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Agricultural Research for Development to Intervene Effectively in Complex Systems and the Implications for Research Organizations

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Agricultural research for development (AR4D) organizations can achieve greater impact by using complexity-aware approaches, but for this to happen a more compelling case needs to be made to justify their use. Our contribution is to develop and test a generalizable complexity-aware theory of change of how AR4D fosters innovation. The proposed model shows that AR4D achieves impact through three interconnected impact pathways:

- Technology Development and Adoption Pathway
- Capacity Development Pathway
- Policy Influence Pathway

The paper presents three cases, which provide an empirical test for the model. The cases give good empirical support to the three impact pathways. The theory of change we developed emphasizes self-reinforcing feed-back loops as mechanisms by which small, well-focused research interventions can achieve impact at scale. However, to harness complexity in this way requires organizations to make broad-based and profound changes to working practices and the institutions that support them. These include being more circumspect about predictions of program impact at the start, putting in place functional adaptive management systems providing support to reflexive practice and other behaviours known to foster innovation.

Photo: Myra Wopereis

Women rice farmers

Introduction

Agricultural research for development (AR4D) programs have faced two trends in recent years: firstly, a growing realization that they intervene in complex socio-ecological systems and secondly, an insistence from donors that the programs set and achieve quantifiable and ambitious development-oriented impact targets. On the surface, the first trend should help with the second. For at least the last 25 years, complexity science has held the promise of 'much coming from little' in complex systems – that is, the idea that small, well-chosen interventions can lead to disproportionately large impacts. A complex system is "one whose properties are not fully explained by an understanding of its component parts" (Gallagher and Appenzeller, 1999), and where the outcomes are sensitive to the history of what has happened before. The mechanism by which 'much can come from little' is emergence, which Goldstein (1999) defines as, "the arising of novel and coherent structures, patterns and properties during the process of self-organization in complex systems".

Unfortunately, the potential of complexity science has not generally been realized in mainstream AR4D, practiced by traditional research and development organizations at national, regional and international levels. Here, AR4D is strong in traditional reductionist science that focuses on research into the component parts of a system rather than the interactions between these components. Complexity science has the potential to complement this strength with an understanding of how emergence occurs in systems that work as sets of interacting components and the instances where history matters.

In general, this is not happening. The vast majority of mainstream AR4D projects are still designed and planned against linear theories of change, without provision for the possibility that they might contribute to the emergence of unplanned and unanticipated outcomes, and with scant regard to what is already happening. As a result, AR4D projects do not look for unexpected outcomes to which they may have contributed during implementation, and do not hold program resources in reserve to support the projects if and when they do have such outcomes. They are missing out on the potential to harness complexity to have a greater impact than at present. This is despite strategic planning that has highlighted the importance of emergent outcomes for at least 30 years (Mintzberg and Waters, 1985).

Theories of change describe how projects and programs are expected to contribute, or have already contributed, to change. Ex-ante, they predict how project inputs and activities are expected to be used by others and the changes that will happen as a result. Theories of change are linear when they assume a direct relationship between project outputs and outcomes without provision for any resulting self-organization within the system in which the project is intervening. Donors are increasingly requesting that projects develop theories of change at the beginning and report on progress against them, hence they represent an important opportunity – if projects can start using more complexity-aware theories of change then they should be able to increase their potential to bring about positive change.

It is surprising that AR4D projects do not use complexity-aware theories of change. Since the early 1990s there have been repeated calls for mainstream AR4D to adopt a different, more systems-based paradigm that supports a broader way of working, which blends both reductionist and more holistic approaches depending on the objective (Schut et al., 2014; Douthwaite et al., 2017). Klerkx et al. (2012), compare the traditional reductionist approach to agricultural innovation systems – one of the more recent members of the complexity-aware approaches (Table 1).

Table 1: Comparison between the traditional AR4D approach and a recent complexity-aware AR4D approach

Characteristics	Linear approach to AR4D	Complexity-aware approach to AR4D
Name	'Transfer of technology' or 'pipeline'	'Agricultural innovation systems'
Era	Central since 1960s to present	Marginal since 2000 to present
Mental model and activities	Supply knowledge and technology to the next user	Co-develop innovation involving multi-actor processes and partnerships
Knowledge and disciplines	Single discipline driven (mainly plant breeding)	Transdisciplinary, holistic systems perspective
Drivers	Supply-push from research	Responsiveness to changing contexts, patterns of interaction
Source of innovation	Scientists	Multiple actors, innovation platforms
Role of farmers	Passive adopters or laggards	As partners, entrepreneurs and innovators exerting demands
Role of scientists	Innovators who hold knowledge	As partners, one of the many groups responding to demands
Key changes sought	Benefits accruing from technology adoption	Institutional change, increase in systems' capacity to innovate

Adapted from Klerkx et al. (2012)

Photo: Remco Mur

Agricultural Research in Kenya: on station trials

There are a number of reasons why the linear approach to AR4D remains dominant, despite its shortcomings. Firstly, the linear model has been seen to be very successful. The breeding of higher yielding rice and wheat varieties is credited with catalysing the Green Revolution that saved millions from poverty in the 1960s and 1970s. The narrative that has grown up is simple, familiar and supported by evidence. Agricultural research centres did develop modern crop varieties that contribute to higher yields, food production and incomes for farmers. Researchers like the model because it puts them in control and casts them as the main innovators, rather than one among many. Organizations have evolved to support the use of the model by rewarding researchers for developing broadly applicable knowledge and technology (sometimes called international public goods). The assumption that change can be brought about in a simple, knowable and step-wise manner simplifies planning budgets and reduces perceived transaction costs. Donors of AR4D, who need to justify the public money spent on agricultural research, like simple and familiar narratives to which the general public can relate.

In contrast, while complexity-aware approaches make a good theoretical argument, the case for using them remains essentially normative: it is not backed up by a body of empirical evidence that tells a clear and compelling causal story to equal the Green Revolution narrative. There are many stories from the field, but these are often dismissed as anecdotal because they are not as generalizable. For many biophysical researchers and donors, the claim that working in a more connected and holistic way will lead to the 'emergence' of unpredictable outcomes sounds too much like putting one's faith in magic.

