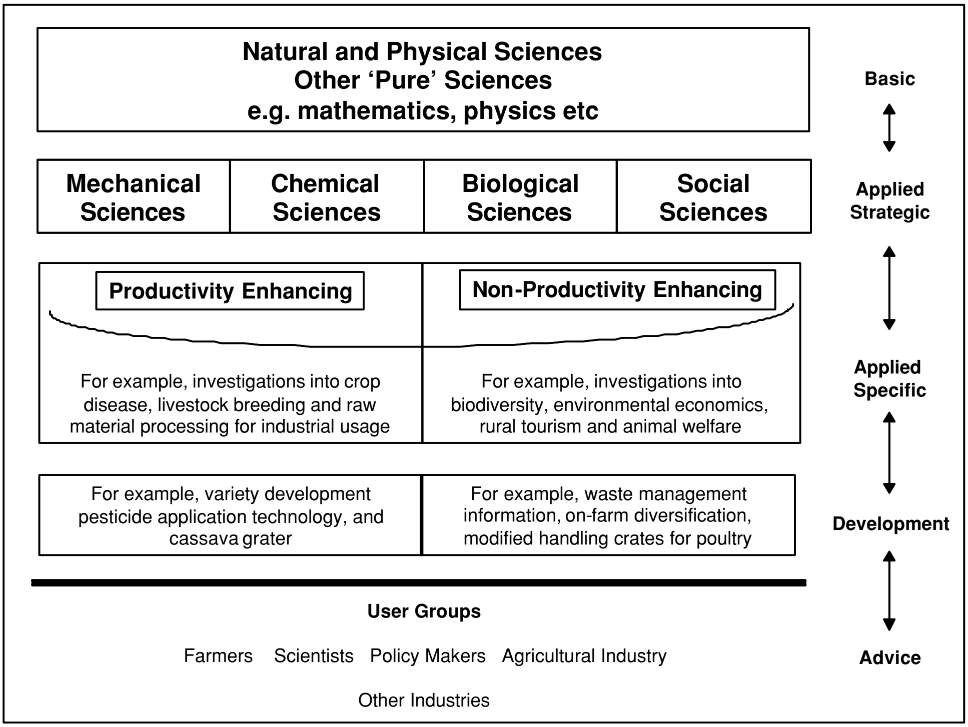

Figure 2. A model of the research process with agricultural science (source: Barnes 2001).

argument of this paper is that as long as the research function (as opposed to new product development) remains central to individual and organizational identity, and the capacity to analyse the relevant characteristics of potential users (i.e. to conduct market analysis) remains limited, the efficiency and effectiveness of agricultural research organizations as sources of useful innovation will continue to be seriously constrained.

Agricultural research through a 'new product development' lens

How do innovations arise? Central to the new product development literature is the notion of the product 'life cycle', which can be portrayed as a series of sequential stages or phases (e.g. pre-development, development and production). Here we will focus on the pre-development and development phases, and note that many authors have suggested ways to divide and describe these further. For example, Griffin (1997) divides pre-development into 'concept generation' and 'project evaluation' stages, while Kim and Wilemon (2002) refer to the concept generation and project evaluation stages as the 'fuzzy front-end' of the new product development process. They suggest that the fuzzy front-end begins when an idea is first considered worthy of further exploration, and ends when a decision is made to commit resources to its development, and argue that this period is 'intrinsically non-routine, dynamic, and uncertain' and

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typically involves ad hoc decisions and ill-defined processes. The implication is that competences, organizational models and management strategies for a successful fuzzy front-end or pre-development phase will likely be different from those required during the product development phase. The phases of the product life cycle can also be seen in terms of a 'stage-gate system' (Cooper, 1990; Hart *et al.*, 2003). Here access to the next stage in the process (e.g. idea generation, initial concept development, business case preparation, development, market testing) is through a gate, where 'deliverables' are evaluated against pre-determined criteria, with the process resulting in a 'Go/Kill/Hold/Recycle decision, and the approval of an action plan for the next stage' (Cooper, 1990).

