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How to Improve the Social Benefits of AGRICULTURAL RESEARCH

The Green Revolution left millions of the world's smallholder farmers behind. Increasing the role of farmers in agricultural innovation can help them catch up—and will lead to better science in the process.

Famines have killed tens of millions of people across the centuries. But as the global population rose from 2.5 billion people in 1950 to nearly eight billion today, mortality from famine was radically curtailed. What accounted for this remarkable accomplishment? Perhaps the most commonly cited factor is the Green Revolution, typically summarized, as in this online encyclopedia entry, as the "great increase in production of food grains (especially wheat and rice) that resulted in large part from the introduction into developing countries of new, high-yielding varieties, beginning in the mid-20th century."

Today, many efforts to address rural poverty and food insecurity in low-income nations through agricultural research for development (AR4D) programs are built on this narrow view of the Green Revolution. And indeed, the accomplishments of the Green Revolution should be celebrated. But they have also been misunderstood. To start, the contribution of Green Revolution crop varieties to preventing famine is overstated. For example, India's food production was increasing steadily more than 15 years before Indian farmers started adopting Green Revolution wheat in 1967. The Green Revolution's successes were also concentrated among wealthier farmers. This was in part because research organizations directly targeted "successful" farmers to test new technologies, with the idea that best practices would trickle down to poorer farmers. But this often didn't happen. Poor, smallholder farmers often lacked access to credit, could not afford inputs such as fertilizers, or grew different crops than the ones developed by Green Revolution research. Overall, the Green Revolution did little to reduce food insecurity and actually increased rural inequality, leaving behind the poorest and most vulnerable.

The continued failure of AR4D donors and research organizations to fully understand these ambiguous and uneven outcomes of the Green Revolution is leading to simplistic scientific and policy approaches that can further exacerbate economic and social inequities experienced by millions of smallholder farmers worldwide. Accordingly, we argue that agricultural research policies need to accommodate the complexity of the real world of smallholder farming if they are to achieve their dual goals of enhanced food security and poverty relief.

Modernizing the peasantry

Starting in the 1940s, the United States became involved in funding international agricultural research centers through the Rockefeller Foundation, the Ford Foundation, and later the US Agency for International Development (USAID). This investment in international scientific infrastructure, along with the spread of synthetic fertilizers, led to a growth in production of grains such as wheat and rice. This era was later dubbed the "Green Revolution." Orchestrators of the Green Revolution focused on maximizing yields in targeted areas in order to increase aggregate food production. The Green Revolution also promoted commercialization of agriculture, which fit with America's political goal of modernizing the global peasantry to promote democracy and economic growth. Production of maize, wheat, and rice increased in the areas targeted by the US-based organizations, and new "packages" of modern crop varieties, fertilizers, and irrigation were applied in geographically disparate regions, especially for wheat. Under certain conditions (typically those of larger farms), farmers increased their yields and incomes. Although the Green Revolution coincided with poverty reduction in parts of the world, a multitude of political, economic, and infrastructural changes were also occurring, and academic scholars continue to debate the extent to which agricultural innovation was responsible for reduced poverty.

A key principle of the Green Revolution was that agricultural science could produce universally applicable agricultural technologies. Donors would fund international research centers to develop universal technologies, tested in controlled field trials. National centers and extension services would adapt those technologies to local conditions where needed, but as much as possible farmers' fields would be expected to imitate the research fields, which were typically well maintained with adequate irrigation, drainage, fertilizers, and pest control. Deviation from these conditions was seen by researchers as evidence of inadequate agricultural practices.

The commonly accepted story that Green Revolution technologies prevented global famine and reduced poverty by modernizing global agriculture continues to dominate the imagination of the public, scientists, and donors alike. Central to this story is a simplistic, linear view of agricultural innovation itself: scientists conduct controlled research in the lab or field, then publish or patent the results, which are then picked up by industry or government and made available to farmers, who benefit from improved crop varieties, greater productivity, and so on.