Our position in this paper is that greater use of complexity-aware approaches in AR4D will only occur when a more compelling and generalizable case can be made for their use, which is substantiated by empirical evidence. This case needs to be built on empirically-based theories of change that operate at, what Pawson (2013) calls, a 'middle-range' between global social science theory on the one hand and rich picture description on the other. In this paper, we develop a middle-range model for how AR4D works to foster change in agricul-

tural innovation systems based on empirical experience and look for evidence from the field to support or challenge the model, before then evaluating its usefulness in terms of its implications for reorganizing AR4D institutions.

In writing this paper we realize that AR4D is just one among a plethora of interventions that lead to change in agricultural innovation systems. However, part of our motivation to write this paper is our belief, based on our decades of collective experience, that although AR4D is a powerful tool for generating 'much from little', it often falls well short of its potential precisely because projects are generally not designed, planned or implemented with a comprehensive and useful understanding of the different and synergistic ways in which AR4D interventions work to foster rural innovation.

Concept and Method

Our starting point is that the case for being complexity-aware needs to be built on a compelling causal narrative, in other words, built on a compelling, generalizable and empirically-based theory of change. By generalizable theory of change we mean one that describes how AR4D projects foster innovation in agricultural innovation systems. Generalizable theories of change have been developed in some fields, for example in the health sector to describe health-related behaviour change, and in policy research to describe how policies change. Our inspiration comes from the latter, in particular from a paper written by Stachowiak (2007), in which she identifies five 'global' theories of change. Each theory specifies how specific strategies are expected to lead to policy change. For example, the 'Coalition' theory of change holds that policy change occurs via coordinated activity among a range of individuals with the same core policy beliefs. In contrast, the 'Power Politics' theory of change states that policy changes are made by working directly with those with the power to make decisions, or influence decision-making.

Donaldson (2007) identifies four ways in which a theory of change can be built for a program: using information from staff close to the project; using outside researchers to observe how the program works; testing critical assumptions; and/or using a prior theory and the research already published in the literature. Our objective is to help research organizations to better harness complexity by building a complexity-aware theory of change that can guide implementation of AR4D programs that seek to foster innovation. We do this through a combination of the second and fourth strategies.

The theoretical basis of this theory of change is that innovation requires hardware (new technology and ways of organizing), software (the capacity to innovate) and orgware (an enabling environment for innovation) (Klerkx and Leeuwis, 2009). AR4D can contribute to all three and the way it achieves this represents three pathways to impact. The empirical basis of the model is from the experience of one of the authors as a 'complete participant', over the last ten years, in helping numerous AR4D projects develop their theories of change in participatory workshops (Douthwaite et al., 2007). The result is the theory of change shown in Figure 1, together with a narrative description.

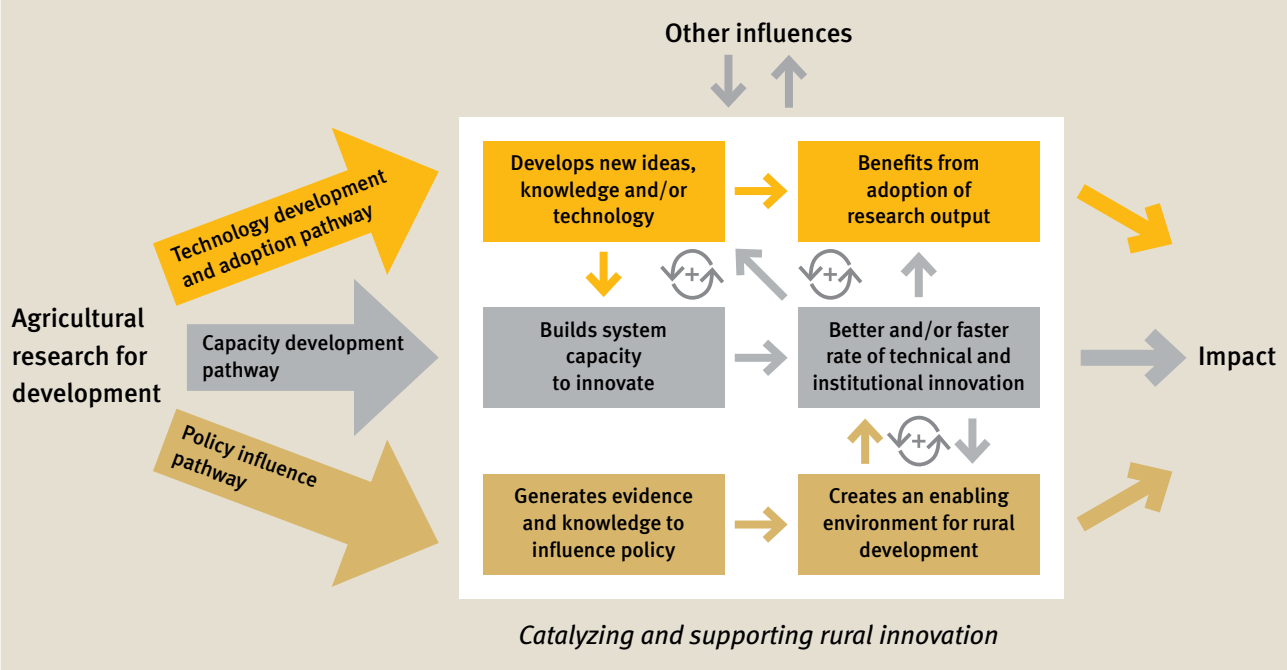
The model shows that AR4D achieves impact through three interconnected impact pathways (Figure 1). The technology development and adoption pathway is the most familiar to many researchers, being similar to the linear model when taken in isolation. It is a reasonable simplification of reality when researchers are developing technology in already-established innovation trajectories, for example, breeding to maintain plant resistance to pests, or the mechanization of agriculture (Hainzelin et al., 2016).

In the capacity development pathway, the process of carrying out research builds the capacity of rural innovation systems to innovate. The pathway emphasises the need to enhance the capacities and interactions of actors that play a role in developing and putting into use the new knowledge, practices and services that contribute to achieving common developmental objectives, or resolving shared problems. The actors involved include farmers and their organizations, but also the private sector, public agencies, NGOs and civil society, as well as research, education and extension bodies. Participatory and collaborative research brings different stakeholders together to identify common challenges, building structural and cognitive social capital in the process. The capacity development pathway can lead to the empowerment of actors in the innovation system, including farmers. The most cost-effective way to do this is within collaborative research processes that engage a range of actors around a shared set of objectives, and according to their interests and comparative advantages.