As described, the pre-development phase starts with an idea, an idea that must have, in effect, two elements: the identification of a function or opportunity, and the outline (fuzzy as it may be) of a way to respond to it (Finke *et al.*, 1992). The emergence of new ideas or the identification of opportunities is clearly a complex, creative process that cannot be reduced to a simple method or set of steps. Indeed if it could, one of the major fronts for inter-firm competition and advantage would disappear. McGuinness and Conway (1989) conceptualize the process of idea or new product 'search' as including problem and opportunity detection, idea generation and preliminary screening. Building on the work of Finke *et al.* (1992) and others, Goldenberg *et al.* (2001) identify five pathways within the search process:

1. '*need spotting* – when need identification precedes product (form) development';
2. '*solution spotting* – when a form is identified and the inventor searches for a suitable need (use), or both the need and a solution are identified concurrently (usually as an improvisation)';
3. '*mental invention* – when the idea is based on a decision to innovate and on internal cognitive process rather than on external market stimulus';
4. '*market research for new products* – when a need is identified by marketing analysis and a suitable product is then developed';
5. '*following a trend* – when a product is developed to follow a market trend in a different class of products'.

Thus, an idea that is the germ of successful innovation may spring from an individual or organization being 'in touch with' the customers, or being an astute reader of social, economic, market and technological trends. In the developed world there is significant investment in the collection and analysis of demographic, consumption, preference and attitudinal data which is used to inform or support the processes of opportunity identification, and Walsh *et al.* (1988) found that successful firms employ a larger number and wider range of these data sources than less successful ones (Table 1). Such data may be particularly useful in relation to incremental innovation, which, by its very nature, lends itself more easily to systematic analysis.

However, complex and radical innovation is still dependent in the first instance on a particular insight or vision that can never be simply 'mined' from data such as these. Leonard-Barton (1995) noted that while commentators on the innovation process agree that understanding 'user needs' is a key factor leading to commercial

Table 1. Firms' sources of information for product planning and design (Commercially successful firms employed sources listed under both A and B. Less successful firms tended only to use A). (from Walsh *et al.* 1988).

Group	Sources of information
A	• senior managements' "feel for the market" • Sales/market statistics • Sales-force feedback
B	• Customer feedback/enquiries/complaints • Service reports/warranty claims • Trade shows/exhibitions • Technical trade literature • Market surveys • Developments in related industries • Competitors' products • User groups/customer panels • Workshops involving engineers, marketers, customers and users etc.

success, the problem is how to acquire such an understanding and then deploy it in new product development. That is, how to derive knowledge from the market under conditions of considerable uncertainty. The difficulty of doing so is particularly acute when the proposed innovation is novel or highly complex, since potential users may be unaware of, or unable to articulate, their 'requirements': in such cases traditional methods of market research will be of limited value. Methods are needed that help the analyst to foresee what the market will be demanding in the future (i.e. incipient demand) or even to lead the market, rather than simply listening closely to what is required at the moment (current or latent demand).

Demand, needs, requirements and interests

So far, in seeing an innovation as a bundle of benefits and resource requirements, we have referred to the interest on the part of potential users in the array of benefits associated with innovation use. We have also referred briefly to various kinds of demand. Notions such as these – to which one could add user needs and requirements – are intimately associated with the search for opportunities which is the essence of new product development. But how should these be conceptualized?

In the first instance, economic theory provides a basis for understanding (current) demand simply as the quantity of an existing good or service that is consumed at a given price. The additional demand for that good that is manifest as the price drops is termed latent demand. It is clear that innovation might allow actual demand to be met more efficiently, or it might allow latent demand to be realized by, for example, reducing the cost of production and thus the price to the consumer. This interplay of demand and supply can be seen in terms of functionality and utility. Thus, Adner and Levinthal (2001) defined the *functionality threshold* as the 'minimum objective performance (independent of price) that a given product must deliver in order for the consumer to consider it' and the *utility threshold* as the 'the highest price a consumer is willing to pay for a product that just satisfies his or her functionality requirements'. If the functionality threshold is too low and/or the utility threshold too high, there will be no demand and the innovation will not be used. Alternatively, such an innovation may be 're-invented' by potential users during the process of evaluation (Rogers, 1983), returned to research for further development, remain 'on the shelf', or drop from view altogether.