This linear story is exemplified by the most famous innovation of the Green Revolution: broadly adapted wheat. The scientist Norman Borlaug, while working with the Rockefeller Foundation in Mexico, realized that certain tropical spring wheats could be grown over multiple agroecological zones. Borlaug, who later won the Nobel Peace Prize, bred several broadly adapted wheat varieties that were successfully grown in Central and South America, India, Pakistan, and parts of Africa and the Middle East. Yet other key crops—maize, winter wheat, and rice—had much more limited success with broad adaptation. Even wheat was broadly adapted only in the sense that it yielded well under well-fertilized, irrigated conditions regardless of latitude. Further, the adoption of Borlaug's wheats in India displaced the production of more nutritious legume crops and did little to reduce widespread malnutrition or poverty. Nor did the new wheat varieties automatically find their way into farmers' fields. Coordinated political and infrastructural changes, such as expanded agricultural extension services, were necessary to facilitate rapid transfer of technology in certain parts of the world, while investments in irrigation and fertilizer were necessary to assure improved crop yields.

In the decades following the introduction of Green Revolution technologies, numerous studies made it clear that new agricultural technologies had mostly benefited wealthier farmers with large landholdings who had access to irrigation, fertilizers, and markets. But small farms were, and today remain, an important part of the food system, the economy, and the social organization of much of the world. Worldwide, 80% of farms are smaller than two hectares (five acres). In low- and lower-middle income nations, these account for up to 40% of total agricultural land; farms smaller than five hectares make up about 90% of the agricultural land. In India today, agriculture accounts for 25% of the nation's gross domestic product and 60% of employment; in sub-Saharan Africa the numbers are higher still. And in many areas of the world, the average size of farms is actually decreasing.

Science for the real world

The linear view of agricultural science and innovation that underlay the Green Revolution virtually guaranteed that smallholder farmers could not benefit from it. For a technology to be adopted by smallholders, it must perform in the real-world conditions that they confront. Such conditions include labor shortages and uncertain access to fertilizer and other inputs—either because they are not available in local markets or because of a lack of capital or access to credit. In order to design technologies that lend themselves to adoption by smallholders, those technologies must be tested with the involvement of the farmers, and on their land. This type of on-farm, participatory experiment is, however, difficult to analyze and interpret because of the high variability of conditions on farmers' fields. In contrast to the uniform, professionally managed fields found on research stations, farmers' fields may have trees, termite mounds, or slopes that result in variability at very small spatial scales. Weeds and insects may not be controlled equally well by all farmers testing a new seed variety or soil fertility practice, confounding efforts to control variability. Soil physical characteristics can range from sand to clay over areas of only a few hectares. Soil fertility is also influenced by the history of cultivation on a plot—long periods of continuous cultivation can lead to depletion of organic matter and acidified soil, which both decrease the soil's fertility and make standard fertilization practices less effective.

Agricultural science that can contribute decisively to the livelihoods of smallholder farmers must accommodate this variability and include actual farms—not just highly controlled test fields—as sites for research. Yet because it is impossible to account for all the factors that can contribute to yield variability, some scientists dismiss on-farm research as insufficiently rigorous. But if science is supposed to provide reliable knowledge about the real world, then agricultural research must study the highly variable conditions in which smallholder farmers work. A study of two thousand soybean trials conducted on farms in 10 sub-Saharan African countries as part of the N2Africa project showed that yield variability at the field level was higher than variability among countries or years. This level of local variability makes adoption of new crop technologies riskier for farmers.

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Understanding the reasons why one farmer's yield was high while a neighbor's was low can reduce the uncertainty, and the risk, of technology adoption. For example, a 2018 study of 372 on-farm trials carried out in the West African country of Mali demonstrated that yields from a range of new technologies were significantly influenced by farmer-identified soil type and by the previous crop grown in the field where the technology was tested. This type of information, which is inherently place-based, allowed researchers and farmers to develop multiyear plans that would place new crop varieties and management practices in the locations and sequences where they have the best chance to succeed. This in turn gives farmers greater confidence in unfamiliar farming practices, and increases the likelihood that they will adopt such practices.

