Linking international agricultural research knowledge with action for sustainable development

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We applied an innovation framework to sustainable livestock development research projects in Africa and Asia. The focus of these projects ranged from pastoral systems to poverty and ecosystems services mapping to market access by the poor to fodder and natural resource management to livestock parasite drug resistance. We found that these projects closed gaps between knowledge and action by combining different kinds of knowledge, learning, and boundary spanning approaches; by providing all partners with the same opportunities; and by building the capacity of all partners to innovate and communicate.

The central role of science and technology in development, recognized since the seminal writings of Solow (1) but underfunded over the last decades, is regaining world attention (2–5). Although researchers and innovators bemoan the failure of society to use the scientific knowledge already available, decision-makers at all levels, from farmers to extension agents to international negotiators, complain they cannot get the knowledge they need to make judicious choices (6). This impasse is thought to have led to suboptimal investment in research for development (7, 8).

This article focuses on gaps that exist between knowledge produced by researchers and action taken by decision-makers, because this type of knowledge-action gap is particularly acute in efforts to reduce hunger and poverty while sustaining the environment (9). A great proportion of knowledge relevant to sustainable development has a "public good" character to it, thus undercutting incentives for private investment in relevant research and development. The dilemmas of integrating global and local knowledge that arise in many efforts to link research with action for development are also particularly acute for many sustainability problems. And those searching for knowledge that can promote sustainability often must grapple with the exceptional complexities that arise from tightly coupled human-environment systems (10–14).

Some efforts to mobilize scientific knowledge to support sustainable development have made good progress—for example integrated pest management, soil fertility enhancement techniques, improved nitrogen-fixing food-feed crops, and advances in El Nino forecasting. Nonetheless, in the course of preparing for the 2002 World Summit on Sustainable Development (WSSD) in Johannesburg, a broad cross-section of the international scientific community concluded that too many programs designed explicitly to bridge gaps between knowledge and action for sustainable development fail to accomplish their goals, and too little consensus existed on what has helped to bridge such gaps, what has not, and why (15).

In the wake of the WSSD, many efforts were launched to develop such a consensus. Our point of departure for the work reported here emerges from a set of empirical studies ranging across agriculture, health, conservation, energy and manufacturing and conducted over the last several years by the Sustainability Science Program based at Harvard University (16), the Academy of Sciences of the Developing World (17) and the Science and Technology for Sustainability Program at the U.S. National Academy of Sciences (http://sustainability.nationalacademies.org) (18, 19). A recent summary of the results of this work by the Roundtable on Science and Technology for Sustainability of the US National Academies advanced a series of theoretical propositions regarding factors observed in several sectors as likely to better link knowledge with action for sustainable development (19). The research reported here juxtaposes those propositions of the Roundtable with experience garnered through knowledge-based projects to promote sustainable developing-country agriculture conducted by the International Livestock Research Institute (ILRI) and its local, regional and global partners. Our goal has been both to analyze the specific ILRI projects in light of the Roundtable propositions and to evaluate how we might generalize those Roundtable propositions in light of ILRI's experience.

Approaches for Linking Knowledge with Action for Sustainable Development. The research reported here investigates what kinds of approaches and institutions—defined as structures, mechanisms and norms governing group behavior—operating under what sorts of conditions are most effective in mobilizing scientific knowledge to inform action for sustainable development. The cases and examples considered in this article are in general highly complex systems involving the production and utilization of scientific or technical knowledge (described in detail in *SI Appendix*). The concept of innovation systems in developing-country agriculture is still at a relatively nascent stage (e.g., refs. 20–25) and we feel that focusing on lessons from empirical agricultural innovation systems-oriented case studies will add some further insights regarding this rather amorphous concept.

For convenience and clarity, we simplify this complexity by referring to the producers and users of knowledge. Producers encompass the scientists and practitioners who through their experiments, observations, and trial-and-error probing create knowledge about how the world works. Users are those who may use knowledge in shaping actions that change how the world is working, including decision makers, such as policy makers, managers, executives, households, and citizens. Because the experience of such users can also be a source of knowledge and it is not just scientists that produce knowledge, the distinction between producers and users of technical knowledge may become (intentionally) blurred.