However, this narrow definition of demand is of limited value for understanding the potential future interest in entirely new products or radical variants of existing products or processes. Here the notion of incipient demand, that is, demand that is expected to exist in the future, comes into play. An estimate of incipient demand effectively represents a guess as to the likely strength of future consumer interest in an as yet non-existent product. While trend analysis and various types of market research may help inform such an estimate of incipient demand, it is clearly less amenable to systematic analysis than current or latent demand. In addition to these various types of demand, the new product development literature uses other terms, such as consumer 'needs' and 'requirements', to indicate the existence of an opportunity (i.e. a possibility to create effectively and then satisfy demand for a new product). However, as pointed out by Mowery and Rosenberg (1979) these terms have limited analytical value: lacking a precise definition, the 'shapeless and elusive notion of "needs"' does little to distinguish among the 'potentially limitless set of human needs'.

We use the phrase 'interest in obtaining benefits' in an attempt to bridge this gap between the strict understanding of demand, which is necessarily limited to existing products and services, and the more elusive notion of needs. In effect we suggest that the 'utility' associated with the consumption of a given product or service can, to some degree, be abstracted from the specific form of the product. This abstraction yields the benefits associated with use of the product. In turn, these benefits can themselves be seen at a number of levels of abstraction.

For example, a rice farmer might be seeking to gain benefits that could be progressively abstracted as: increased land or labour productivity; increased marketable surplus of rice; increased disposable income; ability to pay a child's school fees; and finally, increased livelihood security. It is important to note that in this simple example, depending on the level of abstraction at which the search for opportunities takes place, a number of very different potential responses might be envisaged. Thus, the marketable surplus might be increased by a new variety, better agronomic management or more effective quality control during post-harvest processing. Similarly, increased disposable income might be obtained by producing and selling more or through more strategic timing of rice sales. Finally, ability to pay a child's school fees might come from rice production or engagement in off-farm activities. The point is simply that it may be possible to satisfy the underlying interest in obtaining these benefits via a number of alternative routes – from the adoption of a new rice variety to engagement in non-farm activities. Thus, from a new product development perspective, it may be as important to know about the underlying interest in increasing disposable income to pay school fees than, for example, preferences for varietal characteristics or the adoption rate of (i.e. actual demand for) previously released rice varieties.[8]

In the field of agricultural research and technology development in the developing world, it has been much more common to conceptualize the initial steps in the innovation process in terms of a problem or 'constraint' rather than opportunity identification. The idea is that in a given situation a single factor (e.g. low soil nitrogen status, poor market access, labour shortage at a critical moment) can be identified that limits or constrains improvement in the outcome variable of interest (e.g. productivity, profitability, quality). This conception is deeply rooted in agricultural science via the work of Justus von Liebig, who, in the mid-19th century, discovered that plant growth could be limited by elements other than those utilized by the plant in the largest quantity. From this observation he formulated his 'Law of the Minimum', which says that if one nutritive element is deficient or lacking, plant growth will be poor even when all the other elements are abundant. In other words, the deficient element is constraining growth. The implication of this law is that if the deficient element is then supplied in abundance, some other nutrient will soon begin to act as the constraint to growth. Unfortunately, this approach, when applied at the level of a production or farming system (not to mention a livelihood), leaves little room for the creativity of people, within either the innovation or the production system.[9]