In addition, smallholder farmers usually have multiple sources of income both within and beyond the farm. Off-farm work can include wage labor for better-off farmers, seasonal or long-term migration, small-scale commerce, or trades such as carpentry or basket-making. Agricultural innovations that require additional investments in labor or capital must not only improve on existing farming practices but also compete with these other investment opportunities. Smallholder farmers might reasonably decide that the costs of adopting agricultural innovations that might work well on larger farms outweigh the benefits. In many areas, even the best agricultural technologies are not, on their own, capable of lifting smallholder farmers and their families out of poverty.

Where the money goes

Major US-based donors and organizations working to advance agricultural research for development continue to embrace a linear model that focuses mostly on technological solutions to increase crop yields, with insufficient consideration of the socioeconomic complexity involved in advancing food security or poverty reduction.

One of the major players in the AR4D space is the Bill & Melinda Gates Foundation, which since 2006 has donated roughly $5 billion to agricultural development in sub-Saharan Africa and South Asia with the goal of "agricultural transformation" that is equitable and brings low-income households out of poverty. But the foundation falls into several traps of the linear model of technology development, including setting its strategies with little to no involvement from farmers, focusing on technology dissemination and increasing farmers' participation in formal markets to "achieve impact," and emphasizing the "scalability" of agricultural technologies across disparate contexts. The foundation also cofounded the Alliance for a Green Revolution in Africa, which seeks to advance agricultural development in sub-Saharan Africa. Yet the foundation's strategies do not address why the *first* Green Revolution failed to take hold in sub-Saharan Africa. Although the foundation acknowledges that Green Revolution technologies' reliance on fertilizer and irrigation has been a barrier to their adoption on the continent, and that crop varieties must be adapted to fit African environments, its approach to research and development remains technology-driven, with a focus on broadly adapted crop varieties. This approach fails to recognize that improving staple crop production has rarely lifted anyone out of poverty.

The US government is another major AR4D investor. Its Feed the Future Initiative, started under the Obama administration and led by USAID, has spent over $3.5 billion on agricultural development since 2010. The initiative focuses on technology transfer, scalability, and demonstrating impact on short time scales. Feed the Future documents show a commitment to the linear model of technology development, but also emphasize collecting "ongoing, iterative feedback from end-users, stakeholders, and technology scaling partners to inform activities throughout the research pipeline." In practice, however, participation is often limited to token stakeholder groups whose inputs to the process come too late to meaningfully influence research directions. The websites of the 24 Feed the Future Innovation Labs demonstrate an overwhelming focus on basic and applied research for crop varietal improvement, increased productivity with reduced environmental impact ("sustainable intensification"), and increased involvement in formal markets, with little to no mention of agroecological context or end-user needs. For example, several of these labs aim to develop heat-tolerant crop varieties. Despite language about specifically targeting smallholder farmers and women, the first adopters of innovations such as heat-tolerant varieties will almost certainly be farmers of higher socioeconomic status. Feed the Future also promotes the assumption that farmers should continue to grow staple grain crops, rather than explore alternative income sources within or out of agriculture. Narrowly focusing on crop improvement locks farmers into a production system rather than expanding options for addressing systemic economic and environmental issues.

Distorted incentives

Implementation of AR4D is substantially carried out by an international research network funded by national, international, and private donors. Known as CGIAR, the network emerged during the Green Revolution and continues to promote centralized agricultural research for development through the creation of what it terms "global public goods," such as new crop varieties. CGIAR receives major support from both the Feed the Future project and the Gates Foundation; for example, nearly 40% of its wheat and maize research spending comes from these two sources.

Starting in the 1980s, international aid began focusing on measuring "impact," and CGIAR typically did this through studies of successful technological change. Adoption studies provided the evidence for justifying further investments in AR4D. But we are troubled by the widespread reliance on farmer adoption studies to provide evidence of impact. These studies typically count the number of farmers or acres that adopt a new technology, but do not look at differences among socioeconomic subgroups, or define "adoption" in a way that is generalizable. A farmer who is reported to have adopted a new groundnut variety may have planted a 10-meter by 10-meter trial supervised by researchers, may have planted half an hectare of seed provided by the project, or may have simply purchased seed. Moreover, rejection of a new technology is rarely considered, so if farmers return to their original groundnut variety in the next season, they may still be included in the project's total number of farmers adopting improved varieties. When adoption is measured as part of a specific project, farmers often receive support including training, free or subsidized fertilizer or other inputs, or a guaranteed buyer for their crop.