As noted above, the conceptual framework for our analysis comes from a series of propositions advanced by the Roundtable on Science and Technology for Sustainability of the U.S. National

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Academies (19). The 6 "Roundtable" propositions that we began with are:

1. Problem definition. Successful programs linking knowledge with action require dialogue and cooperation between the scientists who produce knowledge (producers) and the decision makers who use it (users). Especially important is that the problem to be solved be defined in a collaborative but ultimately user-driven manner.
2. Program management. Successful efforts to develop programs linking knowledge with action generally adopt a project orientation and organization, with dynamic leaders accountable for achieving user-driven goals and targets. They avoid the pitfall of letting a study of the problem displace creation of solutions as the program goal.
3. Program organization. Successful programs linking knowledge with action include boundary organizations committed to building bridges between the research community on the one hand and the user community on the other. These boundary organizations often construct informal and sometimes even partially hidden spaces in which project managers can foster user-producer dialogues, joint product definition, and end-to-end system building free from distorting dominance by groups committed to the status quo. To maintain balance, most effective boundary organizations make themselves jointly accountable to both the science and user communities.
4. The decision-support system. Successful programs linking knowledge with action create end-to-end integrated systems that connect basic scientific predictions or observations to decision-relevant impacts and options. They avoid the pitfall of assuming that a single piece of the chain (e.g., a climate prediction) can be useful on its own or will be taken care of by someone else.
5. Learning orientation. Successful programs linking knowledge with action are designed as systems for learning rather than systems for knowing. Because of the difficulty of the task, such programs are frankly experimental—they expect and embrace failure to learn from it as quickly as possible. Success requires appropriate reward and incentive systems for risk-taking managers, funding mechanisms that enable such risk taking, and periodic external evaluation.
6. Continuity and flexibility. Successful programs linking knowledge with action must develop strategies to maintain program continuity and flexibility in the face of budgetary and human resource challenges; pressure to highlight short-term, measurable results; uncertainty regarding future budgetary priorities in a dynamic political environment; and shortages of people who can work effectively across disciplines, issue areas, and the knowledge-action interface.

Empirical Investigations. Our empirical investigation of the Roundtable propositions drew from a variety of approaches used and lessons learnt in ILRI-led field projects conducted in many countries over the past dozen years. The broad goal was to understand the contributions research can make to delivering real and sustainable benefits in real communities. In particular, we conducted case studies of 5 ILRI projects, the details of which are provided in the *SI Appendix*. The cases were selected to reflect a wide range of countries, agricultural systems, type of partners, type of research outputs, and length of time since the start of the project. They cover 5 different broad problem areas (captured in the titles below) with data gathered from multiple regions within each of 9 countries, and can be described as:

1. Better policy and management options for pastoral lands (Kenya, Tanzania) (26, 27).
2. Fodder and natural resource innovations for smallholders (India, Nigeria) (28).
3. Poverty and ecosystem services mapping (Kenya, Tanzania, Uganda) (29, 30, 31).
4. Improving productivity and market success of smallholders (Ethiopia).
5. Improving the management of trypanocide resistance in West Africa (Burkina Faso, Guinea, Mali) (32).

We focused on these criteria and projects to generate lessons that are broadly applicable to international agricultural research for development in general, not just livestock research. Thus, this set of case studies allows us to make comparisons and learn across a wide range of cultural, socioeconomic and agroecological systems.

Results and Discussion

We used the Roundtable's 6 propositions to examine factors determining success and failure in linking knowledge with action. We explored how well each of these propositions held for each of our case studies, how important they turned out to be, and what major constraints were faced by project members. Project-specific lessons learned regarding each proposition are reported in (33). Here, we focus on the most critical and broadly applicable lessons we learned about increasing the likelihood that research will generate knowledge that is useful, and actually used, for sustainable development.

Problem Definition. Researchers have traditionally focused on research outputs—articles, methods, technologies, trainings—rather than research outcomes. However, it is by jointly defining with project partners the desired outcomes of a project—including changed behaviors, policies, and practices—that links between knowledge and action can be discerned and strengthened.