In the policy influence pathway, researchers generate insight and evidence with the specific intent of influencing policy, for example, in respect to strategies for agriculture to mitigate and adapt to the effects of climate change. Policy change then helps build an enabling environment for beneficial rural innovation. There are many examples of this, not least the growing evidence of man-made climate change. Other examples include analyses of market trajectories and the implications for food production, for instance, an analysis of the rapid growth of the poultry industry in India and the consequences on demands for maize as feed – this in turn contributes to the technology development and adoption pathway by suggesting to maize breeders to aim for maize characteristics in line with the animal feed industry's demands.

Our model suggests the existence of three positive feedback loops dependent on the capacity development pathway (see Figure 1). In the first cycle, an increased rate of innovation leads

Figure 1. A causal model showing how agricultural research for development contributes to impact through three interconnected pathways



to more interactive, experiential learning, which in turn leads to greater capacity and more opportunities to innovate in terms of new links and new ideas, knowledge and technology. In the second cycle, faster rates of innovation speed up the adaptation and adoption of research outputs, thus increasing the impact of the technology development and adoption pathway. In the third cycle, faster rates of institutional innovation create an enabling environment for innovation, and so on. The model suggests that agricultural research might better serve overall rural development if it were to focus on inducing sustained virtuous cycles, rather than the current focus on the first pathway.

The idea for this paper came out of a workshop held at the Royal Tropical Institute (KIT), in September 2016. The authors were part of the group interested in transforming AR4D institutions to better enable them to intervene in complex systems. Members of the group volunteered three cases to be used to provide an empirical test for the model. The cases were chosen as examples of each of the three pathways. The selected programs are discrete, time bound research projects, each of them operated in different geographical areas. The other criterion used for selection was that at least one author knew the case well enough to carry out the causal analysis.

The way in which the cases are used to empirically test the model is by writing them out as historical causal narratives, identifying and explaining how the project or program activity led to the outcomes. This is a way of articulating the ex-post theory of change underpinning each case. This narrative is then scrutinized for evidence as to whether the story followed one or more of the impact pathways and triggered any feedback loops.

The cases

Technology Development and Adoption Pathway: How the Sterile Insect Technique (SIT) helped Eradicate Tsetse Flies in the Niayes region in Senegal[1]

Context

In the Niayes region around Dakar, where the study was conducted, the population density is more than 150 inhabitants/km^2. Half of the Senegalese population live in the area, making the competition for space severe. In this context, climatic change threatens the maintenance of traditional cattle systems, with reduced precipitation linked to lower production of natural forage and overgrazing (F. Bouyer et al., 2014). The latter has been identified as a major cause of land degradation in Senegal (Budde et al., 2004, in F. Bouyer et al., 2014). Most domestic animals are susceptible to animal trypanosomosis which was until recently highly prevalent in the Niayes area (Seck et al., 2010) and causes major pathological problems, especially for cattle. The Senegal government has committed itself to controlling tsetse fly in this area.

History of work on tsetse fly in Niayes

Work to control tsetse fly populations in Africa using the sterile insect technique (SIT), has been ongoing since the 1970s (Cuisance and Itard, 1973; Cuisance et al., 1984; Vreysen et al., 2000; J. Bouyer et al., 2016). In 2001, the Pan African Tsetse and Trypanosomiasis Eradication Campaign (PATTEC) was launched by the African Union. In 2005, the Senegalese government joined this campaign, starting its own tsetse control effort to eradicate tsetse flies from the Niayes area.

[1] Authors: S. Audouin, Barret D., Faure G., Hainzelin E., Bouyer J.

The tsetse fly eradication project began in the same year and was jointly implemented by the support services for livestock farmers, the *Direction des Services Vétérinaire*s (DSV) and regional veterinary services, including the *Institut Sénégalais de Recherche Agricole* (ISRA), *Centre de coopération internationale en Recherche Agronomique pour le Développement* (CIRAD), *Centre International de Recherche-Développement sur l'Elevage en zones sub-humides* (CIRDES) and the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture. The project set out to control tsetse fly with a three-pronged strategy based on technical, institutional and process interventions. Firstly, the proven approach of releasing sterile insects to eliminate the tsetse fly population; secondly, the establishment of an institutional partnership between different mandated agencies; and finally, adaptive management based on learning from monitoring early results.

In 2016, CIRAD developed and tested an impact evaluation methodology, called ImpresS (Impact of Research in the South), to better understand and document how CIRAD fosters innovation and produces impacts at scale over an extended timeframe. The tsetse fly eradication project in Senegal was selected among 12 other case studies that CIRAD and its partners have conducted, or are still conducting. This case study is based on an analysis carried out as part of ImpresS (Hainzelin et al., 2016).

Causal history of the intervention

The project began with informal discussions in 2005 between the DSV and the International Atomic Energy Agency (IAEA) as part of a national program headed by the DSV *(Programme National de Lutte contre la mouche Tsé-tsé et la Trypanosomose au Sénégal, PNLTTS)*, to implement SIT and management practices. This led to a feasibility study, which took place from 2007 to 2010 and demonstrated the prevalence of trypanosomoses in a 1000 km² target area and identified an eradication strategy. The methods developed by the project's research component (ISRA-CIRAD) were vital for this phase, for example, in reducing sampling costs by over 90% when identifying the target population.

The pre-implementation phase started in 2011. The pre-implementation phase enabled methodologies to be established for the transport of irradiated males and the study of

Release of sterile males using an automatic release machine on board a gyrocopoter

Photo: J. Bouyer

the quality, competitiveness, survival and dispersion of the sterile males. It also allowed the strategy to reduce densities of tsetse flies (using insecticide traps and insecticide applications on livestock) to be tested, and thus helped to build the sequential eradication strategy deployed from 2012 (Dicko et al., 2014).

Then followed the implementation phase in 2012, which is still currently underway in 2017. In this phase, the research tools and methodologies were deployed using the technology development and adoption pathway, in a quasi-military manner, by the regional veterinary services staff and ISRA technicians employed by the project. The sterile males were released by an automatic machine loaded on a gyrocopter (Mubarqui et al., 2014). The first aerial automatic tsetse fly release machine was developed and tested in collaboration with Mexican researchers, and a second machine, adapted to the local context, was developed and patented by CIRAD and its partners. In addition, the distribution models were used to determine where to set traps and the density of the sterile males to be released (Dicko et al., 2014). The target area (1,375 km^2) has been divided into three blocks, the project has successfully eradicated the fly population in the first block, and reduced the presence of flies by 99.9% and 99% in the second and third block, at the time of writing. The overall number of trypanosomosis cases in the region has gone down from 40% to 10%, paving the way for local farmers to replace their herds with more productive and higher yielding cattle breeds. From 2015, the Sine Saloum region in the south of Senegal and the north of Gambia were included in the control program, starting with a feasibility phase. The methodology and expertise have been transferred and adapted to Ethiopia, supported by the African Union and IAEA, with research activities led by CIRAD.