Quantitative measures of impact are important considerations when evaluating AR4D. But adoption and impact are not the same. Projects with the long-term objectives of decreasing rural poverty may use adoption as an intermediate metric, but the connection between adoption of new technology and impact on farmer incomes and livelihoods is difficult to demonstrate. Using adoption to evaluate impact reinforces the view that farmers are mere passive recipients in the innovation process. It strongly biases AR4D toward linear approaches that view research as best carried out under controlled conditions at the beginning of the innovation process. It thus fails to recognize the value of iterative processes where farmers provide feedback to scientists that can allow product improvement over time, to say nothing of including farmers' input in the development of research questions.

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Agricultural research is slow. Field trials can be conducted once, maybe twice a year. Interannual climate variability makes multiyear trials important for evaluating new technologies. Building the relationships and level of trust needed for collaboration among multiple stakeholders—farmers' organizations, extension services, national and international research centers, and universities—also takes time. But CGIAR researchers typically rely on short-term project-based funding to cover operational and administrative costs as well as their own salaries. Projects are often funded on three-to-five-year time frames, and evaluated on an annual basis. Because researchers are directly accountable to donors, projects that allow short-term, quantitative demonstrations of impact are incentivized. Accountability to the intended users of the technologies is in turn disincentivized. One result is that technologies that may appear to have widespread success during the course of a project are abandoned once the project ends and the incentives it provided disappear. Paradoxically, increased emphasis on quantifying impact may actually reduce the long-term impact of a project.

Whose excellence?

CGIAR is also organized around regional research centers that focus on particular crops. The International Maize and Wheat Improvement Center (CIMMYT) in Mexico is responsible for maize and wheat worldwide; the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in India researches sorghum, millet, and groundnut, among other crops; and the International Rice Research Institute (IRRI) in the Philippines researches rice, except for African rice varieties, which are the purview of AfricaRICE. Each of these centers has regional subcenters and satellite locations around the world, all focused on the center's mandated crops. A center's focus on particular commodity crops limits the flexibility of researchers—if farmers are interested in rice, but researchers at a nearby location work for ICRISAT, there is no way for those researchers to meet farmers' needs. Attempts have been made to develop partnerships and structures that allowed multiple stakeholders to participate in the research process. However, despite their increased complexity these collaborative programs were still expected to demonstrate impact in terms of quantitative metrics, such as adoption, on an annual basis.

CGIAR currently promotes three "research support" platforms: Big Data, Excellence in Breeding (plant breeding using "cutting edge" tools), and Genebank (maintaining diverse seed collections and facilitating their use in breeding as a source of desired traits). Notably absent is any support for on-farm research, systems analysis, or technology development processes that include farmers' and other stakeholders' input. Rather, the focus is on better data analytics, crop modeling, and other computational methods that reinforce CGIAR centers' traditional focus on developing improved commodity crop varieties. If "excellence in breeding" research is defined as computationally intensive, high-throughput, high-tech studies carried out in controlled settings, then on-farm research and participatory plant breeding are not "excellent." Instead, these are seen as separate, lesser activities.

Donors and researchers alike often view breeding and varietal development as the principal role of agricultural research. But better seeds don't solve all of farmers' problems. A high-yielding rice variety may not be adopted if it cannot be hand-threshed and machine threshing is not available locally. A sorghum hybrid that produces high yields a few weeks before the local varieties may sound ideal, but if all the birds in the area show up for an early feast, the farmer may harvest almost nothing. In many cases, low-technology agronomic changes in crop patterns and simple technologies such as nets and stakes may contribute as much or more to increasing farmers' yields and incomes than the latest crop variety. But broadly adapted, commodity plant breeding to produce global public goods has always been the primary focus of CGIAR, and so it remains.

What's the problem?