Few of the case studies we analyzed initially adopted a rigorous stakeholder engagement process to bring together their diverse partners at the outset of the project to agree on outputs, outcomes and impacts being sought. The exception was the pastoral project, which wanted to work closely with largely marginalized pastoral communities and more effectively contribute to scientific evidence-based policies and practices (an outcome) for the sustainable use of their rangelands (a longer-term impact). They used a process called "outcome mapping" (www.outcomemapping.ca), developed at the Canadian International Development Research Centre to help principal project partners articulate what it wanted the project to achieve. Each partner chose specific metrics that measured progress toward achieving those outcomes.

Articulating the outcomes sought by the different individuals and organizations at the project outset helped bring the different actors toward a joint understanding of overall project goals and come up with innovative strategies to achieve them. At the same time, scientists found out quickly that they had a lot to learn from pastoralists about sustainable rangeland management and indigenous livestock health and breeding practices. One challenge faced by the project team, for example, was the fact that local pastoral communities were not being included in critical land policy debates. By jointly producing and interpreting new and timely land-use maps after training community members in the use of simple mapping technologies, the local community group was able to catch the attention of the policymakers and have their information and concerns included in a new land policy.

Thus, we learned that it helps if scientists share the role of generating knowledge with practitioners and acknowledge the value of coproducing knowledge together. Along with the pastoral case study, the fodder project case study highlights the benefits of knowledge sharing between local and scientific communities arising from the codevelopment of products based on both practical and scientific knowledge, and through community-to-community visits. Indigenous knowledge was key in the development of a farmer-designed system (i.e., new institutional arrangements regarding leasing of irrigated plots from wealthier farmers) in India, enabling

poorer farmers to adopt a higher yielding fodder variety for the first time. At the same time, joint definition is not always possible at program onset. In the trypanocide resistance project, the problem was essentially invisible to those outside the research community; hence, stakeholder appreciation of the problem was an end-point rather than a point of departure.

Program Management. All of our case studies involved a project orientation and organization, and we learned that having dynamic project leaders accountable for meeting use-driven goals and targets was indeed critical to success. The poverty and ecosystems services mapping project found that the time bound, limited and narrowly focused resource approach was not conducive to taking a broader systems and learning approach and focused instead on short-term capacity building and codevelopment of research outputs. Considerable time and effort was spent in building new institutions to ensure ultimately linked pro-poor and proenvironment impacts from the research, but the project ended, as do most, before a sufficient amount of time had passed to reasonably assess those impacts. We have certainly learned that it is much easier to achieve use-driven goals (e.g., maps targeted to addressing timely policy issues, new institutional arrangements giving poor farmers access to fodder) when project investors recognize the importance of, and provide sufficient time and resources for, defining the systems, building the partnerships, and devising solution-oriented learning approaches.

Boundary Spanning. Conducting a research project with people in the user community (e.g., local or national policy makers, smallholders, consumers) targeted by the research requires first getting access to the community and then gaining its trust. This collaborative work requires brokering that *spans the boundaries* between the partners (6, 19, 34, 35). Boundary work takes place between 2 or more groups that work to different standards and objectives (e.g., basic scientists evaluated by peers versus action people who are validated by political processes). Boundary objects are joint creations at the interface of communities (e.g., models, maps, assessments, contracts, posters).

We learned researchers and communities interested in linking knowledge with action must explicitly recognize that boundary spanning is an important part of their projects, and require testing different approaches and processes to do this more efficiently and effectively. The ILRI research projects reviewed took various boundary-spanning approaches, with varying degrees of success.

For example, the fodder innovation project team faced numerous institutional constraints that limited their ability to address fodder scarcity through purely technological solutions, such as "baskets of options" and advice to farmers of fodders best suited to their particular environments. They overcame some of these challenges by bringing together public- and private-sector stakeholders in a "learning platform" [referred to elsewhere as "coinnovation" in the context of such public-private research partnerships (36)]. The researchers now work directly with communities and other organizations to analyze formal and informal fodder networks and the factors that affect their ability to work together to bring fodder services to poor livestock keepers.

