TRANSFORMING RESEARCH AND DEVELOPMENT PRACTICE TO SUPPORT AGROECOLOGICAL INTENSIFICATION OF SMALLHOLDER FARMING

Rebecca Nelson and Richard Coe

Millions of smallholder farmers face the daunting challenge of sustaining or improving productivity in the face of rising input costs, limited access to input and output markets, climate vagaries, and depleted natural resources. These farmers' objectives and circumstances are diverse, varying with both their biophysical environments and their socioeconomic and cultural contexts. Agroecological intensification (AEI), or the integration of agroecological principles into farm and system management, can improve the performance of agriculture—"performance" being locally defined and potentially including productivity, nutrition, resilience, and sustainability. In principle, AEI is relevant for all forms of agriculture, whether it is pursued as a business, as a means to support family nutrition, or for both income and self-provisioning. Conventional approaches to research and extension are, however, poorly designed to support AEI across diverse socio-ecological contexts, particularly given the weakness of research and extension systems in food-insecure parts of the world. Because agroecological principles must be implemented in a context-dependent manner and AEI is a knowledge-intensive process, delivering the benefits of AEI requires a radical reconsideration of the ways in which agricultural knowledge is produced and shared. Emerging developments in participatory methods, as well as in information and communications technologies (ICT), can contribute to innovative strategies that allow systematic matching of options—diversification strategies, crops or varieties, agronomic practices, and market arrangements—across heterogeneous contexts.

Much of the world's food is produced by farmers who cultivate two hectares or fewer.[1] Globally, there are over half a billion small farms, and smallholder farming provides livelihoods to 2.2 billion people.[2] In Africa, more than 90 percent of farmers are smallholders, and in India, over half the farms are two hectares or fewer in size. Because of their resource limitations and vulnerability to climate and other shocks, many of those who produce food do not enjoy food security; half of the world's food-insecure people are rural smallholder farmers.[3]

Rebecca Nelson is a professor of plant pathology and plant-microbe biology, plant breeding and genetics, and International Agriculture and Rural Development at Cornell University. Richard Coe is a principal scientist and research methods specialist at the World Agroforestry Centre (ICRAF), Kenya, and the University of Reading, United Kingdom.

Journal of International Affairs, Spring/Summer 2014, Vol. 67, No. 2.

Smallholder farmers face difficulties accessing markets and rely substantially on self-provisioning. It is thus of enormous importance for both global food security and poverty reduction to enhance the performance and sustainability of smallholder agriculture.

However, how best to achieve enhanced performance and sustainability of smallholder agriculture is under debate. Some propose transforming labor-intensive, semi-subsistence agriculture to modern, commercial, input-intensive agriculture, either via farm consolidation and mechanization, or by intensifying the use of external inputs with the intent of increasing productivity while maintaining small farm size.[4] Another vision emphasizes a reliance on ecological approaches and local food sovereignty.[5] Still others entail context-responsive blends of ecological and purchased inputs: fertilizers, chemicals, hybrid seeds, and tools and energy for mechanization.[6] Each of these visions implies a type of trajectory for farming practice. The purpose of the policy, research, and development systems supporting agriculture is presumably to support and nudge farms and farmers along the trajectory that is considered desirable.

It is thus of enormous importance for both global food security and poverty reduction to enhance the performance and sustainability of smallholder agriculture.

In this paper, we argue for the agroecological intensification (AEI) of smallholder farming based on the flexible matching of options with contexts, and then consider implications for how research and development (R&D) processes must change to support AEI, as well as the policies needed to effect those changes.

Problems with Energy-Intensified Agriculture in the Smallholder Context

An argument in favor of AEI must, among other things, dispute the dominant narrative that argues for "modernization" of smallholder agriculture. In an extreme version of the modernization vision, smallholder farming is in itself a problem, an archaic way of life that should be terminated in favor of more efficient and productive ways of farming. For example, Paul Collier considers support of smallholder agriculture wrong-headed and romantic. This narrative responds to the obvious success of modern, energy-intensified agriculture with the idea that it should be implemented everywhere. However, there are several reasons to be cautious about this approach, including the environmental, economic, and cultural downsides of large-scale, external input-based farming.[7]

Agricultural modernization in industrialized countries has decreased the labor intensity of agriculture largely by increasing its energy intensity. Agricultural transformation processes have produced large, labor-efficient farm operations that enable small numbers of farmers to support largely urban populations. The availability of inexpensive petrochemicals and research systems that effectively took advantage of the opportunities presented by cheap oil have fueled the agricultural innovations that have made these transformations possible. The products of these research systems have included: manufactured fertilizer formulations; crop varieties that can efficiently convert these nutrients to high yields; the means of mechanizing farm operations; and irrigation. In turn, these products have allowed farming contexts to become increasingly uniform, such that standardized farming methods can be broadly applied. But resource-constrained smallholder farmers generally cannot access the resources and investments needed to implement energy-intensive farming methods. Oil has never been cheap in Africa, global prices have quintupled in recent decades, and oil is likely to get more expensive there and elsewhere.

Modern farming methods are associated with a number of problems beyond entry barriers for smallholders. Problems with energy-intensive agriculture include aspects of performance, sustainability, and social impacts. Performance issues include the overemphasis on cereal productivity, with consequences for dietary diversity and diet quality.[9] Sustainability issues include loss of soil health, pollution associated with pesticides and fertilizer runoff, and greenhouse gas emissions, the last of which contributes to climate change. Social issues relate to the equity implications of the farm consolidation processes. Cultural issues include food preferences and other issues related to "food sovereignty," or the right of peoples to influence the nature of their food systems. For these and related reasons, there is growing interest in transforming food systems in both developed and developing countries. There is a rising conviction among policymakers, scientists, and development practitioners that smallholder-led development is not only a viable way forward, but is necessary to ensure rural poverty reduction.[10]

Agroecological Intensification of Smallholder Agriculture

In the debate about the future of agriculture and food systems, the term "sustainable intensification" is widely used.[11] Since sustainability is hard to determine and measure, this concept is quite vague. We prefer the term "agroecological intensification" (AEI) because it more clearly implies the means—ecological—by which change is intended to occur, and connotes the socio-technical context—agricultural—in which it takes place. We define AEI as improving the performance of agriculture by integrating ecological principles in farm and system management. AEI involves integrated crop, livestock, soil, pest, and system management through processes such as diversification, improved biomass and nutrient cycling, biological interactions that reduce pest and disease pressures, and synergies that maximize resource-use efficiencies and reduce risks. While modern agriculture is the art of optimized simplicity, post-modern agriculture must be the art of optimized complexity. Because of its complexity, AEI requires considerable information and knowledge. Because of its context dependency, AEI requires local adaptation and assistance from local policymakers, local NGOs, and international organizations to foster adaptive, variable approaches that shift with the different contexts. The capacity for large-scale local adaptation in turn requires new policies and approaches to supporting change in farming practices.

