



Agricultural innovation for smallholders in sub-Saharan Africa

Steve Wiggins, Dominic Glover and Alex Dorgan

July 2021

degrp.odi.org

[@degrp_growth](https://twitter.com/degrp_growth)

About DEGRP

The Development and Economic Growth Research Programme (DEGRP) funds world-class scientific research on inclusive economic growth in low-income countries (LICs). The programme's principal aim is to generate policy-relevant research on four key areas: financial sector development and growth; agriculture and growth; innovation and growth; and China's engagement in sub-Saharan African countries.

Readers are encouraged to reproduce material from DEGRP publications for their own outputs, as long as they are not being sold commercially, and as long as there is due acknowledgement. For online use, we ask readers to link to the original resource on the DEGRP website.

Cover image: One Acre Fund staff delivering inputs of seed and fertiliser to farmers in Kayenzi, Kamonyi District, west of Kigali in Rwanda, 2012. Credit: Used with kind permission from the One Acre Fund.

Suggested citation: Wiggins, S., Glover, D. and Dorgan, A. (2021) *Agricultural innovation for smallholders in sub-Saharan Africa*. DEGRP Synthesis Report. London: ODI.

About the authors

Alex Dorgan is PhD candidate at the University of Sheffield.

Dominic Glover is Fellow of the Institute of Development Studies (IDS), Brighton.

Steve Wiggins is Principal Research Fellow at ODI, UK.

Acknowledgements

The authors would like to thank participants of the agricultural innovation roundtable held on 15 April 2021 for their time, insights and feedback. They were: Andy Hinsley, Growth Research Team Leader, Foreign, Commonwealth & Development Office (FCDO); Arjan Verschoor, Professor of Economics, School of International Development, University of East Anglia; Beverley Leahy, Portfolio Manager, International Development, Economic & Social Research Council (ESRC); Chris Udry, King Professor of Economics, Co-director Global Poverty Research Lab, Buffett Institute for Global Studies, Northwestern University; Christine Okali Independent Research Professional; Douglas Gollin, Professor of Development Economics, Department of International Development, Oxford University; Howard Standen, Climate Change & Food Security Adviser, Agricultural Research Team, Research & Evidence Division, FCDO; James Sumberg, Research Fellow, IDS; Joanna Francis, Livelihoods Advisor, FCDO; John Piper Senior Economic Adviser, FCDO; Karen Macours, Professor, Paris School of Economics; Maarten Voors, Associate Professor, Development Economics Group, Wageningen University; Philip Woodhouse, Professor, Global Development Institute, University of Manchester; Robert Lensink, Professor of Finance & Financial Markets, University of Groningen; and, Ruth Meinzen-Dick, Senior Research Fellow, International Food Policy Research Institute.

We particularly thank Saweda Liverpool-Tasie, Michigan State University, for detailed written comments on a previous draft of this report.

We benefitted considerably from the leading researchers that we interviewed: Ousmane Badiane, Chris Barrett, Ken Giller, Doug Gollin, Andy Hall, Thom Jayne, Ian Scoones, Melinda Smale, Jim Sumberg and John Thompson

Emilie Tant, Aaron Bailey-Athias, Amanda Jones, Harriet Flower and Louise Shaxson provided project management and communications support.

All views and opinions expressed in this report, however, are those of the authors, and do not necessarily represent the position or policy of the ODI or the programme's funders, the FCDO and the ESRC.

CONTENTS

About the authors	3
Acknowledgements	3
Acronyms	7
Executive Summary	8
1 Introduction: agricultural innovation and development	13
2 Method	21
3 Findings	24
4 Conclusions	60
References	65

LIST OF BOXES

Boxes

Box 1	A new conceptual framework for understanding technological change: PEDR	17
Box 2	The promise of innovations for the future	24
Box 3	How complicated and complex are agricultural innovations?	28
Box 4	Yield gaps: terms and definitions	30
Box 5	What factors lead to on-farm yield gaps?	32
Box 6	Male and female farmers as innovators	35
Box 7	Farmers' learning in variable local conditions	36
Box 8	Lessons from the Kivus on farmer-to-farmer dissemination	40
Box 9	The value of timely advice in coping with agricultural problems	42
Box 10	Testing better ways to provide information to farmers in northern Ghana	43
Box 11	Do medium and large-scale farms encourage innovation by smallholders?	47
Box 12	Risk for farmers in eastern Uganda	49
Box 13	Packaging insurance and credit for farmers in Kenya and Ethiopia	52
Box 14	Collective tenure in Ethiopia	59
Box 15	Land reform in China: allowing farmers to lease land	59

LIST OF FIGURES AND TABLES

Figures

Figure 1	Increases in world agricultural output (broken down by source)	14
Figure 2	Modelled impact on poverty of a 1% increase in productivity in agriculture, industry and services	14
Figure 3	Yield gaps	29
Figure 4	Expected returns to different crops in eastern Uganda, 2013	49

Tables

Table 1	DEGRP studies on agricultural innovation	19
Table 2	Studies in the 2010s of land tenure and innovation	57

Acronyms

ADOPT	Adoption and Diffusion Outcome Prediction Tool
AEZ	agro-ecological zone
AIS	Agricultural Innovation Systems
ASAT	Agricultural Sustainability Assessment Tool
CGIAR	An inter-governmental consortium for agricultural research, formerly known as the Consultative Group for International Agricultural Research
CIMMYT	International Maize and Wheat Improvement Center, part of the CGIAR
CRISPR	Clustered Regularly Interspaced Short Palindromic Repeats
DEGRP	DFID-ESRC Growth Research Programme
DFID	Department for International Development
DIRTS	Disseminating Innovative Resources and Technologies to Smallholders
DNA	deoxyribonucleic acid
DRC	Democratic Republic of the Congo
ESRC	Economic and Social Research Council
FCDO	Foreign, Commonwealth & Development Office (UK government)
FFS	farmer field schools
FOB	free-on-board
FPR	farmer participatory research
FSR	farming systems research
GDP	gross domestic product
GM	genetically modified – and transgenic
IFAD	International Fund for Agricultural Development
LIC	low-income country
NGO	non-governmental organisation
PEDR	propositions, encounters, dispositions and responses
PROMIS	Practice-Oriented Multi-level Perspective on Innovation and Scaling
SME	small- and medium-scale enterprise
SPIA	Standing Panel on Impact Assessment
SSA	sub-Saharan Africa
SUM	scaling up management
T&V	Training and Visit
ToS	theory of scaling
TOT	transfer-of-technology

Executive Summary

Background, aims and methods

Without innovation, farmers would struggle to raise production and productivity. Innovation explains in part why more food per capita is produced in 2020 than in 1960, despite rapid population growth. Innovation increasingly contributes to agricultural growth: since 1990, most agricultural growth has come from rising (total factor) productivity, made possible by innovation.

Technical innovations do not just drive production. They can raise the farm incomes of smallholders: in low-income countries (LICs) productivity gains in agriculture do more to reduce poverty than those in industry or services. Innovation potentially conserves resources and can make agriculture sustainable. In sub-Saharan Africa (SSA), agricultural innovation is especially important.

When FCDO and ESRC commissioned research into agricultural development in 2011 and 2015, of the 18 agricultural studies approved, no fewer than ten addressed questions of innovation – and another three dealt with irrigation, itself often the single largest innovation most crop farmers ever undertake (Wiggins and Lankford, 2019). The ten studies variously mainly concern the obstacles facing farmers when trying to innovate and potential ways to overcome them.¹

This synthesis aims to summarise the results of the DEGRP studies, to situate them within the wider literature on agricultural innovation in SSA, and to discuss implications for policy.

It is largely about adoption of technology produced by formal research for improved production on farms by smallholders. Agricultural innovation is broader than this, embracing all sources of ideas that reach farmers – not just those from formal research, but also from commercial companies, other farmers and their own experimentation.

To produce this report, literature on innovation by farmers, mainly smallholders, in SSA was reviewed, including reports from DEGRP studies. Publications since 2010 were the main (but not exclusive) target, to focus on new understandings to add to the already considerable body of work in this area. Interviews with ten leading researchers complemented the literature review.

Material collected was organised within a (simplified) framework that addressed two sets of questions:

1. Are there innovations that can be used by many or most smallholders in SSA?
2. Can farmers make use of these innovations in practice?

Findings

Stark differences can be seen in the way that innovation on farms is conceived. Some see innovation as farmers adopting technical improvements that have been created by scientists and disseminated to farmers through extension agents: a linear transfer from the top down. This has been much criticised.

In reality farmers receive messages about potential improvements from other sources, including agricultural dealers, radio, social media and other farmers. Farmers do not simply adopt or not; rather, they evaluate new ideas, test them on their fields – thereby sometimes finding better ways to apply them – and only then change their farm practice.

The linear model assumes those directing public research are well informed about farmers' priorities, field conditions and resources – which is often not the case.

The two different conceptions clash when considering the gaps between the yield per hectare that researchers can achieve with optimal

¹ None of the studies then commissioned looked at new digital technologies. In the 2020s, this omission would be less likely.

conditions and management of a crop, and the yields realised by the average farmer — the latter often being less than half of the former. Yield gaps are often cited as grounds to believe that research can contribute mightily to agricultural development and to encourage policy-makers to invest in research and extension.

Good and not-so-good reasons, however, explain much of the gaps. Farmer priorities may not be the highest yields per hectare, and the technical maximum is usually higher than would make economic sense. Farmers additionally face considerable social, economic and institutional obstacles to raising their yields. Such considerations cast doubt on the usefulness of yield gaps to guide innovation, public research and extension.

Specialist opinion is thus divided over whether suitable technology has been developed for most crops, livestock and agro-ecological zones (AEZs) in SSA. Some crop scientists and economists see the challenge is to inform and encourage farmers to make use of existing technology, removing any barriers to them doing so. Others, including sociologists and anthropologists, prefer to see technical ideas from public research as one element in the systems within which processes of innovation arise.

Agricultural extension – getting appropriate messages to farmers about potential technical improvements – is a longstanding challenge in agricultural development. More than one model for public extension has been proposed, found to be flawed, then replaced with a new model.

Broadly, thinking has moved from extension as giving farmers standardised recommendations from experts to more participatory methods where extensionists work alongside farmers to test options that may be effective for different farmers in different conditions. Farmer field schools (FFS) – where groups of farmers facing common or similar problems come together to share ideas, try them out and discuss results – are one way this latter ideal might be achieved. Innovation platforms – bringing together not just agronomists and farmers, but also buyers, transporters, input suppliers, bankers and others in supply chains to solve pressing problems – is another, more ambitious model.

Research in the 2010s has helped inform this debate. Studies show just how much variation exists between farmers' fields in soil fertility and topography, even within villages. Such differences invalidate standard recommendations set for AEZs. Instead, farmers need to try out potential improvements, to adapt principles to fit their farms and their fields. This is powerful support for more participatory forms of extension.

Those same studies show that farmers can learn effectively, especially if given some support; but that transmission learnings from farmer to farmer is limited. Ideas may pass along family lines, between close friends, but not generally throughout the local community. That is another powerful argument in favour of FFS, especially if they can target disadvantaged farmers, such as women or poorer households.

Some promising technical improvements are not always profitable for farmers in rural Africa.

When, for example, roads are poor and transport costs are high, pushing up costs and reducing returns at the farm gate, intensified farming simply does not pay. In the last two decades roads have improved and transport costs cut in many parts of Africa – thereby widening the range of technical options that pay off.

It is not just transport costs that hinder farmers. Rural markets for inputs and financial systems often fail, in three ways. One, although inputs such as seed, fertiliser, agro-chemicals and veterinary drugs are now more commonly available in local market centres than they were, the profusion of brands and labels confronts farmers with bewildering choice. Worse, some inputs may be either adulterated or fake, although the problem is far from universal.

Two, increased choice adds to the second problem: risk. Most farmers in Africa face considerable risks – bad weather, pests, disease and unpredictable prices when selling: risks that deter investment and innovation. Ideally, research can generate seeds, inputs and practices that reduce vulnerability of crops and livestock to bad weather, pests and disease. But not all risk can be eliminated technically.