The poverty and ecosystem services mapping project linked poverty analysts from 3 countries by giving them the same tools with which to undertake a common analysis designed to have impacts on development policy. The main strategy to achieve the outcomes, high resolution national poverty and ecosystem services maps linked with other spatial data to inform better targeted pro-poor interventions, was to involve policymakers as integral team members from the outset of the project.

The pastoral project hired community facilitators as research team members who worked full-time spanning boundaries between communities, scientists and policymakers, all the while colearning and cocreating a hybrid of traditional/local and scientific/universal knowledge. In this case, constant engagement essentially blurred the boundaries between researchers, policy makers and communities, increasing the probability that the information generated would not only be useful, but used. The result was Kenya's first ever land-use master plan for a pastoral area.

The drug resistance project used participatory methods to span the boundaries between community members and researchers. They succeeded in generating understanding, enthusiasm and ownership and as a result, the strategies the project developed to deal with drug resistance were successful and acceptable. They did learn that boundary-spanning mechanisms need to be reinvented, however, because the boundaries they span shift with changing partners and changing agendas.

Institutional Change Supporting Boundary Spanning. Our case study lessons suggest that even more important than "boundary-spanning organizations" are boundary-spanning individuals and efforts (26). Having said that, individuals work within institutional frameworks, and these need to be supportive of such work (or at the very least, not block it). We need to better understand what kinds of institutional change, if any, encourage or accelerate boundary work. Because boundary-spanning activities, behaviors and approaches can be learned, developing courses and training materials in this area may profit research for development. Some helpful tools and processes that can help span boundaries efficiently and effectively via collaborative efforts were identified in the analysis of the case studies and are described in ref. 33.

New Arenas for Boundary Spanning Work. Several of our projects successfully created the new "safe spaces" highlighted as key by the U.S. National Academy of Sciences (NAS) Roundtable. These are environments where partners come together to solve problems and create joint outputs and reach agreement as to new rules of engagement that encourage and support creativity and innovation. At the same time, strategies that account for poor incentives, limited capacity and other existing constraints need to be developed for achieving desired outcomes. For example, faced with capacity and poor institutional incentives for collaborative work, the poverty and ecosystem services mapping project brought together poverty and environmental mapping specialists with analysts from various Ministries associated with the environment (land, water, agriculture, livestock) in hands-on training exercises that resulted in policy-relevant outputs (e.g., a poverty and poultry distribution map for the Minister of Agriculture who was developing an avian flu strategy). Looking across our case studies, another strategy for creating safe spaces was professionally facilitated workshops in environments outside each of the organizations involved that created a more neutral space conducive to creativity and cocreation. Clearly there is room for more thinking about additional strategies and approaches for creating these new arenas.

Systems Integration. One way in which to produce both international public goods (those with significance across borders) and local poverty impacts is for research projects to engage local partners in multiple strategically selected sites to ensure the knowledge generated can be extrapolated more broadly. Does mission-oriented research always require a systems approach (e.g., involving public- and private-sectors, nongovernmental organizations, community members, scientists, and policymakers)? All our case studies suggest the answer is yes. There is certainly a role in sustainability science for both traditional, curiosity-driven research and for context-specific problem solving—so long as both are conducted within a larger framework

that ensures rigor and usefulness (37). Many scientists fear that their adopting a systems approach will reduce their comparative advantage (e.g., in-depth knowledge of a disciplinary field) and lead to their spending all their time on partnership building and other processes. This risk is real. Our case studies all point to the need to use rigorous processes, "tried and tested" tools, and world-class expertise in facilitating stakeholder engagement, building teams, and establishing ways to measure and communicate impacts and outcomes.

The drug resistance project started by attempting to join all of the dots between all of the activities needed to stop or control drug resistance. The ambitious objectives of this project encompassed detecting drug resistance, managing the problem, building capacity in animal health, and changing livestock health policies. In practice, the project team soon learned there were some things they could deliver, some they could influence, and some that were essentially outside their control. Imperfect initial knowledge, evolution of the systems under study, and new findings appearing along the way made the continuum between research results and impacts (less drug resistance) appear shifting and nonlinear. Rational drug use, the solution to the drug resistance problem the project members eventually settled on, was not even considered an option at the beginning of the project. So although drawing out perceived links between knowledge and action at the start of projects can be helpful, any early commitment to a particular pathway disallows learning and joint exploration of various paths.