Commercialization has been successful in environments with relatively favorable and uniform production conditions. Markets drive the orientation of large-scale farms, so productivity and income have clear primacy for commercial farmers, even when pursuing these goals places high costs on society at large. Commercial farmers are likely to be specialized, due to the coupling of production decisions and market demand. As a cause and consequence of their links to markets, commercial farms have the resources and opportunity to invest in inputs that enable their managers to smooth environmental variability. The modern research systems serving commercial agriculture focus on improving and delivering technologies that contribute to smoothing performance, and on technologies with wide adaptation that can be distributed by relatively centralized providers. These production systems then provide substantial markets for agricultural inputs. AEI for industrialized agriculture tends to focus on improving input-use efficiencies, e.g., more precise timing and location of the application of fertilizers to coincide with crop uptake; and to shift, when possible, from input-derived services to agroecologically-derived ones, e.g., pest management based on biological interactions, rather than on the application of pesticide.[12]

AEI of smallholder farming poses a different set of challenges and constraints than AEI of industrialized agriculture. It is important to consider what "performance" means for smallholder farmers, with some reflection on how the needs of smallholders differ from those of larger-scale farmers. Smallholders are more numerous and diverse than large-scale farmers, and serving the needs of smallholders is therefore trickier. Their resource limitations often prevent them from investing in inputs that would make their holdings uniform and highly productive. The AEI options, such as diversification or germplasm management that could reduce their losses and increase their productivity, are more context-specific than inputs like synthetic fertilizers. Smallholders are more likely to be immediately dependent on their own production, which is typically vulnerable to climate and other challenges. The poorest have low resilience and cannot absorb shocks, which makes managing risk often a higher priority than maximizing production, particularly if market access is limited. Depending on the context, AEI of smallholder systems may focus on managing risks by providing households with adequate nutrition; building organic soil matter; increasing nutrient inputs and cycling; reducing pest and disease losses before and after harvest; and enhancing access to input and output markets to permit and incentivize investment.[13]

While much of the contemporary development discourse is focused on market-led development, it is important that approaches to supporting agriculture ensure food and nutritional security, as well as environmental services and sustainability, while also improving livelihoods and incomes.[14] Smallholder farmers' objectives often include both accessing markets and self-provisioning: they typically consume a portion of their harvests and sell the rest. It is rare for households to be entirely self-sufficient, but the extent of market orientation may vary among households, even in a given location.[15] In Eastern and Southern Africa, for example, approximately half of food consumed is marketed and purchased, while half is self-provisioned.[16] The reasons for self-provisioning include high transaction costs, price, risks, and possibly issues of quality or safety due to mycotoxin risk.[18] De Janvry and Sadoulet point out the importance of subsistence in protecting households from price shocks, such as those that have recurred since the 2008 food crisis.[19]

While much of the contemporary development discourse is focused on market-led development, it is important that approaches to supporting agriculture ensure food and nutritional security, as well as environmental services and sustainability, while also improving livelihoods and incomes.

Markets and AEI are not necessarily at odds, but can and should be closely aligned to ensure that sustainability and other aims are met. Agricultural value chains should be built on sound production ecology, and farmers need markets to invest in sound production ecology. When Bolivian farmers have responded to the overheated market for organic quinoa by using unsustainable production methods, they have run the risk of imperiling both production and organic markets by failing to employ the rotations that maintain soil fertility.[20] The excessive emphasis on market orientation without the integration of sustainable practices and appropriate policies benefits neither farmers nor markets. Govereh and Jayne found that among Zimbabwean smallholders, production of market-oriented crops led to greater productivity of food crops.[21] Tittonell and

Giller found that more market-oriented smallholders were better able to manage soil fertility than less market-oriented farmers, presumably because investment in soil fertility requires resources, organic and otherwise.[22] Markets need AEI and AEI needs markets. Farmers need both, and policymakers can help facilitate this.

Constraints of Current Approaches to Research and Development for the Support of AEI

There is a considerable gap between the norms of existing research and development (R&D) systems and the systems and policies needed to support AEI for smallholders. R&D systems designed to nominally support smallholders fail to do so, and AEI is neither a value nor an aim of most systems. This may be because of conceptual gaps, or because policies are not intended to support smallholder development. The way that research is conducted and recommendations are released suggests a conviction that farm conditions are uniform, and that fixed recommendations are widely applicable. Conceptual gaps may include: a lack of systems thinking about the way research is taught, organized, and conducted, which generally does not support systems-oriented analysis; the assumption of uniformity of farmer conditions; the conduct of research under conditions that do not resemble those of smallholder farmers; and the assumption that simple economic theory predicts the behavior of farmers and the uptake and impacts of technology.

Researchers who serve smallholder agriculture generally focus on a particular crop or problem, often without much consideration for how that crop or issue fits into the larger system or policy environment.[23] The researcher or research team will identify solutions—often optimal varieties or management practices, for instance. A "best bet" solution is developed under conditions that do not accurately reflect the conditions into which the technology will be deployed; research station conditions are often outliers in the sense that they are managed with greater input levels than most farmers are able to invest. Farmers' conditions—environmental, political, or economic—are indeed so diverse that it would not be possible for research stations to cover the full spectrum. Under farmers' diverse conditions, blanket recommendations are unlikely to be optimal and may be far from what farmers are interested in or able to use. Technologies of potential value to farmers, such as crop genotypes adapted to marginal conditions or varieties that are adapted to production in intercrops, get filtered out by researchers before farmers have a chance to evaluate them.[24] Many technologies cannot be assessed without close involvement of farmers, including features defined by farmer preference, taste, or opinion. Social, political, and economic evaluations, if conducted, are typically done to follow up technology adoption, rather than to inform it.