Much thought has gone into providing farmers with relatively inexpensive insurance. Indemnity insurance – that pays out against actual losses – tends to be costly, in part to offset adverse selection (careless farmers seek insurance), moral hazard (once insured, farmers may not take due care) and outright deception (reporting fictitious losses) by those insured. Index insurance that pays out on a proxy measure, such as local rainfall, removes the need to assess crop loss field by field. Farmers given such insurance do indeed respond by investing more in their crops and growing more.

But two stumbling blocks arise. One is the (basis) risk that the proxy may not correspond to conditions in individual farmers' fields. Given local variations this risk may be high. The other is that, although farmers appreciate index insurance when highly subsidised or offered free, most are not prepared to pay a market premium for it.

Insurance, however, can generate benefits for others in the community who are not insured, often people on low incomes. Public subsidy of insurance may thus be justified.

Three, few farmers can obtain formal finance for working capital, and still less investment capital. How much this hinders innovation varies. Some studies show that when insured, farmers invest more. Capital, it seems, can be found when risks are removed.

Despite much experimentation to improve rural financial systems, to date generalised solutions to the difficulties of linking creditworthy farmers to formal lenders have not emerged. Nor have attempts to develop local financial institutions, such as village savings and loans groups, (yet) made a difference for farmers, either. This may change: the sheer weight of initiatives, and technical advances such as mobile phones, may make it attractive for lenders in the near future to offer a deeper and wider range of financial services to farm households.

In the past, some observers worried that collective land tenure – so prevalent for smallholders – would discourage farmers from investing in or conserving the land they farmed. Given the great variety of ways such collective regimes operate to allocate land, studies in different localities

came to different conclusions about tenure's effects on investment.

In the 2010s, this question has been much less studied than before. Instead, other effects of tenure have been examined.

One is the economic efficiency of collective tenure. If this means that land cannot readily be transferred between farmers – and this may only apply in some unusual cases, such as the very particular case of Ethiopia – then a mismatch between farmer skills and aspirations and the land they operate is likely. Modelling of Ethiopia shows collective tenure could lead to massive misallocation of land and labour with substantial economic losses – were it not for general equilibrium effects of price movements. Factor these in, and effects become minor. Studies in China show that allowing more flexible tenure, in this case through leasing of land, can stimulate farmers to invest.

Reflections and implications

Systems views, rather than linear transfer of technology, better represent innovation.

A systems view reminds us that:

- (a) Farmers are best placed to assess technical options. They may not always already have the skills, information and techniques needed to assess them to best effect. But they can be supported to do so.
- (b) Farmers' options are not restricted to recommendations from formal public research. They get other ideas from private goods on sale in local dealers, some of them, especially seeds and chemicals, the result of formal private research. They can also buy – at increasingly low cost – equipment and tools such as irrigation pumps from Asia. And they may be offered fake options as well: low quality and counterfeit seeds and chemicals.
- (c) Smallholders in SSA, like their counterparts in Asia, are increasingly part-time farmers. Households have other activities and other sources of income. This can limit what household members can do on the farm, but non-farm earnings may enable more investment in farming.

A systems view should lead to some humility in public policy. What makes a difference to the lives and livelihoods of farmers comes only partly from public efforts. Public action can do so much, but if it can be allied with effort coming from the private sector, both formal and informal, and above all with the agency of farmers – who are not waiting for others to sort out problems they face or help them seize opportunities – then much may be accomplished.

While SSA faces some daunting challenges – providing jobs and livelihoods to still rapidly growing populations, making sure that farming is environmentally sustainable while adapting to climate change – **some circumstances are far more favourable than in the past.** Urbanisation and the rise of a middle class means a swelling demand for higher-value foods. Asian industrial success brings cheap tools and machines: motorcycles, pumps, solar panels. Better education and improving health mean farmers can work and interact with the rest of the economy more effectively. In the supply chains,

private firms are finding ways to help farmers access inputs, advice, credit – because they need the farmers to grow the produce that they can then sell to their customers.

New and emerging technologies, such as gene-edited crops, drones, data and artificial intelligence hold promise – so long as these are seen not as a panacea, but rather as options for tomorrow’s farmers, for them to assess and make use of as suits them.

Policy implications

Innovation matters, invest in it. Innovation is the only way to conserve resources while producing more for growing populations. It is the best way to raise labour productivity on farms, raise farm incomes and reduce poverty. Some innovation will come from the private sector, some from informal processes in villages, but some can and must come from formal public research and extension. Most analyses show high returns to public investment in research.²



2 Not reviewed in this synthesis are the many studies (for example, Alston et al., 2009; Fuglie and Rada, 2011) that demonstrate high pay-offs to public investment in research.

Steer practice of agricultural research and extension towards more participation. In a world where private enterprise is a major player, where many farmers have more agency than before, it makes sense to find ways for public actors to work with multiple actors, rather than imagining that all depends on their efforts. Methods to actively engage with farmers and enable them to join in innovation are needed. Extension in the forms of FFS and innovation platforms is indicated, even if the very best way to implement these may be in debate.

Work hard to resolve market failures. If risk can be reduced by insurance, and if, as some studies suggest, positive externalities benefit those on low incomes, then subsidise insurance. Make it part of social protection. Investigate how to do this, how much it would cost, and compare it to the likely benefits.

Great efforts are being made by banks, microfinance agencies and non-governmental organisations (NGOs) to improve **rural financial systems**. Ideal models may not yet be apparent, but the many pilots must surely pay off – so long as they are reviewed and evaluated.

How to deal with **variable and fake inputs** – where they exist – presents a new policy challenge, but one for which social scientists should be able to assist policy-makers. It does not necessarily require new discoveries; some countries have better ways than others of dealing with the issue. We need to know those experiences, to understand how they work, and

in what conditions.

Addressed individually, market failures seem daunting in their number and severity. Dealing with them as one offers some promise: bundling inputs with credit and insurance, for example, can greatly reduce transaction costs. Most clearly that applies with contract farming, but that option is open to only a minority of farmers. Other actors – input dealers, NGOs, farmer cooperatives, etc. – are finding ways to bundle their offers to help farmers overcome risks and lack of liquidity.

Research challenge

Much of the research reviewed consists of detailed studies covering small areas, using rigorous (sometimes experimental) methods with high internal validity. Valuable as they are, they can be expensive. Researchers often create new experiments, rather than examining accidental, natural and less formal ones.

Yet, across rural Africa, informal pilots and trials to get information, advice, technology, marketing, and capital to farmers are multiplying. Some are undertaken by businesses to make profit (see Liverpool-Tasie et al., 2020b), others by more altruistic NGOs and farmer associations. These initiatives offer a rich opportunity to learn practical lessons about how they work, and with what outcomes and for whom – and to test theories and expectations against such observations.

1 Introduction: agricultural innovation and development

1.1 Why innovation matters

Agriculture relies heavily on biology. For crops, the sun provides energy, the rain supplies water, and the soil, where plants take root, holds moisture and nutrients. The same applies for the grazing and fodder that livestock eat. At its simplest, the farmer needs to do relatively little – farming is a matter of facilitating biology.

Farming systems that evolved where and when populations were low maximised biological processes. Forest or bush was cleared and burned to allow crops to be planted to take advantage of initially fertile and weed-free soils. But this could only last so long before natural soil fertility began to be exhausted and weeds invaded. The plot would then be abandoned to fallow and new ground cleared to take advantage of fresh natural resources.

In most parts of the world such farming systems are long gone. Farmers have learned how to select their crops for desired characteristics, to fertilise the land, to control water through drainage and irrigation, and to protect crops and livestock against pests and disease. More labour, manufactured chemicals, tools and machinery have been used, but output has risen more than commensurately.

This explains in part why farm produce has increased per person since the 1960s, despite the world's population growing at the fastest rates in human history.³ It also explains why many farmers can still make a living from the land, despite the long-run tendency of the price paid for staples, in constant terms, to fall.⁴ Without technical improvements it would not have been possible to feed populations nor would farmers have been able to make a living.

Moreover, the contribution of better technology to increased agricultural production has been rising through time (Figure 1). From the 1960s to the 1980s much of the growth of farm output came from increasing use of inputs and added land. Since 1990, however, the bulk of the increase has come from rising factor productivity, the result of the application of improved technology and increasing farmer skills.

This applied across most of the developing world as well as in high-income countries, although increases in total factor productivity have been less in much of SSA than in Asia and Latin America (Fuglie et al., 2020).

Technical innovations do not just drive production, they also matter for farm incomes, for reducing the poverty of many smallholders. Modelling shows that improvements in agricultural productivity have more impact on poverty than improvements in industry or services (Figure 2), and that these effects are strongest in low-income countries (LICs) (Ivanic and Martin, 2018).

Technical advances can also reduce social inequalities because they allow those who possess only small amounts of land and water to produce more, freeing them from dependence on landlords who have monopolised natural resources.

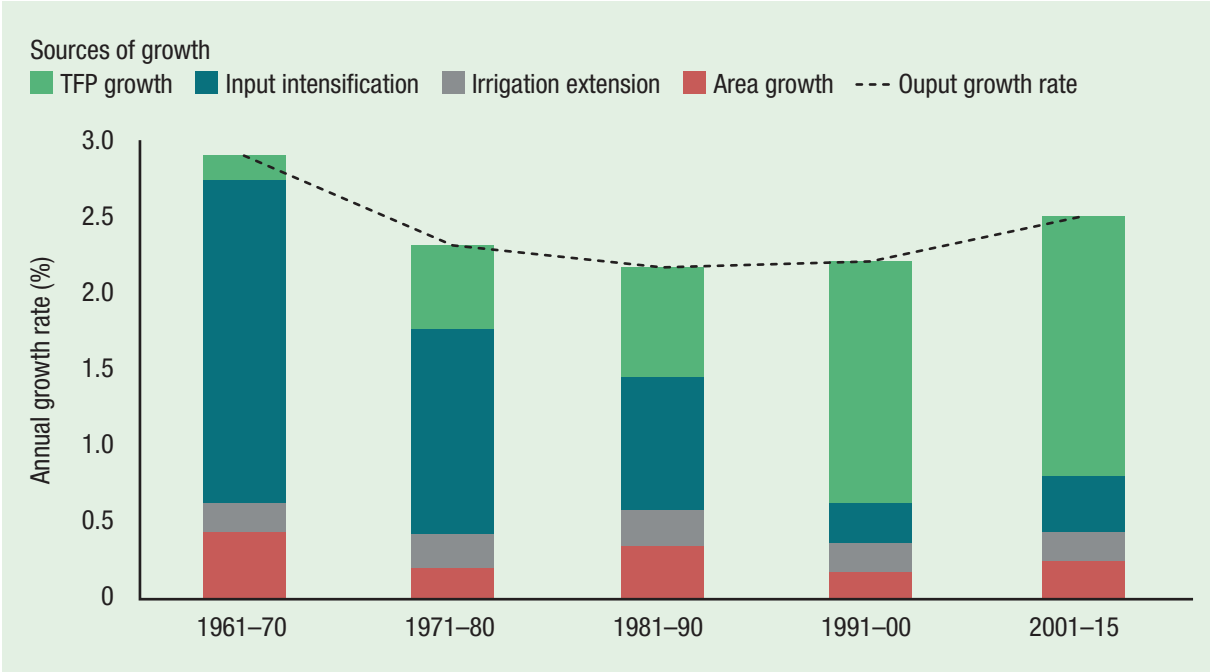
Innovation is, finally, central to the pursuit of environmental sustainability, since potentially fewer resources can be used to produce; and because farming systems can be created that recycle nutrients and water, conserve soils and even store more carbon.

Thus, understanding what allows farmers to innovate is important for policy-makers, not least in sub-Saharan Africa (SSA).

3 World cereals production per person grew by more than one third between 1961 and 2014–2016 (FAOSTAT gross per capita production index).

4 For example, the world price of rice in March 2020 stood at \$317 a tonne in constant US dollars at 2000 values. In January 1980, the equivalent price was \$756 a tonne (IMF Primary Commodity data, for 5% broken milled white rice, Thailand; deflated using US GDP deflator).

Figure 1
Increases in world agricultural output (broken down by source)



SOURCE: FIGURE 1.7 IN FUGLIE ET AL., (2020), DERIVED FROM THE UNITED STATES DEPARTMENT OF AGRICULTURE (USDA) STUDIES. TFP = TOTAL FACTOR PRODUCTIVITY.

Figure 2
Modelled impact on poverty of a 1% increase in productivity in agriculture, industry and services



SOURCE: FIGURE 2 IN IVANIC AND MARTIN (2018).