The Ethiopian market project took a "value chain" approach (a type of systems approach) and created multiactor platforms that included policymakers. Challenged to link smallholder agricultural producers to emerging markets, project members had to persuade their government partners of the benefits of new institutional arrangements, and provoke private sector interest in increasing farmers' access to markets in a country still dominated by the public sector. Thus, taking a systems view essentially meant putting a lot of effort into trust-building and cooperation between local governments and a nascent private sector that had previously not interacted, a time-consuming process that initially limited the project team's ability to operate. Now, however, farmers and entrepreneurs are allowed to produce and sell seeds and tools (certified by the government) for the first time, and paravets allowed to operate.

The project teams in all of the case studies found that just defining a "knowledge-action system" is a challenge. A first step taken in the second phase of the fodder innovation project was to undertake a scoping study aimed at better understanding fodder and fodder innovation systems and determining the key players that should be involved in the project. The project members are now developing diagnostic tools to facilitate and explore institutional change processes. Once again, the key to sustainable development appears to lie in investing in appropriate partnership processes and tools at the outset of any project.

Learning Orientation. All organizations interested in transforming themselves (or their self-perceptions) from knowledge producers to knowledge learners face challenges in doing so. Management must support a learning culture and provide incentives for adopting learning approaches, as it has at ILRI, where research performance criteria now include collaborative partnerships and communication outputs beyond scientific journal articles. However, ILRI and other institutions ambitious to transform themselves into learning cultures need to go further in supporting and rewarding failures (as often encouraged in private sector research). Initiatives are needed to fund collaborative teams experimenting with different learning approaches to find those that help them link knowledge with action.

All our case studies have experimented with different approaches and strategies and attempted to learn from them. For example, in the markets project, advisory and learning committees were created to serve as learning platforms, define actions to address government priorities at various levels and create "safe spaces" for these negotiations and activities. However, the functions of these committees were not sufficiently defined and they ended up playing "policing" and resource allocation roles that essentially defeated their original purpose. Learning seems to still be a fairly abstract concept for most project staff and partners, and lack of appropriate skills, tools and experience remain constraints in Ethiopia (e.g., the facilitation and communication approaches required for full implementation of this approach). A cultural and institutional environment that discourages risk taking and finds failures generally unacceptable adds considerably to the challenge of taking a learning-based approach.

A lesson from the pastoral project with respect to a learning orientation is that convening the right team and committing to colearning and coproducing "hybrid" knowledge (e.g., a combination of indigenous and scientific knowledge) for action at the beginning of the project is absolutely critical to success. Taking a learning approach can be unsettling as there is no set recipe for what will or will not work. Relatively frequent team meetings to discuss progress and problems are needed. Confidence is built as lessons are learned and successful outcomes are achieved. Experimentation with new avenues of communication such as radio programs and community briefs were quite successful.

The pastoral project is also a good example of how institutional "protection" is needed to truly encourage innovative and risk-taking behavior; ILRI management and large external financial support effectively provided a safe space in the sense that the team was protected from external criticism concerning a livestock institute working on wildlife conservation issues. The community researcher-facilitators were highly supported and encouraged to take a learning approach by their research managers at ILRI.

The issue of improving incentives and rewards for individuals that are successful "boundary spanners" arose in all of the case studies. A critical challenge to institutionalizing boundary spanning functions within an organization is to do so while maintaining flexibility to adjust and organize according to constantly changing needs for specific information products. Many institutions are not eager to invest in boundary functions (e.g., workshops, forums, reports) that are perceived to be not a core part of their mission, nor do government or private funders want to invest in the creation of freestanding boundary organizations (36). We also saw "informal communities" of actors who play no explicit role in the system—often making one-on-one connections between explicit actors who otherwise might not meet—creating key relationships. Because of their "stealth" nature, these are very difficult to identify, yet can be important for successful boundary-spanning, and the links from knowledge to action, to occur.