Studies conducted at a few locations that poorly represent farmers' conditions are frequently used to make a single recommendation for a large area, sometimes an entire country. Given that local conditions vary widely, these blanket recommendations are likely to be suboptimal in most locations, and even dangerous in some.[25] In the face of sweeping recommendations and without the benefit of information about agroecological principles and processes, local actors, such as farmers, non-government organizations, community-based organizations, or local businesses, are not in a position to be as innovative as they would be if they were better informed. This undermines the legitimacy of researchers and their potential contribution to agricultural policies and practice.

In the face of sweeping recommendations and without the benefit of information about agroecological principles and processes, local actors, such as farmers, non-government organizations, community-based organizations, or local businesses, are not in a position to be as innovative as they would be if they were better informed.

Research and extension services have long neglected food production oriented to home consumption.[26] Given the importance of self-provisioning for the nutrition of a large proportion of humanity, it is important to ensure that production-oriented feeding be taken seriously as an important function of agriculture. Because self-provisioning does not generate cash, it is unlikely that resource-limited farmers will invest purchased inputs in subsistence-oriented production.[27] They may or may not be able to invest ecological knowledge and labor to enhance food for home consumption, depending on their resources and capabilities. In integrated crop-livestock systems, such as the push-pull system that has been developed in Western Kenya, market-oriented livestock production provides nutrient inputs to maize production that is primarily oriented to home consumption.[28] Counterintuitively, neither increasing nor diversifying production necessarily ensures adequate child nutrition; support for agriculture must be linked to policies that promote nutrition education, with the goal of improving nutritional status.[29]

In summary, the current system is oriented to the production of sweeping scientific or policy recommendations and prescriptive packages that are, by dint of their very uniformity, unsuited to many farmers' conditions. Without institutional, political, or legal support for their own innovation processes, farmers are left with little guidance on how to optimize their production. To support local innovation and integration, researchers should take responsibility for understanding the agroecological principles and processes that determine productivity and risk, as well as the links between productivity, diversity, risk, livelihoods, sustainability, and nutrition, and how these risks play out in the political, environmental, economic, and social atmosphere. To identify practical solutions to local problems, researchers should then collaborate with local governments, instutions, actors, and NGOs to support innovation and the integration processes at the micro level.

To identify practical solutions to local problems, researchers should then collaborate with local governments, instutions, actors, and NGOs to support innovation and the integration processes at the micro level.

Information and Innovation for AEI

We have attempted to summarize some practical and conceptual inadequacies of a top-down, centralized research approach to support agroecological intensification of smallholder agriculture. Change is needed and should leverage inexpensive resources, while economizing on those that are costly.[30] In this section, we discuss approaches that can provide diverse and dynamic rural populations with relevant sets of options, upon which they can draw as their circumstances change.

In order to contribute to AEI, a systematic approach to R&D should involve identification of problems and opportunities, or diagnosis; local and global sourcing of principles and technologies that would address the diagnosis; formulation of a implementation strategy for local adaptation and innovation based on identified opportunities; and contextualized scaling of approaches. Although the steps described below are illustrated as sequential, they may be overlapping in practice, and the process may begin at different stages. Their relative importance and the weight given to each step will depend on the problem and situation. This generic approach can be used to support AEI, whether the problems and actions considered are technical, social, political, or institutional. The approach, elaborated below in greater detail, has emerged from the authors' experiences in supporting researchers in AEI-oriented research programs, and is conceptually similar to the "DEED" framework articulated by Giller.[31]

Diagnosis. The diagnostic phase goes beyond describing the extent of a particular problem to understanding the farming system and the social context in which it occurs, since these determine feasible AEI solutions. A rich collection of participatory tools is available, often described under the heading Participatory Rural Appraisal, to enable outsiders to gain insight into farmers' objectives, constraints, and incentives, as well as the social and economic diversity in a given place and over time and space.[32] But these tools are not sufficient for comprehensive diagnosis. Global scientific knowledge of processes and conditions must be combined with local understanding of the implementation constraints (including cultural, biophysical and policy constraints) if the value of knowledge is to be realized. Explicit data and models are needed to understand geographical variation, and to define the domain within which a problem will be addressed. The other steps require definition of this domain, with geographical and other limits—classification thresholds for factors, such as population density or distance to market—rigorously established.[33] Without delineating the problem domain, it is impossible to determine where the work of the other steps should be done and which actors should be involved.

Principles and technologies. In some cases, current global knowledge and technologies are sufficient to propose interventions for local adaptive work.[34] For example, strong evidence indicates that the pesticide sprays used to control rice pests in southeast Asia are unnecessary. More often, research is needed to refine and contextualize knowledge and technologies. For example, the general principles related to planting densities and geometries are well understood, but local optimization of planting configurations, determined though participatory research coordinated by informed NGOs on the ground, could result in enhanced yields.[35] Multi-environmental trials are a key tool for matching options to contexts. When designed based on geospatial and socioeconomic analyses of the problem, such trials can contribute to understanding how the principles of AEI operate in the given problem domain, and how derived technologies and other options interact within the political, institutional, or economic context.

Getting it right locally. Based on sound diagnosis and relevant principles and options, this includes local adaptive research should aim to fit broad sets of policy or technical options into specific farm contexts. This is likely to both require and support social innovation processes: local people must organize to make the most of options and to sustain the innovation process, and policies must be in place to allow this organization. As expressed in a slogan of the National Smallholder Farmers Association of Malawi, "the future belongs to the organized."[36] Local adaptation involves the testing of options by farmers with the multiple aims of adapting details, seeking innovation, training, and learning.[37] Details of the relative roles of farmers; farmer organizations; NGOs and extension institutional, political or legal organizations; and researchers must be carefully constructed and negotiated to empower farmers to address the issues of greatest relevance to them. Rather than dictating outcomes, researchers should provide access to multiple options, increase choice, and seek to understand outcomes, such as drivers of local performance and decision-making. Farmers, working in groups with institutional or government support or as individuals, should prioritize options, conduct coordinated trials to explore the consequences of knowledge-based choices, analyze results, and adjust farming practices.