1.2 Innovation and the adoption of technology

Many studies of agricultural innovation implicitly or explicitly focus on farmers' adoption of technical improvements for crops and livestock produced formally by public agricultural research stations, and by the research labs and workshops of private companies selling seeds, youngstock, sperm and embryos, agro-chemicals, veterinary medicines, tools and machinery – that is, by scientists and technologists external to farms. For them, the critical issue is whether farmers do or do not adopt the ideas and products on offer.

Not all innovation on farms stems from external sources. Farmers have their own knowledge which develops as farmers try out new methods and inputs, drawing on their own experience and experiments, and on what they learn from other farmers (Richards, 1985). When they do adopt ideas and inputs developed formally, they often change other aspects of their management of crops and livestock to make the innovation effective on their own farm. Such adaptation is especially important in agriculture because farms vary so much in their physical characteristics, their location and access to the wider economy, and in the economic and social circumstances of farm households.

This part of innovation may be recognised, but it is less studied and documented. That is largely because those generating technical innovations for farmers as public duty or for profit, focus first and foremost on whether farmers are using the ideas and products they have generated.

Indeed, professional scientists and technologists may see their role as part of a linear transfer of technology (TOT) (see Chambers and Jiggins, 1987a) in which the formal researchers develop what they hope will raise productivity on farms, probably with some on-farm testing to check that it can work. Once tested, the technology is then transferred to farmers – through extension agents who visit farmers, through other media and through the sales efforts of agricultural dealers in the case of innovations embodied in products. Farmers, once acquainted with the innovation, then make the decision to adopt or not.

This simplified model best fits innovations which require only small changes to existing farm management. For example, a new crop variety may demand little more of the farmer than to replace existing seed with that of the improved variety, perhaps accompanied by use of manufactured fertiliser. Seed and fertiliser were core elements of the green revolution that began in the 1960s that saw much of the best lands of Asia and Latin America planted to hybrid maize, rice and wheat. Plant scientists developed varieties capable of yielding several times more than landraces, so long as they were fertilised and adequately watered, so the remaining innovation challenge was that of convincing farmers to adopt the new seeds.

As formal public research was producing relatively straightforward innovations that promised to increase yields several times over, then adoption by farmers seemed to involve little more than demonstrating the potential of the new seeds and issuing instructions on how best to make use of them.

The TOT model of innovation was criticised as a top-down approach, which neglected the agency of farmers (Chambers and Jiggins, 1987a and 1987b). Extension services were organised to disseminate knowledge and technologies down to farmers, who were regarded as passive recipients of innovations generated by scientists rather than holders of knowledge, skilled practitioners and potential innovators.

Agricultural extension services typically suffered from several handicaps, including scant resources and weaknesses in leadership and accountability. The Training and Visit system (T&V), pioneered in the early 1970s by the World Bank, epitomised the TOT approach but attempted to overcome the poor performance of extension services through additional investment and organisational reforms. The T&V moment passed as evidence accumulated to suggest that it was not very effective, despite high costs of implementation (Anderson et al., 2006).

Farming systems research (FSR, sometimes adding Extension, FSR/E) came into vogue during the 1980s. FSR/E was supposed to grapple with the 'complexity of total farming systems',

including 'the farm household and its needs and objectives, and biological, economic and human dimensions' (Chambers and Jiggins, 1987a: 45). Research priorities would be set once researchers had concentrated on understanding the problems that smallholders faced (Maxwell, 1986; Simmonds, 1986).

Efforts to mainstream FSR/E approaches and use them to define research priorities met with limited success (Biggs, 1995; Woodhouse, 1989). The farming systems lens required looking beyond commodity orientation in towards a more interdisciplinary focus on farming livelihoods, but the basic TOT-mode of engagement with farmers remained intact (Chambers and Jiggins, 1987a and 1987b).

Critics called for a more profound reorientation towards participation by farmers in agricultural research and extension, using an approach known as farmer participatory research (FPR) (Chambers and Jiggins, 1987a and 1987b; Chambers et al., 1989). Its advocates argued that research would be made more effective and equitable if farmers themselves were more actively involved in formal research. There was an awakening of interest in the longstanding practices of farmers and their indigenous management practices (e.g. Richards, 1985). Attempts to mainstream FPR approaches met again with limited and patchy success (Okali et al., 1994).

In similar vein, others have applied innovation systems thinking to agriculture (Hall et al., 2003). The key insight of Agricultural Innovation Systems (AIS) is that successful innovation is not a discrete process of technical invention that happens in the seclusion of research laboratories or workshops, with finished products being handed over to be adopted in society. Instead, successful innovation involves interactions among various stakeholders, including the potential users of technologies.

Technological change in agricultural systems is now widely understood as a process that occurs through a confluence of multiple factors which combine to stimulate change in situ (Glover, 2014; Glover et al., 2017; Comptour et al., 2020). Conventional portrayals of technological change,

based on the notion of technology 'adoption' and 'diffusion', have come under increasing criticism (Glover et al., 2016). Academics have criticised, among other problems, the narrow theoretical and conceptual foundations that underpin linear models of innovation and technology transfer. Conventional narratives have relied heavily on a restrictive selection of theories, notably the innovation–diffusion approach associated with Everett Rogers; theories that see innovation as a response induced by changes in external contexts (such as a change in resource prices); and evolutionary accounts of technological change (which conceive of technologies as entities with intrinsic properties, whose fitness is tested by their ability to spread in societies and markets) (Glover et al., 2019).

Alongside these traditional narratives, only the AIS literature has made inroads into professional practice. The mainstream narratives have largely ignored insights from other disciplines and approaches that have undermined the traditional linear view of innovation, including participatory and learning approaches, social constructionist accounts and technography (ethnography of technology). In an effort to use insights from these neglected theories to build a more complete foundation for a practical analysis of how technologies spread, Glover et al. (2019) have broken down technological change into four connected aspects: propositions, encounters, dispositions and responses (PEDR) (see Box 1).

1.3 Africa's changing context

The arguments in this synthesis are set against changes in SSA and differing appreciations of agricultural and rural development of the region.

In the early 2000s, observers of agriculture in SSA focused on problems and deficiencies in a region where farmers struggled to increase production ahead of population growth, where yields per hectare were low as was labour productivity on farms, and where improvements were slow. This correlated with widespread rural poverty and low welfare, including high rates of malnutrition. SSA was often unfavourably compared to East and Southeast Asia where a combination of industrialisation and an agricultural green

Box 1 A new conceptual framework for understanding technological change: PEDR

The PEDR framework is based on an actor-oriented understanding of technology as a form of situated practice, in which the agency of the practitioners is central. The framework diverges from techno-centric conceptions of technology, which implicitly or explicitly place technical artefacts and processes at the centre of attention and conceive of technologies as discrete, independent and mobile entities that can be smoothly transferred from one setting and community of practice to another.

The term 'proposition' represents the idea that a novel technical practice is first encountered as an idea or concept that suggests a new way to work or make, in order to achieve a new or better outcome. 'Encounters' are the occasions when, or arenas where, a person (such as a farmer) becomes aware of the proposition. 'Dispositions' are the unique orientations of individuals (e.g. farmers, households) towards the proposition; dispositions are shaped by the situation of the individual, their relationship to and perception of the proposition, and the quality of the encounter. Finally, 'responses' are the steps an individual takes to react to and/or engage with the proposition; for example, by learning more about it or experimenting with it – or ignoring it. The four aspects are causally interrelated and connected by feedback loops.

SOURCE: GLOVER ET AL. (2019).

revolution had transformed economies and societies. 'African poverty and stagnation is the greatest tragedy of our time,' declared the Commission for Africa in 2005.

Over a decade and a half later, much has improved. Many African economies have seen renewed economic growth outstrip population growth in the new century. For all of Africa, economic growth averaged 4.6% a year between 2000 and 2017 (AUC/OECD, 2018).⁵ The proportion of Africans living below the international poverty line (less than \$1.90 a day per capita in 2011 purchasing power parity) fell from 60% to 40% between 1996 and 2018 (World Development Indicators, World Bank). Africa has also been urbanising rapidly, the share of the population living in urban areas rose from 35% in 2000 to 43% in 2018 (FAOSTAT data). With this, the urban middle class has expanded, consumers who increasingly demand higher-value foods constituting a growing domestic market for farmers.⁶

Social indicators have also improved in most

countries since 2000: higher enrolment in primary and secondary schools, especially for girls, lower rates of mortality for under-fives and increased life expectancy, and lower rates of stunting (World Development Indicators, World Bank).

Agriculture has also grown ahead of population in the new century, also by 4.6% a year on average from 2000 to 2018 for SSA – the highest rate of any world region (Jayne et al., 2020). In part this can be attributed to increased domestic demand from the cities. Road improvements have helped, while the growth of secondary cities and district centres has reduced the distance from most farms to a market for their output. In the 2010s, moreover, it seems something remarkable has taken place with little fanfare. The supply chains connecting farmers and urban consumers, small-scale informal traders, processors, and transporters and wholesalers, have reduced costs and increasingly provided more services – technical advice, credit, input supply – to farmers (AGRA, 2019; Liverpool-Tasie et al., 2020b). Farmers have thus become

5 Performance varied considerably from country to country, with countries affected by conflict lagging behind the others.

6 Not all the food that the growing middle class demands represents an opportunity for domestic farmers; processed and convenience foods, for example, often depend on imported ingredients, such as wheat for noodles and bread or mozzarella cheese for pizza. The best opportunities for local farmers lie with perishables: fruit, vegetables, dairy.

much better connected to urban consumers and their rising demand than before.

Annual reports from the continental institutions of Africa reflect these changes. Since the mid-2010s, they refer increasingly to agriculture and the rest of the rural economy as opportunities rather than problems (see, for example, AfDB, 2016; AGRA 2017).

That said, improvements since 2000 still have far to go before SSA has prosperous rural areas, free from poverty and hunger. Some aspects of agricultural development seem disappointing. For example, if the yields of some of the main food crops in Africa are compared to those in Asia, they remain well below Asian levels and have increased by less since 2000. Cassava yields in 2019 averaged 7.6 tonnes per hectare in Eastern African and 9.6 tonnes per hectare in Western Africa, with no improvement since 2000. Meanwhile, in Southeast Asia cassava yields grew by 66% from 2000 to 2019 to reach 22 tonnes per hectare. Maize yields in 2019 averaged 2.0, 1.7 and 4.7 tonnes per hectare in Eastern

Africa, Western Africa and Southeast Asia, respectively. Maize yields had grown since 2000 by just 32% in Eastern and 19% in Western Africa, but by 83% in Southeast Asia.

Hence, when assessing the prospects of Africa producing enough food for self-sufficiency in cereals by 2050,⁷ this was presented as a difficult challenge by van Ittersum et al. (2016):

SSA is the region at greatest food security risk because by 2050 its population will increase 2.5-fold and demand for cereals approximately triple, whereas current levels of cereal consumption already depend on substantial imports.

1.4 DEGRP research

When the UK Department for International Development (DFID) and Economic and Social Research Council (ESRC) commissioned research into agricultural development in two rounds in 2011 and 2015, of the 18 agricultural studies proposed and approved, no fewer than 10 addressed questions of innovation (Table 1).



RURAL FARMERS IN KENYA HARVEST THEIR VEGETABLE CROP WHICH HAS BENEFITTED FROM THE ADOPTION OF A DRAINAGE SYSTEM. KAJIADO, KENYA 2020. CREDIT: BILLY MIKON SHUTTERSTOCK.COM

7 Rising demand in this framing is less an economic opportunity than a problem. Imports of cereals to Africa are seen as a failure of local agriculture, although much of these imports are for animal feed, brewing or high-status staples such as processed bread, pasta and white rice – imports that respond to urban incomes rather than the nutrition needs of people on low incomes.