Continuity with Flexibility. Our case studies highlight constraints that limit achieving continuity and flexibility, including entrenched top-down systems of governance; poor human capacity and skills in local institutions; project-trained individuals and champions moving on to other jobs; the slow pace of institutional change; and projects too short to have the kinds of impacts needed to convince governments and other partners to change their behaviors and adopt new approaches. Institutionalization of systems approaches and scaling out of project results arguably remain our greatest challenges in more successfully linking knowledge with action resulting in sustainable poverty reduction.

The main strategy pursued by all teams to enhance the probability of continuing progress after the project involved training and capacity building of partners and/or community members. In looking at the evolution of these projects and their

training activities, a clear lesson is that project managers need to be thinking about building project competency (whether by recruitment or training) in more of the so-called "soft skills"—e.g., facilitation, synthesis, stakeholder engagement, monitoring and evaluation, impact assessment—and in the use of tools and processes that will lead to faster and broader outcomes and impacts ("action"). For example, the pastoral, fodder and markets projects all built capacity to examine desired project outcomes in terms of behavioral, institutional, policy and other desired changes for each key partner involved in the project. We have seen that such efforts can result in the recognition and articulation of institutional changes that are needed for sustainable development to occur, and the design of strategies to achieve those desired outcomes.

Other strategies aimed at achieving project continuity and institutionalization (i.e., with the project team "handing over" the lead to local partners) seen in our case studies include empowerment of community members and support for collective action efforts, strong support for continuous engagement between local users and producers, joint producer-user proposal development, and creating demand for institutionalization of research activities by raising the visibility of project partners through high profile, high quality research and communication coproduced products, or "boundary objects" (6). These are cocreated objects that span two different worlds, e.g., science and policy, and meet the needs of individuals within each (19, 38), and they were important elements of success for several of our case studies. In the poverty and ecosystems services mapping and pastoral projects, these boundary objects included maps, policy briefs and reports. It was through these boundary objects that herders, state and local officials, poverty analysts, environmental modelers, conservationists, etc. began to work together toward solving complex sustainable land-use problems.

Our case studies support the idea that building innovation capacity for getting research into practical use in a range of organizations remains critically important. In particular, we need to improve stakeholder engagement, project management, and the definition, achievement, and communication of outcomes and impacts. Building capacity to innovate and communicate is key to closing the gaps between knowledge and action. We do not know enough, however, about how best to build innovation capacity in different systems.

Manage Asymmetries of Power. This 7th proposition emerged while examining critical aspects for success (or failure) within our case studies. Linking research knowledge with practical action often requires dealing with large (and largely hidden) asymmetries of power felt by stakeholders (14). The pastoral project team explicitly recognized perceived huge power imbalances across their multipartner project team, such as the often unrecognized power of scientific experts, particularly in a rural community context and pursued multiple strategies (e.g., hiring local community members as members of the core project research team, cocreation of knowledge by a hybrid community-scientist team) to build trust and demonstrate respect for the knowledge of all partners in the project. These efforts led to the inclusion of Maasai voices in national and local land-use policymaking.

Less optimistically, the drug resistance project found that vested interests whose livelihoods depended on their monopoly of drug sales could be influenced neither by participatory processes or rigorous science. Despite clear evidence that training farmers in drug use was safe and beneficial they continued to oppose involvement of nonprofessionals. The successful redressing of entrenched power imbalances by any single project is probably the exception rather than the rule.

Methods

A workshop was convened at ILRI with members of the National Academies' Roundtable and researchers involved in ILRI's case studies. The workshop benefited from two prior workshops organized by the National Academies' Roundtable on Science and Technology for Sustainability's Task Force on Linking Knowledge to Action for Sustainable Development. The ILRI workshop participants first considered the set of 6 propositions described below in relation to their case studies in advance of the meeting, and were asked to prepare analyses of their case studies in light of these propositions for distribution to all attendees (see *SI Appendix*). Participants' written answers to the questions were collected as a set of case summaries to be discussed at the meeting. The criteria used to select these case studies included geographic focus, problem area, type of partners and research outputs. This compilation of case studies on linking knowledge with action for sustainable development will be further developed for future research and teaching.