Gaining control of trypanosomosis also involved the capacity development pathway; it depended on organizing the training of veterinary agents in control and monitoring methods to ensure effective use of the technology. The training contributed to the establishment of a formal adaptive management coordination cell, which brought together veterinary service staff and researchers from a Senegalese research institute (ISRA) and CIRAD. This arrangement helped with the continuous adjustment of the technology during implementation, which contributed to successful control. CIRAD and IAEA brought in their experience from eradication programs in African countries, such as Burkina Faso and Zanzibar (Cuisance et al., 1984; Vreysen et al., 2000; Vreysen et al., 2014). Field trips were organized for members of the management cell (veterinary agents and managers) to visit other successful eradication projects in other parts of the world, particularly the MOSCAMED project in Central America (Enkerlin et al., 2015), in order to learn about other experiences of SIT and Area-Wide Integrated Pest Management (AW-IPM). The capacity that was built led to the veterinary services being run more efficiently, for example, with greater use of geographic information and positioning systems to organize tsetse control (Dicko et al., 2014). Institutional support for doing so came from the highest level of veterinary services; DSV coordinated the project and its leaders were informed monthly on the progress of field activities through rigorous statistical analyses of the results, carried out by the researchers. This method of working was formalized in a regional training course, as part of scaling the SIT approach to other African countries. Acknowledgement of the success of the program by policy makers, namely after it received an international best practice award[2], led to the extension of control areas to other parts of the country and the Gambia, thus contributing to the up-scaling (institutional) and out-scaling (spatial extension) of SIT. Hence the project made use of the policy influence pathway. Moreover, the new relationship between veterinary services and the national research institute, allowed for better collaboration in order to manage other animal diseases (e.g. Rift Valley fever, Peste des Petits Ruminants and African horse sickness virus).

Table 2: Timeline of key events in the history of the tsetse fly control program in Senegal

1970-1985	Chad, Burkina Faso and Nigeria: research projects to develop the sterile insect technique against tsetse, headed by CIRAD and other research centers, based on integrated pest management principles
1980-1995	Two research-development projects (in the Sidéradougou agro-pastoral area in Burkina Faso for CIRAD and Zanzibar for IAEA) demonstrated the feasibility of eradication using an integrated control method with a SIT component
2000	Launch of the pan-African campaign for the eradication of tsetse flies and trypanosomosis (PATTEC) by African Union with 6 key projects, of which 5 were unsuccessful and the last (Ethiopia) is currently being supported by IAEA and CIRAD
2005-2007	Discussions between DSV and IAEA for the eradication project in Niayes (Senegal)
2006	National decree setting up a national Senegalese tsetse fly and trypanosomes control program (vet. service)
2007-2010	Launch of the eradication project in Niayes (Senegal), feasibility study and coordination cell
2011-present	Pre-operational (2011) and operational (starting in 2012 and still underway) phases
2015	'Best Sustainable Development Practices' award at the Milan exposition 2015
2015-present	Extension of the control area to the Sine Saloum region (currently under its feasibility phase, funded by IAEA) and exportation of the methodology and expertise to Ethiopia
2016	Impact analysis of the research project led by CIRAD (ImpresS: 'Impact of Research in the South')

[2] Awarded Best Practice for Sustainable Development of Small Rural Communities in Marginal Areas at the Milan universal exposition in 2015

Photo: J.-J. Etienne

Trypanotolerant cattle (Djakoré) in the Niayes area

Outcomes and success factors

The brief history shows that the main research outputs were technical, consisting of the optimization of the use of a new technology and engineering to eradicate tsetse fly. Impact was augmented by overcoming non-technical challenges, such as ensuring consistent use of the technology by the veterinary services and developing the capacity to rapidly react to difficulties encountered during the implementation process. Thanks to a strong partnership between veterinary services and researchers, challenges have been addressed successfully. To this end, a joint adaptive management coordination cell consisting of research teams and the central veterinary services was created. The cell meets on a monthly basis to allow adjustments in order to correct problems and increase impact. This process of re-adjustment, in itself, became a central part of the innovation, along with the technical eradication aspects (Devaux-Spatarakis et al., 2016).

Each stage of the project involved methodological and technological innovation through major operational research. The involvement of public actors guaranteed a controlled and top-down process for the use of the technology and the transfer from central veterinary services to regional veterinary services or dedicated personnel from ISRA.

The analysis of causal relations conducted in a participatory fashion with ImpresS helped researchers and stakeholders to identify the impacts. The major outputs are (i) the SIT control method, (ii) the training of veterinary agents, and (iii) monitoring tools to implement the technology. The latter output has led, with multiple ramifications, towards major outcomes: (i) the homogenous use of new control material and methods, (ii) the optimization and implementation of the monitoring system, and (iii) the joint adaptive management coordination cell, which triggered the targeted impact of eradication of tsetse flies. This intermediate impact will ultimately contribute to reducing herd sizes and increasing milk and meat production thanks to the intensification of livestock breeding.

Empirical evidence to support the theory of change

The case shows clearly how the technology development and adoption pathway can work on the ground. Research has developed and tested the sterile insect technique for controlling

tsetse fly in Africa since the 1970s. The program adapted and successfully applied the technology to Senegal, which led to almost complete control of the fly and the disease, trypanosomosis, within 10 years. As a result, the program has been extended to other areas of Senegal and the Gambia.
The case also shows that this success depended on the two other pathways and the self-reinforcing feedback loops. Successful application of the technology depended on the training of veterinary agents in control and monitoring methods (the capacity development pathway). In turn, the training contributed to the setting up of a formal adaptive management coordination cell (policy influence pathway), which helped with the continuous adjustment of the technology during implementation. This continued improvement contributed to growing recognition of the work that led to the project scaling out to other parts of the country and the Gambia (self-reinforcing feedback loop).