Table 1
DEGRP studies on agricultural innovation

Title	Principal Investigator, country and code	Main questions addressed
Information, market creation and agricultural growth	Subramanian Arjunan, India, ES/J009334/1	What happens when farmers receive information about weather, input and output prices, cultivation practices and technical advice through telecentres and other digital telecommunications?
Which farmer(s) should we target? How do extension approaches influence social learning and spread of agricultural innovations?	Erwin Bulte, DR Congo, ES/J009008/1	What impact has agricultural extension offered as part of the N2Africa programme in South Kivu, Democratic Republic of the Congo (DRC), had on crop yields, production, income and food security? How has information passed among farmers?
A behavioural economic analysis of agricultural investment decisions in Uganda	Arjan Verschoor, E Uganda, ES/J008893/1	How do farmers assess the riskiness of investment, and how does this influence their propensity to invest? Are their investment decisions influenced by (anticipated) peer responses?
Innovation systems, agricultural growth and rural livelihoods in East Africa	Peter Dorward, Sudan, Kenya, Uganda, ES/J00975X/1	How do innovations reach farmers, both through formal services and informally? How can public policy and service best support farmers to acquire technologies suited to their needs?
Disseminating Innovative Resources and Technologies to Smallholders (DIRTS) in Northern Region, Ghana	Chris Udry, Ghana, ES/LO12189/1	What are the impacts on the cultivation of cereals when farmers are provided with (a) intensive extension through a community-based extension agent; (b) commercial fertiliser and improved seeds through a network of affiliated retailers; and (c) rainfall index insurance?
Heterogeneous quality of agricultural commercial inputs and learning through experimentation	Karen Macours, Kenya, ES/LO12324/1	What is the impact of providing information on returns to combinations of inputs derived from experimentation on the farmer's own land? How much do such returns vary by soil and by farmer skills?
Optimal packaging of insurance and credit for smallholder farmers in Africa	Ana Marr, Kenya, Zambia, ES/LO12235/1	How does insurance affect supply of credit for farm inputs? How does insurance-cum-credit affect the uptake of inputs by farmers?
Integrated assessment of the determinants of the maize yield gap in sub-Saharan Africa: towards farm innovation and enabling policies	Martin van Ittersum, Ghana, Ethiopia, ES/LO12294/1	What gaps can be seen between typical farmer yields and research station yields in Ghana and Ethiopia? What are the key biophysical, farm and crop management factors that determine the gaps?
Agricultural misallocation, occupational choice and aggregate productivity – the role of insecure land rights and missing financial markets	Jan Grobovšek, Ethiopia, Uganda, ES/LO12499/1	How does limited land transferability under collective tenure affect agricultural labour productivity, employment in agriculture and overall economic growth?
Rural property rights, returns to scale and contracts	Elaine Liu, China, ES/J008966	How do rural property rights affect investment and agricultural production? In particular, how do land leasing rights affect area farmed and migration?

The 10 studies address one or more of three questions:

- **Problem.** What gaps exist between farmer practice and what might be achieved using reasonably readily available technology?
- **Causes.** What are the obstacles to innovation, through what processes and to what degree?
- **Solutions.** How effective are policies, investments or programmes in overcoming obstacles and otherwise encouraging farmer innovation?

Other studies among the eight remaining also report on innovation to some extent. For example, three studies focus on irrigation – itself often the single largest innovation that most crop farmers ever undertake – while another deals with innovations taking place on dairy farms and in dairy supply chains.

1.5 Objectives and scope

Overall, this synthesis aims to:

- summarise and discuss the results of the DEGRP studies
- situate them within the wider literature on agricultural innovation in SSA
- derive implications for policy.

The synthesis looks primarily at the adoption of formally generated innovations by farmers on their farms. It is less concerned with the full range of innovations undertaken by farmers derived from their direct and pooled experience. It also focused solely on changes on farms; it does not address the many changes being seen in agricultural supply chains.

It is not concerned, either, with a major policy interest, that of the generation of

appropriate agricultural technology. A large literature exists on this, dealing with returns to agricultural research, how to identify the most productive lines of investigation and the most productive technology for differing agro-ecological conditions, how to manage public research programmes, and the roles of public and private research.

Important as these questions are, they are not the focus of this synthesis for two related reasons. One is simply that DEGRP research did not study them. The other is that while new technology is both valuable and necessary – conditions change, new challenges arise with pests, diseases, changing climate – by the 2010s, for most parts of SSA, more productive technologies were already developed for most of the crops and agro-ecological zones (AEZs), so that encouraging farmers to take advantage of them and overcoming obstacles to adoption had become a pressing concern.

1.6 Organisation of report

Chapter 2 sets out the methods used to collect data and the framing deployed to organise and synthesise it.

Chapter 3 lays out the evidence collected in two sections, one dealing with technology and innovations, the other assessing the social, economic and institutional barriers to farmer adoption.

For ease of reference, DEGRP research has been set out in boxes, highlighting these studies, their findings and, where possible, their implications. For reasons of completeness, nevertheless, DEGRP findings are also recorded in the main text.

Chapter 4 concludes by summarising the main points, then discussing their implications.

2 Method

2.1 Data collection

2.1.1 Literature reviewed

Much of this synthesis report is based on a review of the literature on technology adoption and innovation by small-scale farmers, primarily those in SSA. Included were reports and papers from the DEGRP studies. The search focused on publications since 2010, to appreciate recent and new understandings to add to the considerable body of knowledge on farmer adoption of new practices in SSA, which began to be documented in the 1920s and 1930s and attracted increasing study from the 1960s onwards.

Literature was searched using terms for agriculture and farming, for technology and innovation, and for the countries of SSA.

The search was helped by the publication since 2016 of no less than three other studies that synthesise literature on adoption by (small-scale) farmers in Africa, and one on the same topic for India, namely:

- **de Janvry et al. (2016)** who review research mainly from India on how to reduce the risk of innovation for farmers.
- **Macours (2019)** who examines recent studies, most of them experimental, about farmer take-up of innovations from formal research. She distinguishes between technologies that enhance yields, reduce the variance of harvests, or save water or labour, as well as the differences that arise from the complexity of the technology.
- **Bridle et al. (2019)** who summarise studies, many of them randomised controlled trials, into obstacles to adoption of formally generated technology by farmers in SSA and South Asia. They centre their review on the four most studied obstacles: credit; risk; access to information; and the markets for inputs and outputs.

- **de Janvry and Sadoulet (2020)** who consider responses to market and government failures that hinder farmers from investing and innovating; responses that come either as deliberate public sector policy (supply side) or from private initiative (demand side). While the former has been extensively studied, the latter has been much less investigated.

These proved very useful in setting out the landscape of knowledge, in highlighting key studies, and in their interpretations. All four focus heavily on studies by economists, usually deploying quantitative analysis. Qualitative studies and work by non-economists are much less well covered.

The literature search on a first scan revealed no fewer than 190 studies published in the 2010s. These were augmented by additional studies cited in them, so that eventually more than 230 relevant publications were found. Abstracts were read to establish how relevant they were to the theme of technology adoption by smallholders, with the more promising being read in their entirety.

2.1.2 Interviews with key informants

To complement insights from the literature, 10 leading researchers were interviewed. They were:

- Ousmane Badiane, Akademiya 2063
- Chris Barrett, Cornell University
- Ken Giller, Wageningen University and Research
- Doug Gollin, Oxford University
- Andy Hall, CSIRO and Costanza Conti, University of Reading
- Thom Jayne, Michigan State University
- Vijesh Krishna, CIMMYT-India
- Ian Scoones, Institute of Development Studies, University of Sussex
- Melinda Smale, Michigan State University
- John Thompson, Institute of Development Studies, University of Sussex

The interviews were (loosely) structured around four questions:

- Why are apparently large gaps seen between yields on farmers' fields compared to those realised in trial plots?
- Are relevant and applicable technologies available for most smallholders?
- If so, then why is adoption often quite limited?
- What do you see as key studies published in the 2010s?

The interviews proved an especially rich source of contrasting perspectives, arguments and evidence.

2.2 Synthesis: the framing adopted

The material collected was organised within a framework based on the working assumptions, as claimed by some observers – for example, Nin-Pratt et al. (2011), van Ittersum et al. (2016), Cassman and Grassini (2020) – that (1) a stock of technical options to improve agriculture in SSA now exists for most crops, livestock and AEZs; and (2) these are not being adopted by most farmers who might benefit from them (Sheahan and Barrett, 2014; Kosmowski et al., 2020).⁸

The framing begins by testing the first assumption, by asking:

1. Are there innovations that can be used by many or most smallholders in sub-Saharan Africa?

Subsequent questions of detail stem from this, namely:

- Are there innovations that can raise input-output ratios because they reduce the limits of water, nutrients, pests, diseases and weeds to crop growth that apply to specific crops in typical AEZs?

- Are they economically attractive? Does the value of gains to productivity surpass costs of innovations (in labour time, in skills, in cost of additional inputs, etc.)? The answer to this will vary across the landscape since prices vary by distance from input and output markets.
- How much of a difference might existing innovations make to smallholders? Do yield gaps help us understand this?
- Are innovations suited to the conditions faced by farmers, in particular their access to necessary labour, inputs, technical assistance, etc.?

An additional question, not central to this synthesis but of considerable policy interest, is whether there are emerging technologies that may soon change the answers to these questions.

If the answer to the former question is broadly that, yes, innovations do exist, then the next question becomes pertinent.

2. Can farmers make use of these innovations in practice?

To be able to adopt or otherwise make use of existing innovations, three sets of conditions need to be met, as follows:

Knowledge and skills

- Do farmers know about innovations applicable to their crops, their farming systems?
- Do farmers have the skills to apply them, or can they readily learn to do so?

Economics: profitability

- Are innovations economically attractive to farmers when faced by field-gate prices for produce, inputs, labour and any other resources used? (Field-gate prices are those in the principal markets of the country, discounted or augmented by the cost of transport from field to market.)

8 It is not easy to establish the extent of adoption of formal innovations. When Sheahan and Barrett (2014) used LSMS-ISA data for eight countries to establish technology used, they found much variation across countries, crops and technical interventions. For some crops, most farmers sowed improved varieties, but not necessarily for other crops; nor had they adopted complementary measures such as use of manufactured fertiliser and irrigation.

More positively, and more recently, when the Standing Panel on Impact Assessment (SPIA) reviewed the reach of CGIAR technologies in Ethiopia, they found a minimum of four million and a maximum of 11 million farming households – the higher figure being 79% of crop farmers – had been reached, more than perhaps they might have expected (Kosmowski et al., 2020).

Economics: market failures

- Can farmers afford to take the risk of innovation? Farmers face natural hazards of poor weather, pest and disease attacks leading to harvest failures. If they have invested heavily in innovative practices, then the losses could drive them into unacceptable debt. They similarly face varying prices in markets for produce, whereby a market downturn could also lead to losses and debt.
- Can farmers insure against (some of) the hazards they face?
- Can farmers identify quality inputs, and inputs suitable for their farms? Increasingly, farmers and herders in Africa find a large array of seeds, fertilisers, crop chemicals and veterinary drugs in local markets. Some of these may be adulterated or counterfeit.

Choosing appropriate, genuine and quality inputs now presents a substantial challenge.

- Can farmers obtain credit to buy seeds, chemicals, tools, machinery, veterinary drugs, etc. that they need to innovate? Credit might come from banks, micro-finance agencies, local cooperatives or dealers.

Economics: institutions

- Do farmers have sufficient confidence in their tenure to invest in innovations to raise productivity or make their farm sustainable?

Findings from literature and interviews have been organised by these two questions and their sub-questions.

3 Findings

3.1 Technology and innovations

3.1.1 Is technology available and accessible?

Are the technological propositions that are typically offered to farmers in SSA generally suitable and accessible to smallholders and cultivators in marginal lands? There is no definitive answer to this question. This is partly because expert opinion is divided on the question of what kinds of technologies are most appropriate, relevant and accessible to small-scale farmers in marginal and resource-constrained environments of SSA.

A long-running debate centres on the question of whether formal and public agricultural research and development systems have been successful in generating technologies that are of a design, scale and cost that makes them suitable for and accessible to smallholder farmers (Hall and Dorai, 2020). This was a key area of discussion and contestation in relation to the technologies of the green revolution during the 1960s and 1970s, and the debate continues to the present day. Social scientists contended that the modern crop varieties

and other green revolution inputs did not fit within existing farming systems, did not benefit small and marginal farmers or landless people, and came with high financial and environmental costs. More recent assessments have confirmed that the green revolution technologies were productive and that the economic advantages did spread eventually beyond the richer farmers who benefitted first, while many people migrated out of farming. However, ecological harms have proved to be serious and enduring, while problems of malnutrition have increasingly been recognised (Orr, 2012; Pingali, 2012).