Market segmentation and the articulation of demand

We have suggested that a technology can be seen as a bundle of benefits and requirements. Ideally, in the market for innovation, these are matched with the interests and resources of potential users (i.e. the opportunity). If benefits match interests and requirements match resources, we would expect the innovation to be used. It is reasonable to assume that both the interests of farmers in relation to the benefits associated with innovation, and the resources that they can mobilise, will vary. In other words, socio-economic factors such as wealth, gender, age and livelihood structure; institutional factors such as resource tenure arrangements; agro-ecological factors such as amount, pattern and reliability of rainfall; spatial and infrastructure factors affecting access to inputs and markets; and many others will be expected to create a heterogeneous pattern of interest in and use of particular innovations, both within and across locations. Continuing with the idea of a market for innovations, we can surmise that such a market is likely to be segmented, and perhaps highly segmented, with the various segments exhibiting different interests in and abilities to use innovations.

Farming systems research came close to the idea of market segmentation with the concept of a 'recommendation domain'. In its simplest form, a recommendation domain was defined as encompassing those people (or situations) for whom a given research-derived recommendation, practice or technology was considered appropriate

[8] See Reece *et al*. (2004) for description of an initial attempt to use the idea of 'interest in obtaining benefits' to develop market segments for agricultural innovation in Ghana.
[9] And it may also account for the fact that agricultural research and extension have too often found themselves in a position of promoting technologies in which the potential users show little if any interest.

(Byerlee *et al.*, 1980). It was suggested that such domains could be defined by one or more of the following two types of factors: 'natural-technical' (including agro-ecological, physical, biological) and 'human-social' (including farm size, farmer resources, goals, attitudes, constraints; community relationships, institutional arrangements). In practice, rainfall, wealth, farm size and level of mechanization were most commonly used to define these domains.

Most of those who tried to make use of recommendation domains did not attempt to define the group of potential users in any real detail. Rather, it was assumed that a limited number of relatively easily determined indicators, such as those listed above, could serve as proxies for the larger set of bio-physical, social, economic and personal factors associated with the fit between an individual and a technology. The calculation was that the cost of developing more tightly defined domains was likely to outweigh the benefits of better targeting. Indeed, Simmonds (1985) specifically cautioned against the use of closely defined domains: 'In real life, obviously, no great depth of understanding will be possible when numerous possible recommendation domains present themselves . . . '. In addition – and here is where the use of recommendation domains differed significantly from market segmentation – the farming systems literature remained equivocal in relation to the question of when in the technology development process the recommendation domain should be identified. In other words, should the identification of the potential users follow or precede technology development? In most cases the recommendation domain was seen as a way to promote more effectively previously developed technology; whereas market segmentation is more often portrayed as playing a more fundamental role in guiding a technology or product development process.

DESIGN: A MISSING ELEMENT?

Within the new product development literature the 'design function' is usually given particular importance. Design is a creative process of visualization of concepts, plans and ideas (Walsh, 1996), which, according to Aubert (1982) is 'the very core of innovation, the moment when a new object is imagined, devised and shaped in prototype form'. More concretely, Roy and Riedel (1997) see product design as 'the choice and configuration of elements, materials and components that give the product particular attributes of performance, appearance, ease of use, method of manufacture, etc.' Put another way, design embodies new technology into a usable form (Walsh, 1996). But the design function goes beyond the 'choice and configuration of elements, material and components'. Indeed Kline and Rosenberg (1986) place it at the very beginning of the innovation process, suggesting that 'contrary to much common wisdom, the initiating step in most innovations is not research, but rather design'. Along similar lines, design can be seen as the means by which technical possibilities are 'coupled' with market demands or opportunities (Walsh, 1996).

During the pre-development stage of the product life cycle, the vision of the new product takes a more defined shape through the design specification, which is an *ex ante* exercise in product description. The design specification is a prioritised list of the major

Table 2. What firms included in the design brief or initial specification (Commercially successful firms included factors listed under both A and B. Less successful firms tended only to include A). (from Walsh *et al.* 1988).