Conclusions

Our case study teams profited from a framework and propositions arising from an examination by a National Academies' Roundtable of approaches taken by research projects likely to lead to actions that sustain development. The Roundtable approaches helpfully explicated strategies pursued explicitly to link knowledge to action. We found all of the propositions relevant and suggested some changes that may make them more helpful to international agricultural and natural resource management researchers and practitioners. We added a 7th proposition to help redress perceived asymmetries of power and to build trust among project partners. The reformulated propositions are as follows.

1. Problem definition. Projects are more likely to succeed in linking knowledge with action when they employ processes and tools that enhance dialogue and cooperation between those (researchers, community members) who possess or produce knowledge and those (decision-makers) who use it, with project members together defining the problem they aim to solve.
2. Program management. Research is more likely to inform action if it adopts a "project" orientation and organization, with leaders accountable for meeting use-driven goals and the team managing not to let "study of the problem" displace "creation of solutions" as its research goal.
3. Boundary spanning. Projects are more likely to link knowledge with action when they include "boundary organizations" or "boundary-spanning actions" that help bridge gaps between research and research user communities. This boundary-spanning work often involves constructing informal new arenas that foster user-producer dialogues, defining products jointly, and adopting a systems approach that counters dominance by groups committed to the status quo. Defining joint "rules of engagement" in the new arena that encourage mutual respect, cocreation and innovation improves prospects for success.
4. Systems integration. Projects are more likely to be successful in linking knowledge with action when they work in recognition that scientific research is just one "piece of the puzzle," apply systems-oriented strategies, and engage partners best positioned to help transform knowledge cocreated by all project members into actions (strategies, policies, interventions, technologies) leading to better and more sustainable livelihoods.
5. Learning orientation. Research projects are more likely to be successful in linking knowledge with action when they are designed as much for learning as they are for knowing. Such projects are frankly experimental, expecting and embracing

failures so as to learn from them throughout the project's life. Such learning demands that risk-taking managers are funded, rewarded, and regularly evaluated by external experts.

6. Continuity with flexibility. Getting research into use requires strengthening links between organizations and individuals operating locally, building strong networks and innovation and response capacity, and cocreating communication strategies and boundary objects and products.
7. Manage asymmetries of power. Efforts linking knowledge with action are more likely to be successful when they manage to "level the playing field" to generate hybrid, cocreated knowledge and deal with the often large (and largely hidden) asymmetries of power felt by stakeholders.

Assessments of the impacts of agricultural projects aiming for sustainable development suggest that measurable livelihood, and particularly environmental, impacts take at least 15–20 years to be realized (39, 40). Our research indicates that projects aiming to improve livelihoods in sustainable ways are more successful if they incorporate most if not all of these 7 propositions. To determine whether these 7 propositions are sufficient and needed for success will require revisiting the projects in another decade or so.

Our results further indicate that boundary-spanning work is most effective when it is regularized yet flexible and when it enlists the support of informal communities of actors. Boundary spanning may be institutionalized by creating a new organization or by making it a function of part of an existing organization. Existing institutions, however, are often disinclined to invest in boundary-spanning activities that appear extrinsic rather than central to their core mission, whereas government and private funding agencies have proved reluctant to invest in the creation of new organizations aiming to serve as "go-betweens." Largely for this reason, there exists little incentive for individuals to build their careers in the "boundary space."

Our valuation and refinement of NAS's propositions in light of research experiences by ILRI and its partners underscores the importance not only of boundary-spanning efforts but also of supporting the individuals who do such work. It is not yet clear what kinds of institutional change is likely to encourage and accelerate boundary work, what kind of incentives are needed to encourage individuals to pursue such work, and what kinds of courses and training materials will build capacity in this area. Although we are ambitious to design experiments that test our hypotheses about what propels research knowledge into development action, we frame the lessons from our case studies as described above to help us and others sharpen current thinking about closing the knowledge-action gaps in sustainable development.

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