Today, debates arise around new technologies, such as genetically modified and, more recently, genome-edited crops (Smale, 2016; Catacora-Vargas et al., 2017). In some quarters, there is much optimism that advanced technologies – digital communications, sensing, robotics, genome editing, etc. (see Box 2) – will greatly increase the range and efficacy of options. How much these technologies will be accessible and useful to poor and small-scale cultivators remains largely to be seen.

Box 2 The promise of innovations for the future

For food systems, promising technical advances can be seen across the board from conventional farming, through improvements in supply chains to revolutionary manufacturing of food through fermentation and culturing meats (De Clercq et al., 2018; King, 2017; Walker and Buhler 2020, Tubb and Seba, 2019). Prominent among these are biotechnology and robotics.

Biotechnology

Techniques of genetic engineering were pioneered in the 1970s and the first genetically modified (GM, transgenic) plants were created in the early 1980s. GM crop varieties were first commercialised in China and the US in the mid-1990s. Today, transgenic crops are cultivated on millions of hectares, by millions of farmers, in dozens of countries around the world, including large areas planted in China, India, Pakistan, South Africa, Brazil, Argentina and others (NAS, 2016).

Commercial cultivation of GM crops is overwhelmingly dominated by a few major commodity crops – soybean, maize, canola (oilseed rape) and cotton – and two types of transgenic traits – tolerance of chemical herbicides and resistance to certain insect pests. The largest share of the GM varieties cultivated worldwide combine herbicide tolerance with insect resistance, known as trait stacking (NAS, 2016).

Box 2 The promise of innovations for the future (continued)

The spread of commercial cultivation of transgenic varieties has led to a huge increase in herbicide use worldwide, and stimulated the emergence of new herbicide-tolerant weeds, a costly challenge for farmers (Heap, 2014; Bonny, 2016; Perry et al., 2016). The widespread use of insect-resistant GM crop varieties has also stimulated the emergence of insect pest populations resistant to toxins expressed by GM varieties (Tabashnik et al., 2013; Tabashnik and Carrière, 2017).

The spread of transgenic crops in developing countries and among small-scale farmers has led to much debate about whether the currently available GM technologies are appropriate, accessible and beneficial for poor cultivators (e.g. Glover, 2010; Jacobson, 2013). Economic analyses have produced good evidence that transgenic varieties of cotton and maize have contributed to economic benefits, including an increase in average farmers' yields, productivity and profitability (Kathage and Qaim, 2012; Klümper and Qaim, 2014). Other types of studies assessing the impacts of GM crop cultivation by small-scale farmers produce a more mixed picture. There is evidence that good outcomes depend heavily on a favourable institutional and market environment (Glover, 2010; Fischer et al., 2015; Schnurr, 2016). The contribution of transgenic technologies to observed yield and productivity gains also looks smaller when other relevant technological changes are taken into account (Kranthi and Stone, 2020).

Since 2012, a new technique of genetic engineering has attracted a lot of attention from scientists, businesses and others (Ledford, 2015). CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats) genome editing has been hailed as a precise and inexpensive tool that can be used to add, delete, change or replace individual nucleotides or sequences of deoxyribonucleic acid (DNA). CRISPR is used to identify a specific genetic sequence, then cut it using an endonuclease, also known as a restriction enzyme. These enzymes are known as Cas (CRISPR-associated) proteins. CRISPR-Cas was first demonstrated in prokaryotes (Jinek et al., 2012), but quickly applied to eukaryotes (Cong et al., 2013), including plants (Shan et al., 2013). It has been used to produce stable, heritable changes in the germlines crop plants such as maize, sorghum, wheat, barley, soybean, brassicas, potatoes, sweet oranges and tomatoes (Bortesi and Fischer, 2015; Khatodia et al., 2016).

Molecular plant breeders believe that modern biotechnology, including genome editing, can be used to develop valuable agronomic traits in crops, such as tolerance to biotic and abiotic stresses, resource-use efficiency and consumer traits such as improved nutritional composition of foods and feeds (Ledford, 2015; Montenegro, 2016). However, important challenges remain in the quest to enhance complex traits, such as drought tolerance, which involve multiple genes. Even with advanced biotechnology, breeders still contend with the effects of pleiotropy – where genes influence the expression of more than one trait – and epigenetics, where the expression of genetic traits can change, and be passed to the next generation, without changing DNA.

The application of genetic engineering in crops, livestock and food products triggers public debate and raises concern among consumers and farmers about ethics, environmental impacts, sustainable development, social justice, and the accessibility and affordability of modern technologies. Genome editing is claimed to be simple to use and affordable, making it more accessible to a wider range of breeders (including, for example, public and non-profit breeders) than the previous generation of GM crop technologies. However, whether this benefit is realised in practice may depend on intellectual property regimes in relevant jurisdictions (Egelie et al., 2016).

Box 2 The promise of innovations for the future (continued)

Differences in the ways GM and genome-edited organisms are regulated internationally make it necessary to segregate production systems and supply chains for agricultural products into GM and non-GM channels, which makes cross-border trade in agricultural products more complex and costly. This situation may affect agricultural producers in SSA, for example, who export products into multiple markets that operate different rules.

Robotics, sensors and data analysis

There is much excitement about the potential of new technologies to transform agricultural production. This section draws largely on the article in Nature by Anthony King 'Technology: the future of agriculture' (King, 2017). The article describes how, in the future, drones may be used to monitor crop development, weeds, pests and diseases, and to spray crops and apply fertiliser, with the possibility of discriminating within a few square metres, to reflect varying conditions at that small scale. Flying drones have the added advantage of avoiding soil compaction.

Even greater precision could be achieved by farm machines that can both sense variations in crops and manipulate crops to the nearest centimetre. Some crops, such as tree fruit, that previously had to be picked by hand can be harvested by such sensitive machinery. Machines can also detect pest infestations and disease in individual plants and apply pesticides more economically than by broad spraying of the field.

Sensors can be attached to individual livestock to track health, fertility and digestion. They can even be stuck on individual fruit to detect precisely when to harvest them.

Increasing computing power can make use of the data collected by sensors and cameras to determine optimal feeding, treatment and insemination of livestock, and optimal fertilisation and protection of plants.

Much depends on the economics of these applications. Most can be applied already, but some are costly compared to using conventional machinery or even hand labour. On past experience, costs will almost certainly fall, meaning that these technologies will be affordable for many farmers.

New technologies of these kinds promise to reduce applications of agro-chemicals, thereby cutting costs to farmers and greatly reducing environmental harm from excess fertiliser leaching into aquifers and pesticides drifting across fields. Because some of these technologies do not require large machines – and because they can be sensitive to very small-scale variations in soils, individual plants and livestock – they may also nullify advantages of farming at large scale with machinery.

Another narrative holds that too few of the scientific innovations produced by scientific research are really suitable for and/or accessible to smallholders, who face multiple constraints (e.g. of resources, information, knowledge and infrastructure) that discourage or prevent them from investing in new technologies or attempting to achieve scientifically optimal production levels. From this perspective, the key problems to address are the appropriateness of the design

and the economic and practical accessibility of new and productive farming technologies.

To some extent, these two narratives view the same problem from opposite ends. Both eventually converge on the necessity of tailoring and embedding technologies in their intended settings, that is, making them as suitable as possible for local agro-ecological contexts and as accessible as possible to relevant socioeconomic communities, groups and/or households. This

can be challenging. It involves both calibrating of technical parameters and configuring of social practices and institutions.

With regard to technical aspects, agronomic researchers and extensionists generally make technical recommendations with respect to a general appreciation of an AEZ. Physical conditions of fields within any zone, however, may vary considerably by soil quality, microclimate, slope and so on. While this point is not new, the degree and significance of these variations has become increasingly apparent. For example, Marenya and Barrett (2009) saw just how much soil organic matter varied between farms in western Kenya. On plots that lacked organic matter – roughly one-third of observed fields – response to mineral fertiliser was limited; so much so that, at prevailing prices, it was not economic to apply fertiliser. Poorer farmers tended to have the most degraded soils, so their ability to gain from investing in fertiliser was limited.

Similar observations of significant variation in returns to fertiliser come from companion studies in central and western Kenya (Suri, 2011; Carter et al., 2015). Once such heterogeneity is appreciated, Suri indicates, it is easy to see why some farmers would rationally adopt mineral fertiliser, while others would not.

Given variable soil quality, it is apparently harder than might be expected to define which fertilisers might be appropriate for particular plots. Analyses of soil taken from selected parts of a field can deceive. A single composite soil sample taken from a field provides uncertain estimates of nitrogen, potassium and phosphorus in the soil, too uncertain to make reliable recommendations. The variability of local conditions and the uncertainty inherent in scientific testing and modelling can make it impossible to determine locally optimised technology specifications across a wide spectrum of narrow agro-ecological niches with a high degree of precision. So much so that a better guide to fertiliser selection may be to start with farmers' knowledge about their management of the field and the performance of crops (Schut and Giller, 2020).

Adopting fertiliser, then, is not quite the straightforward innovation it might at first seem, where it might be thought that all farmers need to do is to follow recommendations on rates and timing of applications for specific crops. Instead, to get the value from fertiliser and repay the cost of minerals, farmers need to attend to complementary practices. (Box 3)

This leads to consideration of the social components of technological systems, and their importance in successfully embedding a new technology into local practice. Collaborative and participatory studies of whole farming systems, conducted over several seasons, have had some success in identifying specific niches and (co-) designing appropriate technical interventions, which have produced substantial and tangible improvements in outputs (Falconnier et al., 2016, 2017; Descheemaeker et al., 2019). However, this progress in tailoring solutions to suit particular situations and communities depended on intensive investments of resources through the N2Africa project,⁹ which enabled commitments of scientific and NGO effort and supported participatory engagements by farmers (Descheemaeker et al., 2019) (see Box 8).

Grappling with the adaptation of new technologies to suit local agro-ecological, socioeconomic and institutional conditions typically leads researchers to explore ways to engage with farmers in processes of experimentation and learning, through field trials on farmers' land. These often serve an ambiguous dual purpose of demonstration on the one hand – to transmit information about recommended practices – and learning on the other – to discover what works, what does not and how to adapt recommended practices to local agro-ecologies and farmers' capacities and preferences (Maat & Glover, 2012).

Working with farmers to discover how best to use improved seed and fertiliser in the diverse settings of their own fields was the subject of experimental studies by DEGRP researchers. Farmers in western Kenya, with a little guidance on setting out trial plots, were able to work out what combination

9 N2Africa: Putting nitrogen fixation to work for smallholder farmers in Africa. Funded by the Bill and Melinda Gates Foundation (2013–2020). See www.n2africa.org/.

Box 3 How complicated and complex are agricultural innovations?

Apparently simple and straightforward technical improvements such as the application of manufactured fertiliser can become a great deal more complicated when considering the specific circumstances of crop, field and soils.

Used well, manufactured fertiliser can stimulate extra grain production, worth far more than the cost of the fertiliser. Supplying extra nitrogen to crops can result in 10 to 30 times more weight of grain. Field trials in Malawi showed that every kilo of nitrogen applied to maize generated on average more than 19 kilos of extra grain with one weeding, and double that, 38 kilos, with two weedings (Kamanga et al., 2014). Similar physical returns to maize were recorded for western Kenya by Ngome et al. (2013) and southern Africa by Vanlauwe et al. (2011).

At typical world prices – urea at \$330 a tonne, free-on-board (FOB) Black Sea with a nitrogen content of 46% nitrogen, equivalent to \$718 a tonne of nitrogen; and maize at \$260 a tonne, FOB US Gulf ports (in late April 2021) – the potential agronomic efficiency of nitrogenous fertiliser represents a hefty profit.

That profit cannot, however, always be realised by farmers in Africa. The cost of fertiliser can be much higher than the international price, as it has to be shipped and then transported overland to villages (Liverpool-Tasie, 2016).

More importantly, many farmers get nothing like the agronomic response that trials demonstrate. In Tanzania, farmers only got about half the agronomic response seen on trial plots (Mather et al., 2016). Similar responses were seen on farmers' fields in Malawi, where only an average of seven to 14 kilos of additional grain were reaped from an additional kilo of nitrogen (Snapp et al., 2014).