Broader applicability of the case

This case is typical of technologies that lend themselves to being implemented in a top-down, quasi-military manner. These are projects that act on the biophysical environment, when research has a high control over the technology and outcomes, and does not necessarily require strong interactions with stakeholders. Research contributes to the impact of projects by providing training and co-monitoring to adapt the technology. To achieve impact, Hainzelin et al. (2016) have found that success factors include a relevant strategy for implementing research, strong institutional and political support, partnerships with a few strategic stakeholders, the provision of adequate funding mechanisms, and training for actors involved in the use of the technologies. The theory of change shows the potential of self-reinforcing feedback, involving interaction between different pathways, to accelerate impact.

Herders with an agent of regional veterinary services in the Niayes area

Photo: J.-J. Etienne

Photo: Myra Wopereis

Women involved in PLAR activities

Capacity Development Pathway: How the Use of Participatory Learning and Action Research (PLAR) helped Develop Inland Valleys in West Africa

Context

Rice is the fastest growing food commodity in sub-Saharan Africa, mainly driven by increasing urban demand. Africa depends to a large extent on imports and the continent accounts for about one-third of the rice traded globally, translating to a foreign exchange expenditure of about US$ 6 billion annually. Development efforts focus on enhancing the production, processing and marketing of domestically produced rice. Inland valley lowlands are particularly promising because of their good water holding capacity and fertile soils.

Inland valleys have an estimated land area of 190 Mha[3] in Africa and, if only a fraction were to be planted with rice, this area has the potential to boost the total rice production in the continent considerably. Therefore, various development agencies are investing in the research and development of this idea, including AfricaRice.[4]

This case study analyzes how the research built the capacity of rural innovation systems to innovate and develop rice production in inland valleys, leading to sustainable economic growth.

History of work on rice production on African inland valleys

The intervention is typical of challenge-based development interventions, in which a research organization convenes a group of partners to tackle a commonly-agreed challenge or set of challenges. In this case, AfricaRice and partners used various approaches from the past decades, which could be grouped into (i) the selection of 'best-bet' inland valleys, either new or already used ones, based on spatial modelling and a detailed feasibility study; (ii) stakeholder-participatory land use planning within the inland valley, based on multi-criteria decision-making (MCDM) methods and using multi-stakeholder platforms (MSP); (iii) participatory inland valley development; and (iv) the identification of local production constraints, combining model simulations and participatory farmer priority exercises to select and adapt appropriate practices and technologies following integrated management principles (Rodenburg et al., 2014).

For the purpose of this paper, we concentrate our analysis on the last three approaches mentioned above, which have more emphasis on building the capacities to innovate by

[3] FAO, 2003. 'Land & Water'. Available at: http://www.fao.org/land-water/en/

[4] AfricaRice is a CGIAR research center – part of a global research partnership for a food-secure future. It is also an intergovernmental association of African member countries. http://www.africarice.org/

bringing together the stakeholders to identify common challenges, and build structural and cognitive social capital in the process.

Causal history of the intervention

In the 1990s, AfricaRice, then called the West Africa Rice Development Association (WARDA), and partners conducted yield-gap surveys in irrigated rice systems in four Sahelian countries (Burkina Faso, Mali, Mauritania and Senegal) to identify determinants of rice productivity. Based on the results, field trials were conducted with farmers, focusing on improved fertilizer and weed management. This led to the development of 'baskets of integrated rice management (IRM) practices' based on improved soil fertility and weed management, but also provided recommendations for other crop management practices, such as the varietal choice, sowing date, harvesting date etc. The dissemination of IRM baskets in the Sahel region resulted in an increased farmer yield of between 1 to 2 t/ha and a narrowing of the yield gap (Häfele et al., 2000, 2001).

In 1993, AfricaRice established the Inland Valley Consortium (IVC), bringing together 10 West African national agricultural research systems (NARS), as well as a number of international and regional research organizations and networks (International Institute for Tropical Agriculture (IITA), the International Livestock Research Institute (ILRI), The International Water Management Institute (IWMI), the Food and Agricultural Organization of the United Nations (FAO) the West and Central African Council for Agricultural Research and Development (CORAF/WECARD), CIRAD and Wageningen University (Rodenburg, 2014)) to work on the sustainable intensification of inland valley systems.

Based on the success obtained in the irrigated systems, the 'IRM approach' was tested, using fertilizer and weed management trials, in inland valley systems in Côte d'Ivoire. After one year it was realized that the diversity and variability of inland valleys was far too great to adopt the same approach as in the Sahelian irrigated systems (Defoer and Wopereis, 2013).

AfricaRice and partners then tested and used a more participatory approach (participatory learning and action research, PLAR). PLAR is a capacity-building process based on learning by farmers and other rice stakeholders and, as such, follows the capacity development pathway rather than the technology development pathway found to work in irrigated areas. The PLAR agenda follows the land development and rice cropping calendar and is set by farmers based on their needs. Solutions are created using the combined knowledge of scientists, extension workers, farming communities and other development agencies. This approach proved to be highly successful and later moved to Benin, Madagascar and Togo. It was concluded that the need to use PLAR-type approaches increases when moving from high to low precision systems, and from relatively uniform to more diverse production systems (Defoer and Wopereis, 2013).

In 2012, AfricaRice further developed an approach that combined the past experiences of research projects in this area, called the participatory integrated development of inland valleys (SMART).[5] The objective is to assist local communities to develop lowland areas (inland valleys) into more productive rice systems by having improved land/water management systems. This involved collective decision-making and planning, as well as organizing farmers to work together towards a shared objective. Actions were initiated by researchers, who organized farmers into autonomous groups that would potentially receive support from extension services or NGOs.

Outcomes and success factors

The outcome and success factors of this capacity development pathway have primarily come from building the capacities of actors[6] to adapt and respond in order to realize the potential of innovation. In particular, along with building the technical skills of actors (e.g. the systematic evaluation of options for use in crop management and land development), the pathway has been able to strengthen the capacities of researchers, and consequently other actors in the rice value chain, to:

- **Navigate complexity**, involving changes in mindsets, attitudes and behaviours to understand the whole system of land development together with cultural values, land tenure and other socio-economic elements.
- **Collaborate** with other actors that have different perspectives and interests. For example, extension service providers with limited capacities to provide all their services (technical and marketing information) and farming communities with specific interests.
- **Reflect and learn** together as a group with common interests. For example, scientific findings were validated by the communities for relevance and how well they fitted in with existing norms and the culture. Land development plans were drawn and re-drawn to consider the actors' interests.
- **Engage in strategic and political processes**, both at higher (global and national) and lower level (communities). At the global level, the consortium evolved to define their own management structures to be more effective in influencing the research agenda. The farming communities engaged in discussions with village elders to obtain clarity in land tenure. The latter ensured that any land developed remains within the group who invested in its development.