Contextualized scaling. In current practice, scaling is often simply replicating a successful pilot effort. Given the importance of context, replication is a dubious basis for seeking impact at scale. Hancock points out that impact at scale entails ongoing adaptation with wider participation; building conviction among stakeholders that change is needed, possible, and imperative; and strategic policy reform.[38] Because of the important differences among farmers' contexts, it is more useful to think of scaling as iteration of the earlier steps to increase the geographical extent and to expand the numbers and types of farms or farmers involved. Increasing scale will introduce new questions and constraints that will need to be investigated using a research perspective. The localized and adaptive research will be repeated, while additional questions, such as group formation or input supply channels are addressed. Rather than considering research and extension or pilot and scaling to be distinct phases, these should all be considered ongoing, adaptive research at different scales. All efforts should generate robust information for the global knowledge base.

Heterogeneous Contexts and Option-by-Context Interactions

Variation in Context. A principal reason for the step-wise approach outlined in the previous section is the very high level of heterogeneity in smallholder farming systems.[39] Matching options to these diverse contexts requires an understanding of diversity. Suitable tools exist for this. Some of the variability among smallholder farms can be understood at larger scales and is captured, if quite crudely, in farming systems classifications. Major agroecological zones are defined, for example, by landforms, soils, and climate.[40] Some larger-scale social differences are captured in related classification schemes, such as development domains.[41] These reflect differences in distances to market, which presumably influence access to input and output markets, length of the growing season as a proxy for agricultural favorability, and population density. Such analyses are informative for national and regional scale planning, but may only explain a relatively small proportion of variance in suitability of any practice for individual farmers.[42] Policy and support environments are not included, nor are individual differences among farms.

At finer scales, biophysical heterogeneity can be understood through analysis of soils because better data at high resolution are increasingly available.[43] Differences among farmers are often associated with differences in resources and market orientation.[44] Availability of labor and credit can influence farmers' opportunities. These factors can be measured and their influence on farmers' choices described and modeled. More difficult to understand, but equally important, are variations in individual objectives, tastes, and preferences.

Various frameworks have been assembled to describe this heterogeneity for specific purposes, such as soil fertility management.[45] It is hard to imagine a framework that will serve every purpose; a framework appropriate for developing soil fertility management options will be very different from one for diversifying grain production or introducing fruit cultivation. Patterns of heterogeneity described are dynamic, changing in response to drivers that operate at different time and space scales. An R&D system cannot expect one-off stratifications, such as traditional agro-ecological zoning (AEZ) and farming systems delineations, to meet their needs for understanding and responding to variation in context. Rather, we need to describe context through dynamic characterization tuned to specific purposes.

Amartya Sen argued that development should be seen as expanding human freedoms.

AEI Options and Interactions with Context. Amartya Sen argued that development should be seen as expanding human freedoms.[46] Applying that view to agricultural research would imply that agricultural R&D systems should aim to increase the choices or options available to farmers and consumers. By options, we refer very generally to the technologies, policies, and institutional arrangements that farmers and farm communities can use to meet their objectives. Use of the term does not imply anything about the relative roles of farmers and others in the process of innovation and testing that leads to useful options. Options range from technologies like new crop varieties and agronomic practices to more radical systems changes, and can be grouped under types of interventions or levers, such as crop improvement; soil and water management; pest and disease management; diversification at plot, farm, and landscape scale; agroforestry; post-harvest handling; value chain development; international agency or local NGO support to farmer organizations; and nutrition education.

For each of these interventions, approaches can involve agroecologically-informed systems thinking to a greater or lesser extent. As AEI aims to reduce risk to farmers, a multiplicity of options will be needed for any problem, supporting an increase in diversity at some scale. Large variation is typically found when options are evaluated with farmers under their own conditions, using whatever performance criteria are relevant, such as productivity, risk, economic value, acceptability, contribution to food security, or nutrition. It has long been noted that data from on-farm trials are variable.[47] This variation is not simply noise, however, to be averaged out with all inferences being based on means. Examination of data typically shows that differing performance of options depends to an important extent on context. For example, plant breeders have long recognized genotype-by-environment (GxE) interaction in yield or other performance measures and developed tools to investigate it and exploit it.[48] The best variety in one context is not the best in another. Similarly, crop management options interact with contexts; the response of maize to nitrogen fertilizer depends on the amount of organic matter in the soil, an example of management-by-environment interaction.[49] Such interactions are general and can be further expanded.[50] This leads to the more general concept of option x context (OxC) interactions.

Tools for understanding OxC interaction include multi-environment trials, process-based models—crop simulation models, for instance—and surveys. Each of these has limitations, and ideally they are used together. Learning from models requires that processes are already understood in sufficient detail to build the model. Surveys can reveal what farmers currently do; comparisons between options often are confounded with differences in context. In principle, multi-environment trials can be designed and implemented at any scale and with any balance of roles of farmers, researchers, and development practioners. In practice, larger scale trials will need to use information technology to be feasible.

Design of efficient multi-environment trials requires hypotheses regarding the nature of OxC interactions. Contextual factors that interact with option performance can be grouped into three categories. Some factors vary in a predictable way in space, and the output of METs would be geographical areas to which different sets of options are adapted. Such "mappable" factors include soil, landform, and climate features. Other factors are predictable but not mappable, such as social factors. Results of interaction of predictable but non-mappable contexts with options are refined recommendations. Still other factors are not predictable. Results of interactions of options and unpredictable contexts need to be described as risks. Whether performance is measured by biophysical, social, or economic criteria, a systems perspective is needed when considering options and hypothesized OxC interactions. For example, if the problem in focus is disease of a staple crop, then options can include deploying resistant varieties of that crop, management that reduces disease pressure, or switching to an alternative crop. Considering only the system components may unnecessarily limit changes that could be beneficial to farmers.

What is New?

Description of the R&D steps above may prompt the question 'So what is new?'. Many of the components of the steps have been described and used in one form or another for a long time. Descriptions of the complexity of farming systems and understanding their problems was the heart of the 'farming systems research' methods of the 1980s.[51] The term 'diagnosis' for generating a detailed understanding of problems has been used at least since the same time.[52] Stakeholder participatory methods have been used and described for all these steps since the early 1990s.[53] The steps have been compiled into packages with a particular focus and branded.[54] So the first answer is that not much is new, but as R&D systems are not currently supporting AEI, there is a need to bring together the concepts of what it takes to do so. Adopting the steps outlined is not sufficient to support AEI, which is still a strategic decision for agricultural planners. But the steps are necessary.