Lower than expected response can be due to soils so poor that crops cannot absorb the nutrients in fertiliser: 'degraded and poorly responsive soils cover large areas of Africa' (Tittonell and Giller, 2013). Low response can also result from inadequate crop management, including late application of fertiliser. This can be the result of subsidised fertiliser arriving late after planting, too few weedings resulting in crops losing out to competition from weeds, or from parasitic plants such as *Striga* (also known as witchweed) that parasitise maize (and other crops) drastically cutting crop yields (Snapp et al., 2014). If fertiliser is to be effective, more must be done than just applying fertiliser. Other studies also stress that complementary inputs to fertiliser and crop management are needed for most farmers to realise the full potential of fertiliser (see Omonona et al., 2020, for sorghum in Nigeria; and Sheahan et al., 2013, for smallholders growing maize in Kenya)

Response to fertiliser depends not only on complementary inputs and practices, but also varies owing to the considerable differences in physical conditions of fields (see section 3.1). Good practice thus needs adapting to suit individual fields and farms. An innovation first presented in terms of applying a given amount of nitrogenous fertiliser to maize at particular times for a given agroecological zone may thus in practice require farmers to attend to many more elements in their farming, thereby adapting the innovation to their highly specific circumstances.

of seed, fertiliser and management gave the best results on their fields (see Box 7). In South Kivu, DRC, newly introduced practices were taken up by farmers who were in direct contact with the

project's partner NGOs and had been supported to try the methods for themselves, but the practices did not easily spread beyond the contact group (see Box 8).

3.1.2 Yield gaps: their size, causes and solutions

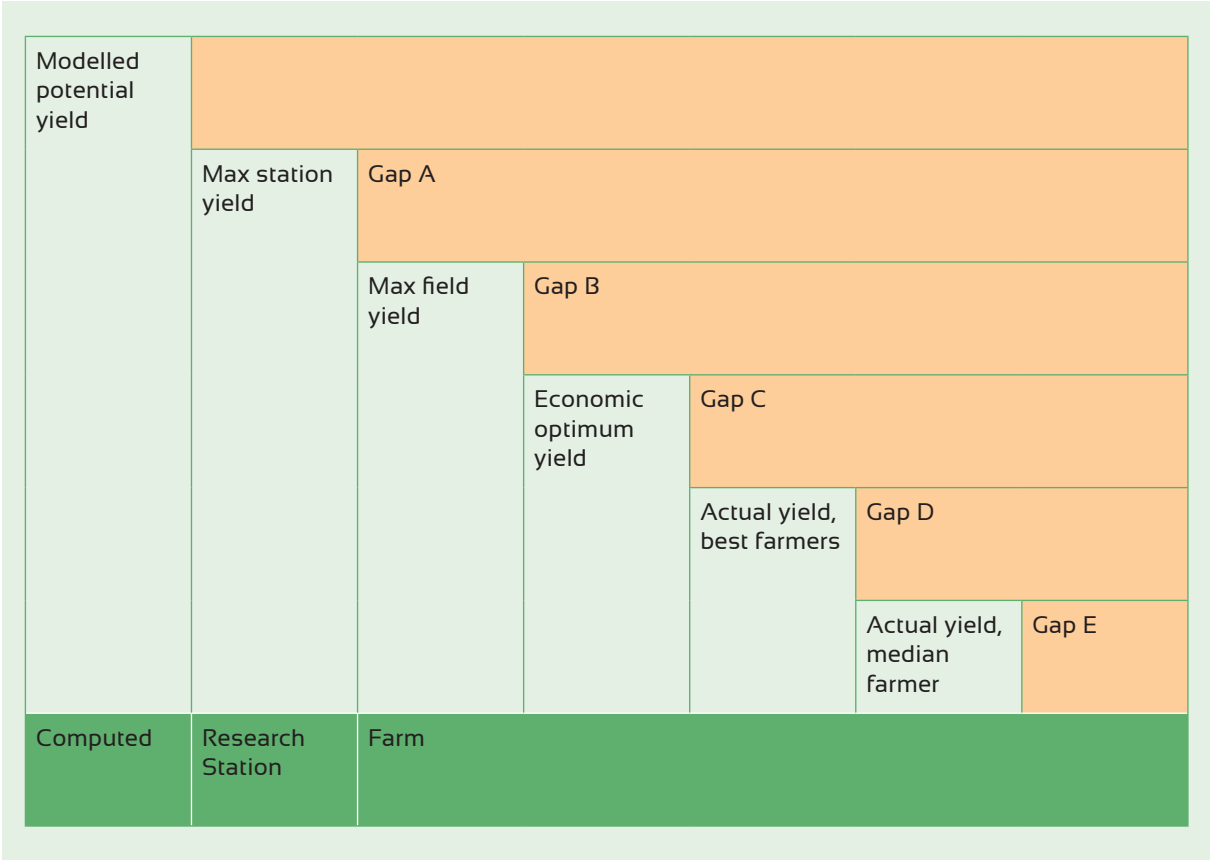
Yield gaps are the distances, measured in volume or weight of crop produced per unit of area, between the yields achieved by different cultivators in different situations and contexts. Yield gap analysis may be useful for comparing the outcomes of different farming operations and practices, and for understanding the potential to increase farmers' yields. It does not necessarily follow, however, that it is realistic or helpful to view yield gaps as a deficit that should or can be eliminated by getting farmers to cultivate their crops according to scientists' recommendations.

It is widely accepted in the literature that yield gaps in small-scale farming systems in SSA are large, and that raising farmers' yields should be a priority. Yield deficits may be attributable to different causes, including biophysical and agro-ecological factors, such as adverse

weather, pests, diseases and nutrient-deficient soils; socioeconomic factors, such as low output prices or problems in accessing credit, insurance and quality farm inputs; and management factors, such as the farmers' skill, diligence and timeliness in establishing, weeding, irrigating and harvesting the crop. Closing yield gaps requires not only that farming technologies work well in farmers' fields, but also that farmers are motivated and confident to do so, and have convenient and affordable access to required inputs, information, knowledge and skills to exploit the technologies' potential.

Agronomists distinguish between several kinds of yield levels, so as to focus on closing the gaps between them (Lobell et al., 2009; van Ittersum et al., 2013). The way yield gaps are defined is often specific to a particular study and the terms used are not consistent. Some generic observations can be made (see Figure 3 and Box 4).

Figure 3
Yield gaps



SOURCE: ADAPTED FROM ZINCK ET AL., 2004, BASED ON FRESCO ET AL. 1994.

Box 4 Yield gaps: terms and definitions

Modelled potential yield

The physical maximum yield that might be achieved for a given variety of crop in given climate, with ideal nutrients, no losses to pests, disease, weed competition. May be expressed as water-limited yield when matched to rainfall of a given agro-ecological zone

Gap A: Even on station we run into some limits of water, nutrients, pests, diseases.

Maximum research station yield

The most that can be achieved on station when providing a given amount of water, ideal nutrients, protection from pests, disease and weeds.

Gap B: On a farmer's field some limits of water, nutrients, pests, diseases will apply.

Comment: Gaps A and B should not be very large. Research-managed plots on farmers' fields should be within 20% of the modelled maximum (water-limited).

Maximum field yield

The most that can be achieved with very carefully managed plots on farmers' fields, usually small plots, supervised by agronomists with as much labour as needed.

Gap C: Maximum yield will be higher than the economic optimum, because the former requires applying labour or inputs at a (marginal) cost greater than the (marginal) value of additional produce gained. $[MC > MR]$ – production economics.

Gap C depends on the curvature of the line that marks yield response to increased use of inputs – defined by the rate at which marginal returns decline as increasing inputs are applied (seen most clearly when plotting yields against application of nutrients). Normally, the difference between economic and technical optimum yields is not so large, at around 20%.

Economic optimum yield

The yield that gives the largest economic margin to the farmer.

Gap D: Market failures, above all those in credit and insurance, mean that farmers dare not risk applying inputs to the economic optimum given the hazard of poor weather, pest and disease attacks; and may not have enough cash to buy all the inputs they would like to.

Gap D depends on the degree of market failures and risk aversion. This gap may be very large indeed if farmers face risky conditions, cannot afford to take risks and do not have cash to buy inputs in the early crop season.

Actual yield, best farmers

The yield gained by best farmers, but who are limited by avoidance of risk and failures in insurance and credit markets.

Gap E: Because farmers are not all equally diligent, skilled, experienced and knowledgeable, the median farmer gets a yield less than the best farmers in the location.

Gap E depends on the crop and conditions: some crops are quite resilient to mediocre farming – for example, the crop tends to dominate weeds, does not suffer badly even when pests and disease attack, still thrives even when fertiliser is applied late, and so on. Other crops may require more precise cultivation so that the most diligent farmers get far more than the median.

Actual yield, median farmers

The yield observed for the typical, median farmer.

The maximum achievable yield for a given crop under ideal conditions is a theoretical construct, sometimes known as the yield ceiling or potential yield, which can be modelled but not realistically attained unless the local agro-ecology is ideal for the crop variety concerned, when adequately supplied with all necessary inputs. Estimates of the yield attainable under favourable conditions, with competent management and productivity-enhancing technologies, can be empirically based. Controlled field trials on research stations may approach the theoretical yield ceiling; however, even the best (or most favoured) farmers' yields are normally some distance below the yield possible under ideal conditions and management. Yields attainable under rain-fed conditions are known as water-limited potential yields.

Agricultural economists highlight three other levels of yield. One is the yield that could be attained for a given level of inputs, when these are being used to a technical optimum; in the literature, this may be called something like the technically efficient yield, and it highlights the skill with which the crop and farm are managed.

A second is the yield which is economically optimal, given prevailing prices in input and output markets. This reflects that farmers are motivated to achieve profits from farming, not necessarily the maximum possible yield for a given crop. This may be termed the economic, or economically optimal, yield.

A third is the yield achieved by the most productive local farmers; or, depending on the study, it might be the reference yield achieved on researcher-managed demonstration plots in the local context. This yield might correspond to that attainable in local conditions using specified technologies, such as improved seeds and fertilisers, which might not be used by all farmers in the area.

The framing of these different yields makes it possible to target different kinds of yield gaps for assessment and analysis. Yield gaps may be defined in different ways for different purposes, but researchers typically target the gaps between average farmers' yields on the one hand, and the yield ceiling, the technically efficient yield, the economically optimal yield, or the best local

farmers' yields, on the other. These gaps may be termed the (total) yield gap, the technical efficiency gap, the economic or resource yield gap, and the technology gap, respectively.

An example is a study by Vasco Silva et al. (2016), who estimated stochastic frontiers to distinguish between three drivers of yield gaps, labelled as *efficiency* (the gap between actual farmers' yields and a technically efficient outcome for given inputs), *resource* (the gap attributable to an investment of resources below the level needed to attain the maximum potential yield), and *technology* (the gap between the best farmers' yields and the theoretical yield potential) (for further examples, see van Dijk et al., 2020; van Loon et al., 2019).

A review of evidence by Lobell et al. (2009) concluded that average yields attained by farmers in a variety of cropping systems across a range of countries were between 20% and 80% below the estimated potential yield. Affholder et al. (2013) investigated yield gaps in four different family farming contexts (including subsistence- and market-oriented systems) in three tropical countries (millet in Senegal, maize in Brazil and Vietnam, and upland rice in Vietnam). They found that actual yields ranged between 20% and 50% of water-limited potential yields. The authors believe that these could underestimate yield gaps in subsistence-oriented systems. This is because farmers in these systems often plant mainly traditional multi-purpose varieties instead of modern cultivars optimised for grain production. They also concluded that differences in crop management were a larger cause of grain yield gaps than climate, which suggests that changes in production technologies and management practices have the potential to close the gaps, particularly in market-oriented systems.

Obstacles to increasing yields may be very substantial for poor and marginal farmers, and can vary widely across seasons, locations, farm plots, farms and/or households. Therein lies a challenge, because estimating the size of yield gaps across scales from farm plot to landscape/region depends on data quality and granularity, temporal variability, framing assumptions and references, as well as degrees of simplification, aggregation

and extrapolation. These make rigorous estimation difficult, and the resulting numbers challenging, and often inappropriate, to apply across a spectrum of heterogeneous micro agro-ecologies and a diversity of individual households' economic circumstances and livelihood portfolios (Lobell et al., 2009; Sumberg, 2012; Affholder et al., 2013; Vasco Silva and Ramisch, 2019).