Empirical evidence to support the theory of change

In the PLAR example, researchers found that a research approach based on the technology development and adoption pathway did not work in less controllable production environments, where greater adaptation to local conditions was

[5] Further information is available at: https://smartiv.wordpress.com/smart-valleys-approach/
[6] Individuals, organizations and institutions engaged in the project interventions, be it research, extension, government agencies, farmer's organizations, agribusiness groups or individuals.

Photo: Myra Wopereis

Young West African rice farmer

needed for farmers to benefit from modern rice technologies. This led to the development of PLAR, which worked to develop the capacity to innovate. In PLAR, the research performs a capacity development role beyond the provision of new technology, such as new crop varieties. The new roles include mobilizing relevant actors to provide inputs and advice at the right time, assessing the needs and capacities of actors, jointly developing action plans, and reflecting on actions for the second cycle of working together. Once the capacities are made available within the communities, the leadership and facilitation shifts to the most appropriate actor, who is able to sustain the role as needed.

Policy Influence Pathway: How a Forest Restoration Opportunity Assessment Influenced Forest Policy in Rwanda

Context

Rwanda is a small country (2.5 million ha) with a relatively large population (11.8 million) for whom forests provide important economic and environmental resources. As well as reducing soil erosion, trees provide habitats for animals, sequester carbon and provide fuel for 96% of Rwandans. Forest covers 18% of the country with agriculture covering another 75% of the land.

History of forest management

Significant efforts were taken in the 1970s to reverse the deforestation which took place under earlier Rwandan and Belgian-led governments. The Umuganda community forest program and National Arbor Day in 1976 led to a 10-fold increase in planted forest area from 25,000 ha in 1975 to 250,000 ha in 1989. In the 1980s the government of Rwanda (GoR) put in place policies to protect existing forests.

The 1994 genocide led to the suspension of all forest management activities, which were resumed again on a small scale in 1995. Activity fully resumed in 2004 with the adoption of the National Forestry Policy that enshrined a number of principles that have governed forestry management since, including the principle that all forest resources should be managed sustainably and stakeholders should be involved in decision-making. The Policy was updated in 2010 to include a 30% national forest cover target by 2020 that was also included in the Economic Development and Poverty Reduction Strategy (EDPRS) in 2013. In 2012, Vision 2020, a policy framework launched in 2000 by President Paul Kagame setting out targets for Rwanda to reach in order to become a middle-income country, was updated to also include the 30% national forest cover target.

In September 2011, the German government and the International Union for the Conservation of Nature (IUCN) launched a global challenge to restore 150 million ha of the world's degraded and deforested lands by 2020. The Bonn Challenge, as it was called, was later endorsed and extended by the 2014 UN Climate Summit. In the same year, Rwanda announced a commitment to the Bonn Challenge to restore 2 million ha of degraded and deforested land, representing 80% of the country's land area, and the highest national commitment to the Bonn Challenge to date, in terms of percentage land cover.

The launch of the Bonn Challenge was the culmination of 10 years of work by IUCN, the World Wildlife Fund (WWF) and the World Resources Institute to build a coalition of support for the concept of forest landscape restoration (FLR). FLR is defined as "a planned process that aims to regain ecological integrity and enhance human well-being in deforested or degraded forest landscapes." The FLR concept emerged from work carried out by IUCN and the WWF, who had been promoting a landscape approach to reforestation at an international level, as an alternative to the mainstream focus on reforestation and plantations. The idea behind FLR is to recognize a matrix of landscape options across forestry and agriculture that would generate multiple forest and tree-related goods and services, beyond what plantations might bring.

The intervention: The Restoration Opportunity Assessment Methodology[7]

The Restoration Opportunity Assessment Methodology (ROAM) was developed by IUCN and the World Resources Institute (WRI) to help countries identify and respond to their FLR targets. ROAM helps countries to identify priority landscapes for restoration, the best mix of restoration interventions and who will bear the costs and reap the rewards from doing so (Clear Horizon, 2016).

The GoR approached the UN Forum on Forests (UNFF) in 2011 to discuss reaching their 80% restoration target. As a result, the GoR started talking to IUCN as a representative of UNFF, and the progenitor of the Bonn Challenge. IUCN was able to raise funds for a ROAM assessment on the basis of the GoR's interest.

Table 3: Timeline of key events with respect to reforestation in Rwanda (adapted from Clear Horizon, 2016)

Date	Event
Pre-1975	Deforestation under successive Belgian and Rwandan regimes
1975-1990	Rwandan government begins a major replanting campaign
1976	Umuganda community-based forestry works program launched to mobilise public support for forest restoration
1976	National Arbor Day launched to mobilise public support for forest restoration (held annually in October/November)
1987-1997	National Forests Action Plan released and implemented for ten years
1990-1995	Rwandan genocide and civil conflict causes large scale fatality, population displacement and ecological damage. All forestry activities suspended
1995-1999	Forestry activities resume on a modest scale
2000	Rwanda Vision 2020 launched by president Paul Kagame outlining vision for Rwanda, setting relevant targets for agriculture, reforestation, energy, water and food
2004	National Forestry Policy (2004)
2010	The GoR, UNFF, IUCN (including Global Partnership on FLR) sign an memorandum of understanding setting out collaboration on FLR
2010	National Forest Policy updated to include a 30% target for forest cover
2010-2011	IUCN engage with GoR ministers to gain support for FLR commitment through the UNFF
2011	The German government and IUCN launch the Bonn Challenge to reforest 150 million ha by 2020
2011	The GoR commits to restore 2 million ha (85% of the country's total land area)
2011	National Forestry Policy (2010) awarded the 'Future Policy Award' by the World Future Council
2011	The GoR approach IUCN to help with their Bonn commitment
2011	ROAM study begins with IUCN working with WRI and the Ministry of Natural Resources
2013	Rwanda sets target of 30% national forest cover in the Economic Development and Poverty Reduction Strategy 2013-2018 (EDPRS2) and the Vision 2020
2014	ROAM validation workshop
2015	Rwanda ROAM assessment launched by the Minister of Natural Resources (June)
2015	ROAM assessment helps secure various projects that support forest restoration
2015	Transfer of responsibility for the Tree Seed Centre from the Ministry of Agriculture to the Ministry of Natural Resources
2015	A task force on FLR and sustainable food and agriculture (SFA) is established as a coordinating mechanism between the Ministry of Agriculture and the Ministry of Natural Resources

[7] This case is based on a study carried out by Clear Horizon (2016) for IUCN on behalf of the United Kingdom Department for International Development (DFID) KNOWFOR programme. The study is used with the permission of IUCN, CIFOR and the author, Stuart Raetz.