The dominant approach to AR4D does result in new technologies, but many of the technologies remain on the shelf rather than becoming integrated into farmers' production systems, especially for smallholder farmers in low- and low-to-middle-income countries. As we have emphasized, the linear approach to AR4D has thus failed to provide adequate benefits for smallholder farms, despite their importance in many regions, especially in South Asia and sub-Saharan Africa. Part of the problem, in our view, is that government programs, donors, and scientists alike continue to view farmers as passive recipients of their technological benevolence. But looking at smallholder farmers as knowledgeable customers, and at agricultural technologies as products engineered to meet customer need, suggests an alternative "product development" model of innovation that is more likely to produce relevant, usable technologies to improve food security and reduce poverty.

The central idea behind product development is to increase the chance of product commercialization. Product development can be described as a series of stages encompassing problem definition, concept development, design, prototyping, final product development, and commercialization, but each stage is iterative and includes multiple sources of input. The starting point in a product-development approach to AR4D is to engage clients at the beginning of the research process. In many projects, the problem is defined as poverty and food insecurity. If we take that as our starting point, we then move to concept development: what are the ways we can address the problem? In the linear approach, a crop researcher might assume the best way to improve a client's income and food security is through increasing the yields of the crops the client grows (or should grow). However, engaging with the client reveals a tableau of their needs, constraints, and priorities. For example, if a farmer's goal is to increase income, off-farm employment might be a better pathway for improving household income than adopting high-yielding varieties. Even where, for example, an improved variety is chosen as a means to address the problem, the process does not revert to a linear model.

Within an iterative process of product development, prototypes are tested under a variety of conditions (including by clients) and the product is altered based on the findings to better address the conditions of actual use. Users are part of the innovation process. Moreover, understanding the economic and social implications of the product's introduction is critical to its success in solving the problem. In the linear approach to agricultural research, new technologies are usually evaluated by only a few factors—yield improvements, disease resistance, and maybe cost. But many more factors go into a client's decision to use a technology. For example, what are the alternatives and how is this product different? Is the market for selling this product well developed? Does the product exacerbate gender inequity by differentially increasing women's labor over men's? These questions are made explicit through the product development process. In contrast, under the current system of research (with its focus on short-term adoption), consideration of user needs and socioeconomic factors conflicts with the researchers' incentives.

Fine, but would you want to eat it?

An example of how AR4D research can approach crop breeding through a product-development approach is a program in Mali developed by Eva and Fred Weltzien-Rattunde, both agricultural scientists with extensive plant breeding experience in tropical and subtropical settings. The couple, working for ICRISAT, ran a sorghum breeding program that develops locally adapted sorghum cultivars and hybrids through extensive work with farmers and helps make those varieties widely available by working with farmers' seed cooperatives. This process includes farmers from the beginning. Some of these farmers plant diverse seed mixtures representing a wide range of plant traits. They then participate in the selection of desirable traits from that population, from which new varieties may eventually be developed. As the breeding process continues, researchers hold culinary test days in villages, where local women process and prepare the local staple, tô, from several sorghum varieties in development. Throughout the preparation process, measurements are taken to quantify processing losses, and qualitative information is collected from the women doing the processing. At the end, men, women, and children conduct taste tests and rank the varieties on flavor, texture, appearance, and any other characteristics they think are important. Finally, ICRISAT works with seed cooperatives to train farmers in producing certified seed of specific varieties and hybrids, and crucially also in accounting, organizational, and management skills. Mini-packets of seed are sold by the cooperatives and through ICRISAT projects, and follow-up research on the buyers of the mini-packets has provided information not only on adoption but also on how these improved varieties spread through both formal and informal seed systems.

The continuous involvement of farmers at multiple stages of the research process contrasts markedly with standard AR4D approaches, as used at the Pan-African Variety Trial, part of the USAID Feed the Future program's Soybean Innovation Lab at the University of Illinois. There, varieties developed and released in the United States and Brazil, and by CGIAR centers and private partners in Africa, are tested in strictly controlled trials, and only the best varieties from those trials are tested on farmers' fields. Farmers' feedback into this breeding system is minimal at best. As the project claims, this may well be a way to quickly get improved germplasm into farmers' hands. But it also faithfully replicates the linear model of the first Green Revolution, and thus is likely to replicate the weaknesses that compromised that approach.