For rain-fed agricultural systems, where many poor people farm, and which are widespread in SSA, estimates of water-limited potential yields are an appropriate benchmark, rather than a notional maximum potential yield under ideal conditions. Yields achieved by households in the same community often vary widely. In these contexts, Tiftonell and Giller (2013) distinguished between two yield gaps: one between the water-limited potential yield and the best local yields ('locally attainable yield'),

attributable to farmers' difficulties in accessing good technologies; and another between local average yields and the locally attainable yield, attributable to limited economic resources.

According to Tiftonell and Giller (2013), in SSA limited soil nutrients restrict yields more than water scarcity. As degraded soils are widespread across Africa, priority interventions should address good agronomic management to restore soil fertility, otherwise farmers struggle to gain any substantial benefit from improved germplasm or fertiliser, and so remain trapped in poverty.

DEGRP research (Box 5) has shed light on the magnitude of yield gaps and their causes. This confirmed that there are large maize yield gaps on farms in Ethiopia and Ghana. The prospect of closing these gaps is a cause for hope.

Box 5 What factors lead to on-farm yield gaps?

Integrated assessment of the determinants of the maize yield gap in sub-Saharan Africa: towards farm innovation and enabling policies. Led by Martin van Ittersum and Pytrik Reidsma

What are the key factors that determine crop yield gaps? This project set out to find the answer to this question through a study of small-scale maize farming systems in Ethiopia and Ghana. The project studied yield gaps at three different scales: the gap between actual farmer yields and the economically achievable yield in the local context; the gap between the economic yield and the best-performing farmers' yields; and the gap between the yields attained by the most productive maize farmers and the theoretical yield potential for maize under ideal management in the local context.

The researchers calculated the magnitudes of maize yield gaps and searched for their underlying drivers. The project applied a conceptual framework that combined insights from production ecology and economic production theory, and used agronomic and economic approaches to assess maize yield gaps at plot and farm levels. To examine why maize yield gaps exist, the researchers used data from nationally representative farm-level surveys, applying econometric estimation techniques to assess the impact of economic and infrastructural constraints at national and sub-regional levels in the two focal countries.

The project sought lessons to inform recommendations targeting farmers, extension service providers, implementers of technology demonstrations and pilots, and policy-makers, to improve agricultural practices, increase maize yields and reduce the gaps between farmers' yields and the theoretical yield potential. Promising technological improvements and policy interventions were identified, and their potential to reduce yield gaps was explored through on-farm experiments and workshops with stakeholders and policy communities.

Box 5 What factors lead to on-farm yield gaps? (continued)

The study made advances in characterising different kinds of yield gap and estimating their size. Some key project findings include:

- On-farm maize yields in Ethiopia were estimated at only 20% of the water-limited potential.
- Factors contributing to the maize yield gap in Ethiopia were estimated as being: technical inefficiency in resource use with technologies already applied (the 'productivity and efficiency gap'); resource constraints (the 'resource gap' between the average and best-performing farmers, which could be attributed to differences in the deployment of inputs); and limitations in the use of technologies (the 'technology gap' between yields achieved by farmers using improved technology compared to those not doing so).
- In Ethiopia, the technology gap accounted for the largest proportion of the total maize yield gap (between 54% and 73% across different maize production systems studied), the resource gap accounted for 12%–25%, and the efficiency gap accounted for 15%–21% of the total yield gap.
- The major constraint contributing to maize yield gaps in Ethiopia was a lack of access to improved technologies (a 'technology yield gap'). Other contributing factors included an 'allocative yield gap' (limits in knowledge and access to information, financial constraints and problems with production risks, which led to inefficient allocation of resources), an 'economic yield gap' (principally transaction and transportation costs, which limited farmers' ability to increase inputs) and a 'technical efficiency yield gap' (suboptimal crop management, limiting productive efficiency with available technologies).
- Tackling all of the above constraints in concert could boost maize production almost fivefold in theory, assuming that the yield gap could be fully closed. To achieve this, the researchers advocated policies to improve extension services and road infrastructure, liberalise input and output markets and reduce transaction costs, provide access to credit and insurance services, and open up access to modern farming technologies.
- In Ghana, maize yields in two regions across two seasons were between 67% and 84% below the water-limited yield potential.
- Maize yields in Ghana were consistently low for all farmers across seasons. However, the researchers were unable to identify consistent drivers of the yield gap problem over consecutive seasons and across sites. Low yields seem to have been driven by interactions among various factors, including characteristics of households (such as household size and ownership of livestock), soil quality and farm management practices. Improvements in inputs and management methods had the potential to increase maize yields in the areas studied. However, in the low-input, complex, heterogeneous and unstable contexts studied, the researchers were unable to identify a blanket set of recommendations that would address yield gaps across different times and settings. They called for longer-term research and advocated the use of combinations of analytical methods rather than a single methodological approach.
- Shedding further light on the spatial and temporal complexity of the factors contributing to large yield gaps, a comparative study of maize and wheat production systems in two Ethiopian sites revealed that labour constraint (as well as a scarcity of animal draught power) was a likely contributor to the yield gap in Asella, but not in Hawassa. The researchers identified two explanations for this contrast between the two locations: first, a difference in the availability of labour to cultivate each unit of land; second, differences in the mixtures of crops cultivated in the two locations, where peaks in labour demand for cultivation of different crops coincided in time in one place, but not in the other. The researchers concluded that mechanisation could be a relevant option to close yield gaps in Asella, but low output prices discouraged farmers from investing in the intensification of production.

What strategies should then be used to narrow these yield gaps? Research in Ethiopia was more successful than that in Ghana in answering this question. Lack of access to improved technologies (the technology yield gap) was the largest driver of the maize yield gap – accounting for between half and three-quarters of the deficit across Ethiopian sites – but they also quantified the substantial roles played by suboptimal use of farm inputs (the resource yield gap) and inefficiency in the use of those inputs (the efficiency yield gap).

In Ghana, the researchers showed that heterogeneity, in both biophysical and socioeconomic dimensions, made it difficult to identify individual factors consistently responsible for driving yield gaps across locations and seasons. They concluded that agro-ecological and socioeconomic factors interacted to produce low yields, but in specific ways at different places and times. They called for further research, using a broader range of methods, to investigate these interactions.

Where do things stand in the debate about yield gaps? Clearly differences arise between the yields that crop scientists can obtain in favourable conditions and what most farmers obtain, or could obtain, in their own conditions. Agronomists' technical optima require degrees of control over the farm that are unimaginable for most farmers. They also often depend on applications of inputs well above the economic optimum, which itself can only be achieved if:

- The farmer can take the risk of investing in optimal labour and inputs, given that harvests may vary for reasons beyond farmer control, and prices in markets may be lower than expected.
- Farmers have either cash or credit to invest in their crop to the desired degree.
- Farmers possess the knowledge and skills to manage their crop well.

Some progress has been made in understanding these constraints and how to alleviate them, at least within the context of small experiments and short-term projects. However, even if the challenges can be understood, they are not easy to overcome without substantial external support.

Farmers may not be that concerned over optimal yields. This may be because, when land is abundant, yield per hectare matters less than total output; or they may have other sources of income off the farm, so that squeezing the last ounce of production out of the farm is not a priority.

Bearing these points in mind, a separate practical and policy question relates to what can be learned from yield gap analysis, which could help resource-poor farmers to improve their farming production and livelihoods. It might not be helpful for agronomists (or policy-makers) to talk about yield gaps as *deficits* and about *closing yield gaps*. Instead, development professionals should perhaps acknowledge the distance between farmer yields and potential yields as a useful heuristic, but the focus should simply be on helping farmers do better than they currently do.

How can this be done? The next problem to present itself is the micro-scale heterogeneity of African farming landscapes. Growing conditions vary considerably within plots, between plots and across a community of farms, which makes it difficult to assess potential yields and measure yield gaps, or to recommend good farming practices, optimise input levels, and so on. Instead of proposing blanket recommendations for large AEZs, it might be preferable to be able to enable farmers to explore a range of technical options, from which they can select the ones that make sense for them, crop by crop and field by field. The next section considers how farmers can be engaged in processes of developing and applying practical farming solutions that combine agronomic science with local knowledge.

3.1.3 Engaging with farmers in innovation processes

Making good use, and realising the potential benefits, of modern agricultural technologies often requires an effective and judicious application of external inputs, skilful performance of tasks, and timely and coordinated completion of farming operations. This is not always the case. For example, some modern farming inputs, such as an improved cultivar, can be simple to understand and easy to use without requiring fundamental changes in farmers' knowledge or practices.

However, realising the potential benefits of more complex improved farming techniques, such as intercropping and the use of inoculants to improve nitrogen fixation in degraded soils (Falconnier et al., 2017; Ronner et al., 2018), certainly asks more of farmers' knowledge and skills. This section considers literature that discusses alternative ways in which scientists and development practitioners can engage with farmers in innovation processes.

Small-scale farmers are often not well equipped to grapple with introduced technologies that are unfamiliar, counter-intuitive, obscure or complex to them. In these circumstances, farmers might learn about new technology by carrying out their own trials and experiments, by observing the experiences and outcomes of their

neighbours, or by following guidelines provided by external actors (Foster and Rosenzweig, 2010; de Janvry et al., 2016; Bridle et al., 2019).

A DEGRP study led by Peter Dorward examined how innovation happens among small farmers in Kenya, Sudan and Ghana. The researchers found that farmers pro-actively sought, tried out and adapted technologies that could help them to improve their farm livelihoods. Farmers would observe, talk to and learn from one another. However, the processes leading to innovations were different for men and women: the women faced more obstacles than men in terms of access to information and the opportunity to try out new techniques (see Box 6).

Box 6 Male and female farmers as innovators

Innovation systems, agricultural growth and rural livelihoods in East Africa. Led by Peter Dorward

This study explored how different forms of extension systems affected innovation by female and male farmers, and the resulting impacts on incomes and the local economy. It examined the institutions to support farmer innovation in the contrasting cases of Kenya, Sudan and Uganda. Using participatory methods, the study team learned farmers' views of innovation and of its impacts.

Multiple paths lead to innovation on smallholder farms. The understanding of how farmers take up technology and innovation from an institutional ('top-down') perspective differs from the reality of how farmers experience and perceive innovation on their farms and in their communities.

While key informants and literature continually refer to 'uptake' as a linear TOT, farmers' experience is very different and much more nuanced. Farmers actively looked to improve their farm enterprise livelihoods. Rather than passively accepting technology, they sought out, adapted and improved technologies to fit their own individual contexts. Men and women smallholders innovated through different processes, using different technologies (some by choice and some due to the influence of policies/intervention or changes in operating environment), influenced by age, marital status and community standing.

The main constraints to innovation were input and output markets, lack of reliable information and lack of support systems.

Smallholders' propensity to innovate led to measurable differences in income and expenditure in households and the local economy, and indeed to their welfare and quality of life.

A major influence on smallholders was learning from farmer to farmer, including from migrants. Farmers would observe what other farms did, discuss this among themselves, try out new ideas to see how they could improve their farming, and would share planting material.

The research team emphasised the gendered dimensions of communications, of innovation and of the outcomes. Women farmers had less access to some channels of information, had differing resources – above all labour – with which to trial new ideas, and the outcomes of innovation could differ – even to the extent of men taking over enterprises and activities after innovation if they proved profitable.

SOURCES: INFORMATION DERIVED FROM PROJECT REPORTS AND CONFERENCE PRESENTATIONS.

Another DEGRP study, led by Karen Macours, examined how farmers learned through trials and experiments, in a setting where input supply was unreliable. When given dependable inputs to try on their own land, farmers were able to learn from guidance and experiments to see what worked in their settings. They could not, however, always obtain quality inputs from local markets (see Box 7).

Approaches to practitioners' knowledge in agriculture have followed four distinct strands which co-exist into the present. The first sees farmers' knowledge as a problem in need of correction, an obstacle to development, to be corrected by transfer of scientific knowledge and modern technology. The second portrays farmers' knowledge as a distinct cultural system, embedded in its context, which has intrinsic value to be documented and conserved. The third sees the situated knowledge of farming practitioners as a potential resource for agricultural innovation. The fourth perspective depicts farmers and scientists as members of

distinct communities of practice, who should communicate with each other to promote sharing of knowledge and improved understanding to achieve better farming outcomes (Girard, 2015).