Considering only the system components may unnecessarily limit changes that could be beneficial to farmers.

A powerful framework for evaluating the effectiveness of an R&D system considers the following dimensions of salience: focus on a relevant topic or problem; credibility, meaning producing knowledge that is robust and valid; and legitimacy, where players are accepted by decision makers as having a role.[55] Considering each of our four steps on these three dimensions suggests that what is new is bringing them all together and emphasizing all evaluation dimensions in each step in a manner that appropriately engages rural people and enhances their freedom and self-determination. This stands in contrast to some current systems that give very different weight to each criterion at each stage; credibility typically drives research on principles and technology development, but when it comes to scaling, legitimacy trumps all, and credibility is not considered.

Other distinctive emphases emerging in this and related thinking include:

1. Explicit recognition of ecological, social, and economic variation at all scales, and the way they interact with farmer options.
2. Links to the global scientific knowledge base at all stages. The status quo often does not use scientific knowledge effectively at the stages of local

adaptation and scaling. This is most noticeable in development work led by organizations guided by ideology and inspiration rather than by reflection on evidence.[56] Therefore, it is critical that development organizations adopt a more scientific approach as well, or at least work better with researchers to ensure their work is motivated not by ideology, but by data. The idea that the local adaptation and scaling activities can be done in a way that contributes to the global scientific knowledge base is also relatively novel. Doing research within traditional 'development' projects that focus on bringing about change at scale is possible.[57]

A participatory approach that draws on farmers' own social technical capital with support from local institutions or international organizations, as outlined below, may be one way forward.

3. The notion that 'moving to scale' or 'scaling up' does not mean that research and the scientific approach is no longer needed. We would be happy to see the term 'scaling up' dropped and replaced with one that describes the concept of research and linked activities being defined by the scale at which a problem is identified and solutions sought. The trick will be to effectively embed a learning process in a widening innovation process. This is very different from the current assumption that research must only be undertaken one time and then is ready for extension, or that there are technologies 'on the shelf' waiting to be rolled out to farmers.
4. Linking social and technical innovation processes to give rural people better access to global knowledge and options as well as relevant—often local—data on technical performance of options by contexts. Ideally, this will enable the massively parallel production of information about technology performance across contexts.
5. A pragmatic view of intensification that draws on agroecological principles and practices, without demonizing or discouraging the use of external inputs, as available and appropriate. A recent example is the recognition that conservation agriculture on its own will often not meet soil fertility requirements without the use of fertilizer.[58]

Arguments against adopting such R&D systems might reasonably focus on the limitations of resources and human capacities to carry them forward. The costs and skill requirements are intimidating for two reasons. First, the skills in both technical research capability and in facilitation and participation are needed in all steps, but are in limited supply. Second, much of the effort on the ground must be undertaken across locations. Exactly what this means and how local work should be done requires more analysis. However, the analysis must depend on the problem context and the heterogeneity within the problem domain. A participatory approach that draws on farmers' own social technical capital with support from local institutions or international organizations, as outlined below, may be one way forward.

Farmer Research Networks as a New Paradigm for Research and Development

It is difficult to imagine the current R&D system obtaining the needed evidence base for AEI and delivering relevant and effective extension messages to serve resource-constrained smallholder farmers in diverse environments. The enormity of the task, coupled with the resource-strapped realities faced by researchers and extension personnel, make this equation seem unsolvable under the existing assumptions that researchers can solve problems and develop appropriate technologies, while institutions on the ground can deliver the goods. This is simply not a viable model. More decentralized and participatory approaches facilitated by NGOs, together with low-cost sensor technologies and information sharing via information and communications technologies (ICT), have the potential to generate an explosion of local and global knowledge that could improve the performance of smallholder agriculture. Perhaps more importantly, approaches to agricultural innovation that focus on linking farmers with one another and with wider sources of information and technology have the potential to transform the rural experience. This is now possible due to the meteoric increase in access to cell phones and the Internet, even in rural areas.[59]

Given the context dependency of AEI, it should be worked out in the context in which it will be expected to perform. New strategies and policies are needed that promote local innovation and allow diverse options to be considered, adapted, and combined in ways that meet farmers' complex and diverse needs and opportunities, with support from local institutions and governing bodies. Criteria for successful strategies include: the potential for large-scale engagement of rural people and farms that represent the important social and biophysical variability; the institutional capacity to provide effective suites of options to farmers; the rigorous evaluation of options across contexts; and the capacity to provide actionable and useful information based on this evaluation, perhaps facilitated by organizations that have the economic means that the resource-strapped smallholder farmers lack. Farmer research networks may be a type of approach that could meet these criteria.

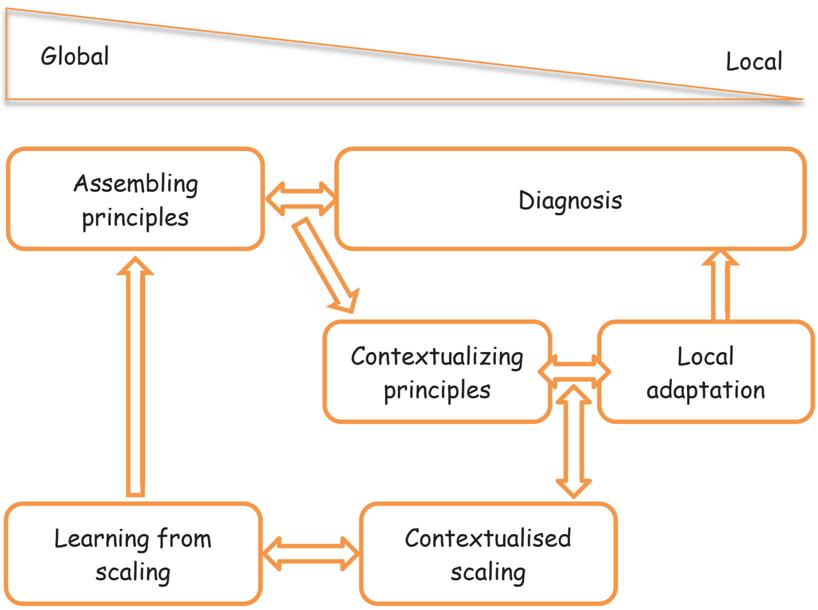
Farmer-participatory research methods have been developed to address many of the issues raised in this paper. Participatory methods have been discussed and practiced for decades, and typologies of participation have been developed to characterize the relative roles of farmers and researchers.[60] Although research and extension approaches still tend to be top-down, there are several examples of participatory approaches that have been implemented at substantial scale. These typically entail work with farmer research groups who undertake experimentation in collaboration with research and extension partners, well-funded NGOs, or international aid organizations who have better access to the information and technology of the researchers, for example farmer field schools (FFS) and local agricultural research committees.[61] These and other models for farmer participatory research vary in: the extent of experimentation; more demonstration versus more extensive trialing of unknown material; the inclusiveness of community participation, e.g., whether trials are conducted by elite farmers or broader groups who represent the diversity of the community; and the intensity of the interaction among farmers, extension and facilitation groups, and research personnel. Participatory approaches are widely used in development, but practiced at a nominal level, if at all, in many national agricultural research programs.