IUCN and WRI had both learnt from an earlier ROAM assessment in Ghana, and as a result included greater stakeholder consultation and the early involvement of key decision-makers who were likely to use the ROAM outputs. A guide to ROAM was published in 2014 based on experiences in Ghana and Rwanda, as well as Mexico. The guide identifies five main outputs from ROAM:

- A shortlist of feasible restoration interventions across the assessment area
- Priority areas for restoration
- The costs and benefits of each intervention
- A diagnosis of success factors and the identification of strategies to address policy, legal and institutional bottlenecks
- An analysis of funding options for restoration

IUCN and WRI worked with the Rwandan Department of Forestry and Nature Conservation, a unit within the Rwanda Natural Resources Authority (RNRA) under the Ministry of Natural Resources. Project staff worked closely with senior officials in RNRA and the Minister of Natural Resources took an interest in the work. The project began by making an initial assessment of restoration opportunities, which it presented to 175 district-level stakeholders in a number of workshops. The assessment was adjusted on the basis of feedback before a final validation workshop in July 2014. The final report was submitted in September 2014 before being officially launched in 2015.

Outcomes and success factors

At the end of 2014, IUCN contracted the consultancy firm Clear Horizon to carry out an evaluation of their ROAM work in Rwanda. The study found that all of the ROAM's recommendations were being adopted with some positive outcomes as a result.

A typical rural landscape in Rwanda

Photo: CDI/WUR

The assessment found that a lack of coordination between the Ministry of Agriculture and the Ministry of Natural Resources was an impediment and suggested setting up joint working groups as a response. As a direct result, a task force on FLR and SFA was subsequently established as a coordinating mechanism between the two sectors. In the most recent reported meeting of the taskforce, 13 institutions developed a work plan and made recommendations for future coordination.

The assessment recommended the transfer of responsibility for the Tree Seed Centre from the Ministry of Agriculture to the Ministry of Natural Resources to improve the quality of supply and diversity, as the availability of tree seedlings is crucial to agroforestry and reforestation. The transfer happened in early 2015, again as a direct result of the report.

The positive response to the ROAM assessment in Rwanda helped to secure the second phase of a German-funded project piloting multi-benefit packages through FLR. The evaluation also concluded that the ROAM assessment helped win a Global Environment Facility (GEF) project to demonstrate landscape management for enhanced environmental services and climate resilience.

The report concluded that the success of the ROAM assessment was due to embedding recommendations for the Bonn commitment to ongoing national processes, namely the National Forestry Policy, the EDPRS and Vision 2020, with the 30% forest restoration target, and providing an umbrella for the plethora of existing initiatives to meet it. Another success factor was engaging with key people who became champions for the assessment, including the Minister for Natural Resources. The report quotes the IUCN team leader:

> ***"I went in to have a meeting with Stanislas Kamanzi [the Minister for Natural Resources], and we had a draft of the report there and this is the first time I've sat in a minister's office, which I've done several times before when talking about a piece of work we've done, and he had personally red penned the whole report. He'd been right through it, circled areas, said he wanted the economics to be explained better. He had a whole load of suggestions".***

In 2014, IUCN and WRI published 'The Guide to the Restoration Opportunity Assessment Methodology (ROAM) Handbook' (Laestadius et al., 2015), largely based on the Rwanda experience. Since then, ROAM has become established as the way for countries to operationalize their promises to international commitments, in particular to the Bonn Challenge. As of 2016, 39 commitments have been made to the Bonn Challenge, and there are 27 ROAM studies that are completed or ongoing. One constraint has become the capacity to carry out the studies as IUCN and WRI do not have sufficient staffing.

Empirical evidence to support the theory of change

The case shows empirically that research, in the form of an assessment of opportunities for forest restoration, influenced policy in Rwanda and, thus, gives support to the policy influence pathway. There is also evidence of positive feedback loops and the importance of context and history. The rapid take up of the ROAM study findings was, in part, because the Rwandan government wanted to help the country deliver on extremely ambitions forest restoration targets. The Minister of Natural Resources made this commitment to forest restoration because it was consistent with government policy, itself the result of 35 years of policy evolution in support of forests and sustainable development. The minister also made the commitment because the need for FLR was gaining ground internationally, in no small part small part because of IUCN lobbying and coalition building over the previous 10 years. The success of the Bonn Challenge, in terms of countries making commitments to restore forest, went hand in hand with IUCN's development and implementation of the ROAM method to help deliver on the Challenge commitments. Adoption of the ROAM method has increased rapidly and is an example of the technology adoption pathway. The case shows an interaction between the two pathways: policy influence created a demand for a technique (ROAM) that added to the success of the influencing strategy and so on. The lack of capacity development – specifically a lag in building a cadre of people able to implement ROAM – is a drag on the virtuous cycle. In Rwanda itself, there is evidence that the ROAM assessment contributed to the capacity development pathway. The work built the capacity to assess trade-offs with respect to reforestation in Rwanda, as well as building linkages between project implementers, key government officials and donors. These links and the acknowledged success of the ROAM assessment, has helped secure funding for new projects that are designed to further build capacity for FLR.

Discussion

Review of the model

In this section we review whether the evidence from the three cases supports the model.

The three cases give good empirical support to the three impact pathways, respectively. This is not surprising since we chose them specifically to represent the pathways. What is more surprising is that all three pathways played a part in all three cases with feedback loops between them. In the SIT case, the control of tsetse fly was successful because a positive feedback loop in which capacity building, together with the formation of an adaptive management cell involving veterinary staff and researchers, led to continual improvements during implementation resulting in greater control over the insect. The success of working in a more adaptive learning manner led to a broader adoption of this way of working and a more enabling institutional environment for doing so. At the same time the success of the project influenced policy makers to extend the program beyond the original area.

In the PLAR case, researchers who had successfully pursued the technology development and adoption pathway in relatively homogenous irrigated areas, found that they needed to pursue a capacity development pathway to achieve impact in more diverse rain-fed areas. This was because with less control over growing conditions, the more diverse areas required further local adaptation of improved technologies, which in turn requires a greater system capacity to learn and innovate.