Group	Included in design brief
A	*Performance requirements* • Basic function *Price constraints* • Target price
B	*Marketing requirements* • Evidence of demand or need • Target customers/market(s) • Advantages over competing products • Compatibility with existing products • Potential for future evolution • Relevant standards and legislation • Guidelines for appearance/image/style • Reliability/durability requirements • Ergonomic/safety requirements *Time and cost constraints* • Timetable and launch date • Development tooling and manufacturing costs

design variables, with a target value for each, which describes the minimum level of performance the product should be able to deliver. Depending on the product, the design specification may include variables such as: fitness for purpose[10], durability, safety, reliability, stability over specified environmental conditions, and usability (ease of use). Walsh *et al.* (1988) observed a difference in the scope of the design specifications or design briefs among firms (Table 2), and concluded that the use of a more complete design specification was associated with greater commercial success. This conclusion is supported by the work of Cooper and Klienschmidt (1993) who studied 252 cases of new product development in business-to-business markets. They found that the greatest difference between successful and unsuccessful innovations was in the quality of the pre-development activities: sharp and early product definition dramatically increased the probability of successful innovation. Thus, the design specification is a key milestone in the product development cycle, and provides the set of indicators against which the success of the effort can be evaluated.

Can anything analogous to the design specification step be identified in normal practice of applied-adaptive agricultural research and technology development? There are certainly some examples of the use of similar approaches, particularly in agricultural engineering with attempts to use ergonomic principles in technology design and evaluation (Rogan and O'Neill, 1992). In the field of crop improvement, 'ideotype' breeding (Rasumusson, 1991; Peng *et al.*, 1999) presents an interesting example, where the design of a desired or ideal plant-type is derived through modelling,

[10] Fitness for purpose refers to generally to the idea that there is an implied warranty that the supplier will deliver a product that is fit for the intended purpose defined by the buyer.

or based on physiological or morphological characteristics or relationships. The breeder's job is then to assemble all the desired characters in one genotype.

But in general, if used at all in crop improvement, the notion of design specification is likely to be implicit rather than explicit. For example, when backcross-breeding or genetic engineering is used to add a single character such as disease resistance into an otherwise acceptable variety, the design specification is simple: all the qualities of the original variety plus the new character. In a similar vein, it could be argued that at least some of the design specification in new variety development is set, by default, through the widespread use of the a so-called 'local check'. In other words, the design specification is basically to 'beat the local check'; however, the 'value' of the check, or the fronts on which it must be beaten, are usually only seen in only one or two dimensions (e.g. yield, disease resistance). It certainly might be argued that as long as the planned innovation is only incremental, this kind of implicit design specification should be sufficient. On the other hand, without an agreed design specification, management and monitoring of the development phase is considerably more difficult.

What might (or should?) be included in a full design specification for a new crop variety or management practice? Clearly specification could be in terms of both level and stability of expression of key characters (such as productivity, profitability, pest resistance and stress tolerance, eating qualities) or responses (for example, to weeding or input application). Other elements that might be specified include the range of environmental or management conditions under which some minimum acceptable level of performance could be expected. In relation to such a range of management conditions, Reece and Sumberg (2003) used the term 'solution space' to denote the 'area' around an optimal set of operator-influenced conditions within which a technology will still yield 'positive' results. Thus, the relative 'size' of a solution space refers to the technology's ability to deliver positive (if sub-maximal) results as the operator-influenced conditions move further and further from the optimal set. Depending on the characteristics (the 'precision') of the intended users, specification of a larger or smaller solution space might be warranted.

A design specification could also be useful in planning, for example, the development of a tool for screening new genetic material for weed competitiveness. In this case, an upper limit on the area, cost and seed required per entry, as well as a minimum level of repeatability could be specified.

Design also has a critical role in creating an interface between the product and the user, in making the product accessible and usable. This is essentially the emerging area of information design. Based on a three-part framework that posits that information can be seen in terms of its physical (the ability to find information), cognitive (the ability to understand information) and affective (the ability to feel comfortable with the presentation of the information) forms, Carliner (2000) suggests that information design involves: analysing communication problems; establishing performance objectives; developing a design plans; developing the components of the planned communication efforts; and evaluating the ultimate effectiveness.