The FFS that have been conducted in Asia, Latin America, and Africa have been used primarily as a participatory extension approach.[62] That is, farmer groups conduct experiments to learn about agroecological principles and practices, but the findings of the tens of thousands of FFS experiments have contributed little to the global knowledge base. The farmer research network concept would aim to implement FFS-type learning and experimentation approaches, but with greater emphasis on negotiation of the research agenda and sharing of research results among various interested organizations and farmers. With the increasing availability of sensor and communications technologies, it should now be possible for farmer researchers to gather and share data on the performance of agricultural options. Exploration of the possibilities will require investments in social innovation processes to fully engage and inspire rural communities, as well as in the relevant technical processes, including those that allow for the collective management, interpretation, and sharing of large, participatory datasets.

Conclusions

The food security of millions of smallholder farmers is poorly served by contemporary approaches to research and development. Much of the current development discourse and investment is focused on modernizing smallholder agriculture in developing countries. Modernity, in this context, is energy-intensive agriculture in which human labor and organic inputs are replaced by fertilizers and mechanization based on fossil fuels. Although much is being invested in fertilizer subsidies, there is emerging evidence that such subsidies are not financially sustainable and that they do little to benefit either farmers or consumers in the long run.[63] Farmers need technologies that work under their environmental, economic, political, and institutional circumstances. This article has illustrated that agroecological intensification approaches must be developed in tandem with local institutions to improve productivity, sustainability, and nutrition. Participatory approaches, practiced on a wide scale and using new information and communications technologies, have the potential to better match AEI options to diverse contexts in order to improve system performance through the integration of agroecological principles. There is a need to change the way research and development systems work in support of smallholders to realize this potential.

Figure 1 shows the conceptual framework for an approach to improving agricultural performance by contextualized scaling based on the implementation of agroecological principles. A cycle of local implementation involves a diagnosis of local priorities, global sourcing of relevant agroecological and intensification principles, and local adaptation. Based on the results of local adaptation, successes and lessons learned are taken into account and utilized when the cycle is repeated elsewhere.



Acknowledgements

The framework and issues discussed in this paper have emerged from work conducted as part of the Collaborative Crop Research Program (ccrp.org), a grants program funded by the McKnight Foundation and the Bill & Melinda Gates Foundation. These ideas have been elaborated, discussed, and practiced with a group of colleagues, including Jane Maland Cady, Carlos Barahona, John Lynam, Richard Jones, Bettina Haussmann, Marah Moore, Claire Nicklin, and others.

NOTES

1 Anna Barnett, Ethel del Pozo-Vergnes, and Bill Vorley, "Small Producer Agency in the Globalised Market: Making Choices in a Changing World" (International Institute for Environment and Development, London: 2012).

2 Sukhpal Singh, "Policy: The Woes of Rural Wage Labor," *Capacity.org*, 24 March 2012, http://www.capacity.org/capacity/opencms/en/topics/value-chains/the-woes-of-rural-wage-labour.html.

3 Marc Cohen, Cristina Tirado, and Noora-Lisa Aberman, "Impact of Climate Change and Bioenergy on Nutrition" (International Food Policy Research Institute/Food and Agriculture Organization, Rome: 2008).

4 "Abuja Declaration on Fertilizer for the African Green Revolution" (report, African Development Bank Group, 12 June 2006), http://www.afdb.org/en/topics-and-sectors/initiatives-partnerships/african-fertilizer-financing-mechanism/abuja-declaration/.

5 "From Maputo to Jakarta: 5 Years of Agroecology in La Via Campesina" (report, La Via Campesina, International Commission on Sustainable Peasant Agriculture, June 2013), http://viacampesina.org/downloads/pdf/en/De-Maputo-a-Yakarta-EN-web.pdf.

6 B. Vanlauwe et al., "Integrated Soil Fertility Management: Operational Definition and Consequences for Implementation and Dissemination," *Outlook on Agriculture* 39, no. 1 (March 2010), 17–24.

7 Paul Collier, "The Politics of Hunger: How Illusion and Greed Fan the Food Crisis," *Foreign Affairs* 87, no. 6 (November/December 2008), http://www.foreignaffairs.com/articles/64607/paul-collier/the-politics-of-hunger.

8 "FAOSTAT" (program, Food and Agriculture Organization of the United Nations), http://faostat.fao.org/.

9 T.S. Jayne et al., "Patterns and Trends in Food Staples Markets in Eastern and Southern Africa" (working paper, MSU International Development, 2010), http://ideas.repec.org/p/ags/midiwp/62148.html.

10 Ibid.

11 "Investing in Sustainable Agricultural Intensification: The Role of Conservation Agriculture, A Framework for Action" (report, FAO, Rome: 2008).; T. Garnett et al., "Sustainable intensification in Agriculture: Premises and Policies," *Science* 341, no. 6141 (5 July 2013), 33–34, http://sbc.ucdavis.edu/files2/Garnett-Sustainable intensification-premises and policies-Science-2013.pdf; "Sustainable Intensification: A New Paradigm for African Agriculture" (report, The Montpellier Panel, London: 2013); Jules Pretty, Camilla Toulmin, and Stella Williams, "Sustainable Intensification in African Agriculture," *International Journal of Agricultural Sustainability* 9, no. 1 (2011), 5–24.