We are contrasting these programs to emphasize that participatory and place-based research can produce the types of widely used technologies—public goods, in AR4D parlance—that are promised by standard Green Revolution approaches. The difference is that the resulting products may be applicable to a much more diverse array of publics—not just wealthier farmers but smallholder farmers in diverse agricultural and socioeconomic settings. Technologies need adequate experimentation and adaptation in different social and agroecological conditions to derive insights about their successful application. Identifying the socio-ecological niche for which a new technology is appropriate can aid efforts to disseminate the technology in other places with similar conditions. For example, technologies such as intercropping that maximize the efficiency of land use may be appropriate for areas with high population density and limited farm size, while labor-saving technologies such as herbicide use may be more attractive in areas with low population density, where farm size is defined by how much area a farm household can plant and maintain. Grain legumes that are successful in well-drained soils will be of little use to a poor farmer whose land sits in an often-flooded depression. Coordinated participatory research in a range of socio-ecological niches can be synthesized to compare findings from multiple locations. And localized, participatory research can still produce technologies that are broadly adapted.

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Farmers are innovators

Donor agencies may be starting to recognize the need to move AR4D closer to a product-development approach. A 2017 USAID report on scaling up agricultural technologies noted that examples of successful commercialization "are neither those where research organizations drive the entire scaling process nor those involving sudden handoff from research organizations to commercial actors, with no further research involvement. The 'handoff' model makes insufficient allowance for the need to modify and adapt technologies iteratively in response to market responses." Successful product development requires integration of multiple stakeholders—such as social scientists, engineers, extension workers, traders or exporters, and farmers—who traditionally have not been involved in agricultural research until the product is already considered "done."

But words are not sufficient. Within the international and national research systems, incentives must be changed to encourage product-development approaches to research that are place-based and participatory. If individual scientists are evaluated based primarily on the number of journal articles they produce or the rapidity with which they can develop new crop varieties, they have no incentive—in fact, given the time required, they have a fairly strong disincentive—to work in an iterative development process. Scientists should instead be given flexibility to champion promising technologies through the development process, participating in the ways that advance that process, rather than solely focusing on advancing a research agenda, with any benefit to the client a secondary concern at best. Our research in India found that scientists wanted to work more with farmers but lacked permission from their employers, resources, or incentives to do so.

Despite decades of efforts to promote change, agricultural research for development continues to be dominated by a linear model that places scientists at one end and farmers at the other. Linear research processes are ill-suited to tackling the problems of food security and poverty reduction that are the stated justification for this billion-dollar research endeavor, but the structure and incentives of research institutions reinforce the linear model. A shift in perspective that treats agricultural technologies as products being designed for clients, instead of "best practices" determined for passive or idealized beneficiaries, would promote a more inclusive process leading to technologies better suited to address the complex socioeconomic problems at which they are aimed.

Implicit in this framing is the idea that scientists do not have a monopoly on innovation. Problem-solving is a collaborative process wherein ideas come from a range of sources: farmers, traders, extension offices, sociologists, and yes, agronomists and crop breeders. A product-development framework accepts the possibility that an identified problem, such as poverty or food security, might be best addressed with new agricultural technologies—but it might not. The avenues pursued might align with scientists' research agendas, or, again, they might not. It is not only scientists whose attitudes should change, but also the donors and research administrators across the AR4D landscape. The flexibility and uncertainty of a product-development process precludes narrowly defined objectives, and turns carefully constructed work plans associated with linear innovation models into implausible fictions. The ways success and failure are defined and measured must shift, requiring institutional innovation on the part of donors, research institutions, and the broader community of agricultural scientists.

This level of necessary disruption may seem impossible—and it may *be* impossible. But 70 years after the ideals of the Green Revolution began to take shape, a continued focus on high-tech solutions to systemic problems only exacerbates economic inequality, disempowers smallholder farmers, and restricts the range of possibilities considered for addressing the needs of millions of people. In a world of increasing food demand, increasing inequality, and changing climate, the challenges farmers face are too important to be held hostage by outmoded beliefs about the best ways to connect science and innovation to human betterment.

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Recommended reading

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