In agricultural research and extension, this interface has traditionally taken the form of a written or verbal 'recommendation' or '*fiche technique*', or some type of 'demonstration'. These basic approaches to creating a user–technology interface have been much critiqued of late, and there is a growing interest in the use of more interactive, adult-learning approaches (e.g. Ooi, 1996; Deugd *et al.*, 1998; Defoer, 2002). It seems logical that for novel and complex products, the design (e.g. in terms of logic, layout, presentation) of instructions, users' manuals or learning modules will be particularly important. It may also be that this aspect of the design function becomes critical when farmers are actively involved in the adaptation, re-invention or fine-tuning of partially finished technologies. Reece and Sumberg (2003) suggested that handing over the final stages of technology specification or fine-tuning to farmers may be the only way that research can cope with increasing demands and declining resources, while Clark (2002) proposed that this kind of 'recipient knowledge investment' is actually a pre-requisite for successful technology transfer. Clearly if attention to information design can facilitate these processes, that would be highly desirable.

DISCUSSION

In effect, the question underlying this paper is: What, if anything, would change if agricultural research and technology development in Africa were conceived, organized, managed and evaluated along the lines of new product development activities?

We have seen that the notion of the product life cycle is central to new product development, with an important distinction being made between the pre-development and the development phases. While in reality there may be overlap and indistinct boundaries between these phases, the basic idea is that the work during these respective phases requires very different outlooks, competences, organizational models, and the like. These phases also make explicit the fact that there are or should be clear points or gates in the process where active decisions regarding further investment in particular products can and must be made.

Most agricultural technology development for small-scale farmers in Africa is undertaken by trained scientists working within publicly funded research institutions. In the vast majority of cases, no distinction is made between the research and technology development functions, nor are the phases of the product or technology development cycle made explicit. In effect, then, there is a seamless, phase-less transition from problem or constraint identification through to the release of the finished product. Within this process, objectives and expectations are unlikely to be made explicit through a design specification, the characteristics of the potential users are unlikely to be fully analysed or specified, relatively little consideration will probably be given to the form of the user–technology interface, and there will be few opportunities for discrete decisions based on likelihood of success or potential pay-offs to further investment in the particular product or technology.

Does this matter? In the light of reduced funding for agricultural research and increased pressure for demonstrable impact, we suggest that it certainly should!

One important implication of a more explicit new product development stance is the absolute requirement for a much better identification and understanding of the potential users of particular innovations. Here, full use must be made of the now vast experience with the principles and techniques of market research, including market segmentation, although innovative approaches will also be required where secondary data are limited and where market survey methods must be altered to accommodate cultural or contextual differences (Reece *et al.*, 2004). For example, recent work by Adesina and Baidu-Forson (1995), Sall *et al.* (2000) and Dalton (2003) has shown how methods that were initially developed in industry in order to elicit consumer perceptions can be used to shed light on farmers' preferences for particular crop varietal characteristics.

The concept of farming precision as described earlier may be particularly useful in the differentiation of market segments or potential user groups. The recognition of a strong link between the degree of access to or control over productive resources, and ability to implement successfully production decisions, has clear implications for the fit between user segments and technologies with particular characteristics or resource requirements. Specifically, it should be expected that 'low precision' farmers will be unable to successfully make use of technologies with precise management demands (i.e. that have a relatively small solution space). Thus, for market segments which are dominated by 'low precision' farmers, a large management range or solution space must certainly be an important element of the design specification. Large solution space technologies may also be important in situations where there is a high degree of livelihood diversification, as the many competing demands on time and resources are unlikely to be compatible with precision farm management.[11]

But, one might ask, have these concerns not already been addressed through the mainstreaming of 'participatory methods' in agricultural research? Have the efforts to introduce, for example, 'participatory technology development' and 'participatory plant breeding' not resulted in the *de facto* creation of a new product development orientation? We suggest not, for three main reasons.