12 X-P. Chen et al., "Integrated Soil-Crop System Management For Food Security," *Proceedings of the National Academy of Sciences of the United States of America* 108, no. 16 (19 April 2011), 6399–6404; Fred Magdoff, "Ecological Agriculture: Principles, Practices, and Constraints," *Renewable Agriculture and Food Systems* 22, no. 2 (2007), 109-117.

13 Sieglinde Snapp et al., "Biodiversity Can Support a Greener Revolution in Africa," *Proceedings of the National Academy of Sciences of the United States of America* 107, no. 48 (2010), 20840–20845; Richard Coe and Roger Stern, "Assessing and Addressing Climate-induced Risk in sub-Saharan Rainfed

Agriculture: Lessons Learned," *Experimental Agriculture* 47, no. 2 (2011), 395–410.

14 Helen Markelova et al., "Collective Action for Smallholder Market Access," *Food Policy* 34, no. 1 (February 2009), 1-7; "8 Views for the G8: Business solutions for African Smallholder Farmers to Address Food Security and Nutrition" (report, Agriculture for Impact: May 2013), https://workspace.imperial.ac.uk/africanagriculturaldevelopment/Public/8ViewsG8-Report_FINAL.pdf.

15 Pablo Tittonell et al., "The Diversity of Rural Livelihoods and Their Influence on Soil Fertility in Agricultural Systems of East Africa – A typology of Smallholder Farms," *Agricultural Systems* 103, no. 2 (February 2010), 83–97.

16 Thomas A. Reardon et al., "Five Inter-Linked Transformations in the African Agrifood Economy: Food Security Implications" (background paper, Optimism for African Agriculture and Food Systems, Addis Ababa, Ethiopia: 2013), http://www.merid.org/Africanagricultureandfoodsystems/~/media/Files/Projects/Africa%20Ag%20and%20Food%20Systems/Thomas%20Reardon%20Paper%20Quiet%20Revolution%20African%20Agrifood%20systems.pdf.

17 Sally Brooks et al., "Environmental Change and Maize Innovation in Kenya: Exploring Pathways in and out of Maize" (STEPS working paper 36, Brighton, UK: 2009).

18 Steven Were Omamo, "Farm-to-market Transaction Costs and Specialisation in Small-Scale Agriculture: Explorations with a Non-separable Household Model," *Journal of Development Studies* 35, no. 2 (1998), 152–163.

19 Alain de Janvry and Elisabeth Sadoulet, "Subsistence Farming as a Safety Net for Food-price Shocks," *Development in Practice* 21, no. 4-5 (29 June 2011), 472–480.

20 Sven-Erik Jacobsen, "The Situation for Quinoa and Its Production in Southern Bolivia: From Economic Success to Environmental Disaster" *Journal of Agronomy and Crop Science* 197, no. 5 (October 2011), 390–399.

21 Jones Govereh and T.S. Jayne, "Cash Cropping and Food Crop Productivity: Synergies or Trade-offs?" *Agricultural Economics* 28, no. 1 (January 2003), 39–50.

22 Pablo Tittonell, and Ken Giller, "When Yield Gaps are Poverty Traps: The Paradigm of Ecological Intensification in African Smallholder Agriculture," *Field Crops Research* 143 (1 March 2013), 76-90.

23 E. Suzanne Nederlof and Constant Dangbégnon, "Lessons for Farmer-oriented Research: Experiences from a West African Soil Fertility Management Project," *Agriculture and Human Values* 24, no. 3 (2007), 369–387.

24 K.D. Joshi, Bhuwon Sthapit, and J.R. Witcombe, "How Narrowly Adapted Are The Products Of Decentralised Breeding? The Spread Of Rice Varieties From A Participatory Plant Breeding Programme In Nepal," *Euphytica* 122, no. 3 (December 2001), 589–597; J.R. Witcombe et al., "Participatory Plant Breeding Is Better Described As Highly Client-Oriented Plant Breeding. I. Four Indicators of Client-Orientation in Plant Breeding," *Experimental Agriculture* 41, no. 3 (2005), 299–319; J.C. Dawson et al., "Decentralized Selection And Participatory Approaches In Plant Breeding For Low-Input Systems," *Euphytica* 160, no. 2 (2007), 143–154.

25 Brian Keating, B.M. Wafula, and Robert McCown, "Simulation Of Plant Density Effects On Maize Yield As Infuenced By Water And Nitrogen Limitations," *Proceedings of the International Congress of Plant Physiology,* New Delhi, India, (547–559).

26 de Janvry and Sadoulet, 472–480.

27 Boughton et al., 38.

28 Hugo De Groote et al., "Economic Analysis Of Different Options In Integrated Pest And Soil Fertility Management In Maize Systems Of Western Kenya," *Agricultural Economics* 41, no. 5 (September 2010), 471-482.

29 Alan D. Dangour, Eileen Kennedy, and Anna Taylor, "Commentary: The Changing Focus For Improving Nutrition," *Food and Nutrition Bulletin* 34, no. 2 (July 2013), 194–198; Corinna Hawkes and Marie Ruel, "Understanding The Links Between Agriculture And Health: Overview" (Brief 1 of 16, Focus 13, International Food Policy Research Institute, Washington, DC: May 2006).

30 John Hicks, *The Theory of Wages* (London: Macmillan, 1932).

31 Ken Giller et al., "Communicating Complexity: Integrated Assessment Of Trade-Offs Concerning Soil Fertility Management Within African Farming Systems To Support Innovation And Development," *Agricultural Systems* 104, no. 2 (February 2011), 191–203.

[32] Robert Chambers, "The Origins And Practice Of Participatory Rural Appraisal," *World Development* 22, no. 7 (July 1994), 953–969; Andrea Cornwall and Garett Pratt, "The Use And Abuse Of Participatory Rural Appraisal: Reflections From Practice," *Agriculture and Human Values* 28, no. 2 (June 2011), 263–272.

[33] Jordan Chamberlin, John Pender, and Bingxin Yu, "Development Domains for Ethiopia" (report, International Food Policy Research Institute, Washington DC: November, 2006), http://www.ifpri.org/sites/default/files/publications/dsgdp43.pdf.