In the ROAM case, there was a strong self-reinforcing feedback loop within the policy influence process itself. The recommendations generated by IUCN and WRI were adopted rapidly because they responded to a need that IUCN and WRI had themselves highlighted in successfully lobbying for FLR and targets. The recommendations were generated using a research method, which is now being scaled up. The eventual success, or otherwise, of the global movement for FLR depends, in part, on building the capacity to implement the method.

In all three cases, the three pathways interacted with each other and created self-reinforcing feedback loops. Most of the feedback loops were not planned for, but rather emerged out of necessity and resulted from the interactions and decisions of the stakeholders involved. Feedback loops go back to Senge's (1990) ideas about system dynamics and the potential for leverage, in which small, well targeted interventions can generate impact at scale in complex systems.

Our learning from this is that a program needs to be clear at the outset as to the main pathway which it is intended to impact. However, the program should also expect that during implementation other pathways may open up and offer opportunities for leverage. Research organizations should be aware of emerging self-reinforcing loops that create the potential for leverage, and be able to support them when they do. In summary, agricultural research needs to be clear on its main impact pathway, but also look out for opportunities to bring in the other pathways as a strategy for achieving impact in complex systems.

The implications for research initiatives and the organizations that implement them

The model has three implications for the way that AR4D initiatives are implemented and for the institutions that support and reward changes in professional practice. These implications are explored below, also drawing from the literature on how research organizations need to change in order to implement a complexity-aware theory of change, as indicated in Table 1.

Clarity at the outset as to main pathway that the initiative will take to achieve impact and awareness that this may change

Encourage the main stakeholders involved in an initiative to agree on a common vision and the main pathway by which to achieve it (technology development, capacity development or policy influence), during the project planning. The participatory impact pathway analysis is a useful tool that can be used to determine which should be the main pathway (Douthwaite et al., 2007). This decision will guide the choice of the initial 'best bets' that the initiative will employ to induce a response in the system into which it is intervening. Research organizations maintain their traditional mandates and expertize to deliver the 'best bets' within a network of organizations with a combined capacity to work across all pathways, should the need emerge as implementation unfolds. This will require research organizations to strengthen their capacity to carry out cross-disciplinary and participatory research (Donnet et al., 2012) and adapt to a change in their respective roles over time, including disengaging when no longer required.

Look for and respond to emerging patterns and dynamics resulting from initial intervention

This is the hardest requirement to meet because it requires initiatives to embrace functional adaptive management. It requires a monitoring and evaluation (M&E) system that is able to identify emerging outcomes, which are both expected and unexpected, in a timely fashion and bring this learning into strategic and on-going planning processes. It requires a flexibility in funding to allow initiative resources to be redeployed to support promising dynamics. Therefore, avoiding the need to renegotiate contracts with donors and partners implies making fewer up-front predictions and commitments to specific research agendas and outcomes, and having greater trust in the process until patterns have emerged. It implies planning for a long start-up phase (1 to 2

years) to identify and embed promising dynamics on which to work. Once the initiative is embedded in development processes, commitments to outcome targets and to support specific (reductionist) research agendas can be made with greater confidence.

Understand development impact as the result of the interaction of different worldviews in a critical and systemic learning process

Much of the debate on how research should best intervene in development processes has pitted a reductionist worldview against a more holistic worldview (e.g. Pretty and Chambers, 1993). Our model implies the need for a diversity of worldviews and pathways that interact with each other over time. For this to happen, research organizations need to be able to create the space for what Schut et al. (2014) call 'dynamic research configurations', which allow participants to reflect on how to improve the credibility, legitimacy and relevance of research in policy and innovation processes. To create such spaces, research organizations will need to encourage researchers to become more aware and accepting of their own worldviews and those of others, as well as to become more reflexive in their own practice. This will require training in soft skills, such as facilitation and leadership.

Reward behaviours that foster innovation

To use complexity-aware approaches effectively will require those involved in 'dynamic research configurations' to employ behaviours that foster innovation, such as innovation brokering and product championing. The capabilities that underpin these roles include:

- Treating people as primary assets
- Valuing openness, diversity and creativity (Donnet et al., 2012)
- The ability to assess options and identify key system challenges
- The ability to go through iterative visioning, planning and reflective learning cycles
- The capacity to link to other actors and to use linkages strategically in support of the program's plans (Douthwaite and Hoffecker, 2017)

Research organizations will need to develop incentive structures to encourage such behaviours.

Final remarks

Our argument in this paper is that mainstream AR4D organizations can achieve greater impact by using complexity-aware approaches, but for this to happen a more compelling case needs to be made to justify their use. Our contribution is to develop and test a generalizable complexity-aware theory of change to explain how AR4D fosters innovation, upon which a persuasive narrative to challenge the dominance of the linear 'Green Revolution' model can be built. The theory of change developed and explained in this paper, emphasizes self-reinforcing feedback loops as mechanisms by which small, well-focused research interventions can achieve impact at scale. However, to harness complexity in this way requires organizations to make broad-based and profound changes to work practices and the institutions that support them. These include:

- Being clear on the overarching pathway on which the initiative will embark and accepting that this may change over time;
- Planning for a long inception phase to identify, or catalyse, and then embed the initiative in a promising dynamic;
- Being more circumspect in predictions of impact or commitments to technical research agendas until after the inception phase;
- Putting in place functional adaptive management based on an M&E system able to quickly identify emerging outcomes;
- Supporting reflexive practice and other behaviours known to foster innovation;
- Creating spaces for 'dynamic research configurations' that allow stakeholders to reflect on how to improve the credibility, legitimacy and relevance of the research over time;
- Critically contributing to building complexity-aware research approaches, giving examples of where they work, or do not work, and building a theory to explain these findings.

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During the seminar, participants dug into critical issues surrounding AIS, aiming to trigger new thinking, as well as collaboration between participants, to influence agricultural research and development policy and practice.

The seminar resulted in five Working Papers:

- Do theories of change enable agricultural innovation systems to navigate? A reality check and comparison from practice.
- Systems Analysis in AIS: potentials and pitfalls.
- Agricultural Research for Development to Intervene Effectively in Complex Systems and the implications for research organisations.
- Diversity, inclusion and Gender Dynamics in Agricultural Innovation Systems.
- The contribution of AIS approaches to achieving impact at scale: intentions, realities and outlooks.

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