First, the primary way that most participatory research attempts to group people is through the use of wealth ranking techniques, with which the experience to date has been decidedly mixed (e.g. Adams *et al.*, 1997; Begeron *et al.*, 1998). While there is no denying that wealth impacts on technology choice, simple wealth ranking as it is commonly undertaken in participatory rural research fails to capture satisfactorily the full range of factors, and their interactions, influencing technology choice decisions.

Second, it is important to remember that experience in other sectors has shown that while user involvement in product design and development may be valuable, it is not sufficient to guarantee a successful innovation process. For example, Leonard-Barton (1995) concluded that the evidence for the benefits of user involvement was ambiguous. She argued that these benefits vary widely depending upon factors such as: the basis upon which the users to be involved are selected, the timing of their involvement, the nature of the involvement required by the relative novelty of the innovation, and the users' ability and willingness to provide the right kind of knowledge. Sumberg *et al.*

[11] See Sumberg *et al*. (2004) for a preliminary exploration of the potential effects of livelihood diversification of technology choice in small-scale agriculture.

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(2003) developed this line of reasoning in relation to farmers' involvement with agricultural research: some areas of innovation lend themselves more to participatory or co-development; for the others, alternative approaches for increasing the probability of success will be required.

Finally, a new product development stance as described here implies fundamental change, not only in method, but more importantly in orientation, organization, systems of management and indicators of success. In other words, it is a whole mentality that goes far beyond the simple introduction of participatory methods. Perhaps the most radical change would be the effective subjugation of research to the higher goal of product development. Such a move would surpass the current vogue of 'research-for-development', which still assumes the research is at centre stage. This assumption is simply not compatible with a new product development stance.

So what would agricultural research re-invented as new product development look like, and how could the real value of such an approach be tested? The experience in industry makes clear there is no single organizational or managerial model that guarantees success in innovation development, however, seven key areas for change can be identified:

1. Redefining the organizational mission, strategy, objectives and outputs explicitly in terms of innovation or new product development.
2. Distinguishing between and clarifying the respective roles of the research and product development functions, with research being defined as 'in the service of' product development. This would require fundamental change in the culture and ethos of most existing agricultural research organizations.
3. Introducing, at a senior level, personnel with experience in successful new product development, particularly in relation to the pre-development phase and the management of the innovation process. At its most radical this might mean that the 'director of research' reports to a 'director of new product development'.
4. Thinking much more systematically about potential users, through the use of methods and approaches for market segmentation, and from market research more generally. One objective here would be to develop, by market segment, profiles of levels of interest in potential benefits that might be satisfied through innovation.
5. Working within a more flexible and dynamic organizational structure, where competences are regrouped in time-bound, new product development teams, that are tasked, for example, with delivering a particular design specification.
6. Making the design function much more explicit, with particular emphasis on the use of the design specification to more effectively target, manage and evaluate the innovation development process. In addition much greater attention would be given to information design to improve the quality of the user–technology interface.
7. Modifying the indicators of organizational, team and individual achievement to reflect the primary goal of providing useful products and technologies to specified groups of users.

While we have argued that the use of concepts and experience from the field of new product development, and in particular the recognition of the central role of the design function, could potentially contribute to making agricultural technology development more effective, we must remain realistic. The suggestion is certainly not that this is a (or the next) panacea for agricultural research. Indeed, a new product development stance will, over the short-term, only place greater demands on the management, staff and budgets of agricultural research and extension, demands that many such organizations are not well placed to meet. Thus, while the integration of new product development ideas may be necessary if agricultural research is to justify its continued existence, a reasonable level of organizational viability will also be required to support this integration. Further, the development of a more systematic understanding of the agricultural and livelihood trajectories of potential users of innovations implies significant new demands on extension providers. In this light, the cautious conclusion of Walsh *et al.* (1998) seems particularly appropriate:

> 'The answer to the frequently posed question, "does good design pay?" is thus a qualified "yes". Investment of resources in design can be a key factor in commercial success, but does not guarantee it. The qualifications are, that it also depends on what a firm means by "good design" and what it does to help the product sell.'

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