[34] K. L. Heong et. al., "Use Of Communication Media In Changing Rice Farmers' Pest Management In The Mekong Delta," *Crop Protection* 17, no. 5 (July 1998), 413-425.

[35] R. W. Willey and S. B. Heath, "The Quantitative Relationships Between Plant Population And Crop Yield," *Advances in Agronomy* 21 (1966).

[36] David Lane, "In Malawi, the Future Belongs to the Organized" (DIPNOTE, U.S. Department of State Official Blog, Washington, DC: 25 January 2013), http://blogs.state.gov/stories/2013/01/25/malawi-future-belongs-organized.

[37] Richard Coe et al., "Designing Participatory On-Farm Experiments: Resources for Training" (report, World Agroforestry Centre, Nairobi, Kenya: 2003), 135.

[38] Jim Hancock et al., "Scaling-Up the Impact of Good Practices in Rural Development: A Working Paper To Support Implementation Of The World Bank's Rural Development Strategy" (working paper, World Bank, Washington, DC: 2003), https://openknowledge.worldbank.org/bitstream/handle/10986/14370/260310White0co1e1up1final1formatted.pdf?sequence=1.

[39] Duncan Boughton and Thomas Jayne, "Smallholder Heterogeneity And Maize Market Participation In Southern And Eastern Africa" (working paper, Food Security International Development, Michigan State University, East Lansing, Michigan: October 2011); Pablo Tittonell, 83–97; Pablo Tittonell et al., "Exploring Diversity In Soil Fertility Management Of Smallholder Farms In Western Kenya," *Agriculture, Ecosystems and Environment* 110, no. 3-4 (November 2005), 166–184.

[40] John Dixon et al., "Forty Years Of Farming System Classification For Enhanced Food Security And Poverty Reduction," *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources* 4, no. 6 (2009), 1–16.

[41] Stanley Wood et al., "Spatial Aspects Of The Design And Targeting Of Agricultural Development Strategies" (report, International Food Policy Research Institute, Washington, DC: 1999)

[42] Chamberlin, Pender, and Yu, (2006).

[43] "Data and Map Portal" (report, Africa Soil Information Service, 2014), http://www.africasoils.net/home.

[44] Pablo Tittonell et al., 83–97.

[45] Giller et al., 191–203.

[46] Amartya Sen, *Development As Freedom* (New York: Oxford University Press, 1999).

[47] H.J.W. Mutsaers, "Farmers' Maize Yields In S.W. Nigeria And The Effect Of Variety And Fertilizer: An Analysis Of Variability In On-Farm Trials," *Field Crops Research* 23, no. 3-4 (June 1990), 265–278.

[48] Paolo Annicchiarico, "Genotype x Environment Interactions-Challenges and Opportunities for Plant Breeding and Cultivar Recommendations" (report, FAO, Rome: 2002), http://www.fao.org/DOCREP/005/Y4391E/Y4391E00.HTM#Contents.

[49] Paswel Marenya and Christopher Barrett, "State-Conditional Fertilizer Yield Response on Western Kenyan Farms," *American Journal of Agricultural Economics* 91, no. 4 (2009), 991–1006.

[50] D. Desclaux et al., "Changes In The Concept Of Genotype × Environment Interactions To Fit Agriculture Diversification And Decentralized Participatory Plant Breeding: Pluridisciplinary Point Of View," *Euphytica* 163, no. 3 (2008), 533–546.

[51] Willis Shaner, Perry Fred Philipp, and W.R. Schmehl, *Farming Systems Research And Development: Guidelines For Developing Countries* (Boulder, Colorado: Westview Press, 1982).

[52] J.B. Raintree, "A Methodology For Diagnosis And Design Of Agroforestry Land Management Systems" (report, World Agroforestry Centre, Nairobi, Kenya: January 1983).

[53] Christine Okali, James Sumberg, and John Farrington, "Farmer Participatory Research: Rhetoric

And Reality" (report, Overseas Development Institute, Intermediate Technology Publications, London: 1994), 159.

54 DEED; Giller et al., 191–203.

55 David Cash et al., "Knowledge Systems For Sustainable Development," *Proceedings of the National Academy of Sciences of the United States of America* 100, no. 14 (July 2003), 8086–91.

56 Jens Andersson and Ken Giller, "On Heretics And God's Blanket Salesmen: Contested Claims For Conservation Agriculture And The Politics Of Its Promotion In African Smallholder Farming," *Contested Agronomy: Agricultural research in a Changing World,* ed. James Sumberg and John Thompson (London: Earthscan, 2012).

57 Richard Coe, Fergus Sinclair, and Edmundo Barrios, "Scaling Up Agroforestry Requires Research 'In' Rather Than 'For' Development," *Current Opinion in Environmental Sustainability* 6 (February 2014), 73–77.

58 Bernard Vanlauwe et al., "A Fourth Principle Is Required To Define Conservation Agriculture In Sub-Saharan Africa: The Appropriate Use Of Fertilizer To Enhance Crop Productivity," *Field Crops Research* 155 (January 2014), 10–13.

59 Madanmohan Rao, *Mobile Africa Report 2011: Regional Hubs of Excellence and Innovation* (Mobile Monday, Johannesburg, 2011).

60 Stephen Biggs and John Farrington, "Agricultural Research And The Rural Poor: A Review Of Social Science Analysis" (report, International Development Research Centre, Ottawa, Canada: 1991); N. Lilja and Mauricio Bellon, "Some Common Questions About Participatory Research: A Review of the Literature," *Development in Practice* 18, no. 4 (2008), 479-488.

61 Ann Braun, Graham Thiele and María Fernández, "Farmer Field Schools And Local Agricultural Research Committees: Complementary Platforms For Integrated Decision-Making In Sustainable Agriculture" (working paper, Agriculture Research and Extension Network, July 2000), http://www.odi.org.uk/sites/odi.org.uk/files/odi-assets/publications-opinion-files/8195.pdf.

62 Ann Braun et al., "Farmer Field Schools And Local Agricultural Research Committees: Complementary Platforms For Integrated Decision-Making In Sustainable Agriculture," *AgREN* 105 (2000), 1–19.

63 Boughton.