The last two decades have seen a convergence of the AIS concept with participatory approaches to agricultural research and innovation for development. The key idea here is that innovation occurs, and can be stimulated and facilitated, by bringing together multiple stakeholders to collaborate in integrated research and development. This involves collaboration not only on technical inventions and the uptake of novel technologies, but also innovations in relationships and practices along value chains. For example, farmers might be connected with other farmers (e.g. in a producer cooperative or farmers' union), input suppliers, grain buyers, extension services, agronomic researchers (e.g. soil scientists, entomologists) and plant breeders to jointly identify problems and develop solutions.

Box 7 Farmers' learning in variable local conditions

Heterogeneous quality of agricultural commercial inputs and learning through experimentation, led by Karen Macours and Rachid Laajaj

The team studied how farmers learned about new inputs in Siaya County, western Kenya, where it was already known from previous research that farmers could find many seeds and fertiliser in local markets, not all of them suited to their farms, not all of them genuine. It was also known that the returns to using inputs depended considerably on soil conditions that varied from plot to plot. If farmers were to make use of improved seed and manufactured inputs, they needed to learn what would work on their farms.

Trials were run in which agronomists helped farmers to set out plots to test varying combinations of seed and fertiliser for maize and soybeans. Some villages were randomly selected for trials, other villages acted as controls. Within treated villages, some farmers were selected for trial randomly, while others were selected for being promising and skilled farmers. The trials ran for three years. Farmers running the trials were surveyed to observe how much they learned and how this changed their farming. Also surveyed were spouses and others in the village to see how learning was shared.

Farmers learned from their trials. It took time, but after a few seasons they could see what worked. Learning was more than just about the trials; wider lessons about crop management were appreciated as well. Lessons were shared within households, but neighbours only learned a little. Farmers running trials wanted to buy more of the inputs that proved effective, but they were not necessarily able to buy what they wanted – indicating failures in markets.

SOURCES: LAAJAJ AND MACOURS (2016); LAAJAJ ET AL. (2020).

This collaborative model is often known as a multi-stakeholder innovation platform or simply an innovation platform. Innovation platforms are a prominent expression of the view that farmers can and should be fully engaged as skilled practitioners, decision-makers and holders of relevant knowledge (Barzola Iza et al., 2020).

Innovation platforms are typically intended to help diagnose problems, explore solutions, improve relationships among stakeholders, encourage mutual learning and empower farmers or specific groups, such as women (Kingiri, 2013; Sell, 2018). Case studies show that innovation platforms and participatory approaches to innovation can be (but are not always) effective in encouraging the uptake and scaling of new technologies and improving farmers' outcomes (Pamuk et al., 2014; Andres et al., 2016; Sanyang et al., 2016; Totin et al., 2020). Evidence that innovation platforms are commonly effective in creating genuinely novel technologies in collaboration with farmers is scant, although studies such as the ones cited provide evidence that innovation platforms can be effective in facilitating the adaptation and refinement of introduced practices, methods, processes and business models to suit local situations.

Innovation platforms may combine 'push' and 'pull' approaches to the development and dissemination of new technologies. Where the aim is to encourage the uptake of specific technologies in optimised configurations – a 'push' approach – the application of a specific technology or use of a specific service is the desired outcome. The push approach was dominant historically, often entailing the promotion of new technologies by a multi-stakeholder platform.

More recently, multi-stakeholder innovation platforms have used participatory approaches, which frame a desired outcome as the point of departure, then seek to assemble resources and coordinate activities in a suitable configuration to achieve that outcome: a 'pull' approach, which focuses on institutional change to foster changes in behaviour, relationships and technical practices, and generate better outcomes. In practice, innovation platforms may be most

effective when they both pull and push; but push often dominates when it comes to scaling (see section 3.1.4). Efforts to increase the numbers of people taking up new technology often default to old-fashioned promotional engagement with farmers (Totin et al., 2020).

Magala et al. (2019) showed that the nature and quality of information flowing within an innovation platform depended on the cohesion of its social networks, which hinged on the strength and quality of social relationships between members, and the influence of prominent people within the network.

Turyahikayo et al. (2018) it was established that the uncertain markets for the agricultural output, sources of inputs and agricultural information were perceived to be the key motivators for the formation of the platform. To maintain the commitment of farmers and other value chain participants, platforms should thus reduce market uncertainty and ensure access to extension services.

Sparrow and Traoré (2018) found innovation platforms to be more favourably assessed by better off farmers (or the 'rural middle class') and in higher-potential agricultural zones with adequate rainfall, compared to those in more arid regions. The authors speculated that the innovation platforms' focus on accessing markets was less relevant or attractive for poorer farmers and those in lower-potential areas, who were struggling to achieve a minimal level of subsistence.

Farmer field schools (FFS) are a relatively recent expression of efforts to involve farmers in research and extension, in which extension officers are expected to work with farmers to identify pressing local problems, make appropriate diagnoses and conduct trials to explore potential solutions (Braun et al., 2006). FFS are often associated with innovation platforms. A systematic review by Waddington et al. (2014) of the impacts and outcomes of FFS in low- and middle-income countries found that FFS improve farmers' knowledge and increase uptake of new practices (such as integrated pest management), leading to increases in farm yields (up 13% on average) and incomes (up 20%

on average). Environmental land management also improved (e.g. reductions in pesticide use). However, the researchers found the evidence base to be thin, being based on short-term evaluations of small pilot programmes that have risks of bias.

Recently Bakker et al. (2021) found persuasive evidence that FFS that more closely fulfil the expectation of authentic collaboration, rather than mere consultation, and were more effective in stimulating enduring changes in farmers' practices. They reported that the collaborative approach even stimulated behaviours of learning and experimentation, which could lead to changes beyond adoption of specific techniques introduced during the field schools. The researchers traced individual trajectories of change in crop management and fertiliser regimes for rainy season crops (including legumes) and vegetable gardens. Among the experimental modifications attempted by farmers themselves were collective preparation of compost and biopesticides for use in garden plots.

3.1.4 Scaling innovations

This section looks at the challenges in encouraging the uptake and spread of new technologies at larger scales, so that improvements in outcomes may be achieved at wider systemic and societal levels. The spread of new technology brings its own challenges, not only in encouraging the more widespread uptake of new techniques and inputs, but also because technologies are adapted and changed as they move into new settings and through new communities of practice. Recognising this means scientists and development agents need to engage with farmers in processes of learning and experimentation.

Recent years have seen renewed interest in understanding the challenge of achieving impact at scale, through the widespread uptake of new technologies (Schut et al., 2020). To move beyond small and short-term pilot projects that have not been designed to stimulate enduring systemic change, development scholars and professionals have called for a 'change of mindset', focused on scaling as a process and task in its own right.

Instead of aspiring to 'reach numbers', or expect scaling to happen spontaneously outside the protected space of a pilot project, development actors should aim to stimulate structural and institutional change so that the system 'perpetuates a solution' instead of 'perpetuating a problem' (Woltering et al., 2019).

For this to work, it is argued, a strategy for scaling needs to be designed into the intervention from the start. Piloting needs to happen not only at the initial stage, but in each phase of a scaling process,

from incubation of the proof of concept, demonstration of viability by first movers, crowding in of a critical mass, and finally, to institutionalization help to establish the improved solution/practice as the 'new normal'

(Woltering et al., 2019: 4).

To enable this, interventions require an explicit theory of scaling (ToS), as part of a wider theory of change, based on explicit analysis and theorisation about impact pathways (Wigboldus et al., 2020). They propose a Practice-Oriented Multi-level perspective on Innovation and Scaling (PROMIS) as an analytical framework for understanding scaling as a process of systemic change involving adjustments in multiple aspects of practices, relationships and institutions (Wigboldus et al., 2016). Several management tools have been developed to guide development actors in tackling the scaling challenge, including the scaling up management (SUM) framework, the Agricultural Sustainability Assessment Tool (ASAT), the Scaling Scan, frameworks developed by the International Fund for Agricultural Development (IFAD) and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) (Woltering et al., 2019), ADOPT (Adoption and Diffusion Outcome Prediction Tool) (Kuehne et al., 2017) and Scaling Readiness (Sartas et al., 2020).

A key aspect of the scaling challenge is the need to tailor and refine technologies to suit the wide diversity of households and socio-ecological niches that characterise small-scale farming systems across Africa. The challenge is to refine a broad 'best bet' option, such as intercropping, into a locally calibrated 'best fit' option for a specific setting co-designed with local farmers. This might be, for example, maize–cowpea

intercropping, to produce additional fodder for livestock without undermining food production for the household (Descheemaeker et al., 2019).

At the same time, scaling technologies necessarily means involving wider circles and networks of actors, which entails letting go of illusions of control when it comes to the many ways in which technologies may be put to use by different people and groups, and their variable impacts in diverse contexts (Schut et al., 2020). Technologies might be used in ways or for purposes that had not been anticipated or intended by the designers of technologies and/or the implementers of development projects; they might also be undesirable from one or more perspectives; for example, destructive of biodiversity or of decent job opportunities for wage labourers (Wigboldus, 2018; de Roo et al., 2019; Glover et al., 2019). Recognising this, discussions about scaling have recently emphasised the ethical responsibilities assumed by promoters of new technologies, creating duties to anticipate and react to possible outcomes, to respond to societal needs and concerns, and to include diverse groups and interests. Once new technologies pass from the seclusion of scientific discovery and enter development and practical use, there is a need to facilitate adaptation, monitor impacts and address negative outcomes (Wigboldus, 2018; Woltering et al., 2019; Schut et al., 2020).

In theory, the larger farmers in a neighbourhood may be in a better position to bear the costs of experimenting with new technologies, so that their behaviours and decisions may be observed at a lower cost and followed by less well-endowed neighbours. However, this type of learning may be more difficult where local agro-ecological conditions vary greatly between farms, affecting the performance of the technology (Foster and Rosenzweig, 2010; Assunção et al., 2013). Indeed, this is what DEGRP researchers found in western Kenya (see Box 7): with much diversity of soil conditions within a village, what one farmer learned by experimenting did not transfer to the neighbours' fields (Laajaj and Macours, 2016).

In practice, information is often distributed through a community unevenly, mediated

via social networks, kin relationships and by socioeconomic marginalisation, gender and caste (Beaman and Dillon, 2018; Nourani, 2018; Krishna et al., 2019). Farmers and cultivators belonging to some groups face systematic disadvantages in access to reliable information and relevant technical assistance. Not only does this matter for equity and inclusion, but evidence also shows that farmers are more likely to be persuaded by demonstrations and demonstrators that resemble their own characteristics and situations (Bridle et al., 2019).

Kondylis et al. (2017) found that providing additional direct training to contact farmers was effective in increasing the uptake of innovative technologies by those farmers. However, this had little impact on the subsequent spread of new practices to other farmers in the community. Emerick et al. (2017) found that field demonstrations, designed to raise awareness of the experiences of early adopters, were effective in increasing the spread of new technology beyond the initial group of contact farmers, and complemented more informal learning from peers.

DEGRP-funded research carried out in South Kivu, DRC, investigated similar issues (see Box 8). These studies found that farmers who were in direct contact with the N2Africa project had acquired technical knowledge about crop management, fertilisers and rhizobium inoculants that enabled them to obtain higher bean yields and improve their household food security. However, the new knowledge (and provided inputs) did not spread easily beyond the contact group. 'Master farmers' were often reluctant to share the advice they received from the project, especially beyond their social networks, unless other farmers asked for it explicitly. Some master farmers demanded that other farmers work for them in return for receiving inputs. Some farming practices, however, spread more easily to other farmers in the community because they were visible (e.g. line sowing). New practices were also more likely to spread beyond the contact group, particularly to disadvantaged members of the community, when the project's local NGO partners made a bigger effort to involve and empower farmers.

Box 8 Lessons from the Kivus on farmer-to-farmer dissemination

Which farmer(s) should we target? How do extension approaches influence social learning and spread of agricultural innovations? Led by Erwin Bulte

This study assessed the impact of agricultural extension offered under N2Africa, a programme to promote soil-improving legumes to small farmers in South Kivu, DRC. Specifically, it looked at the effects of various packages' technical advice and inputs on crop yields, production, income and food security.

In South Kivu, N2Africa worked through six local NGOs to extend technical advice to smallholders, along with starter packs of fertiliser, improved seed varieties for cassava, soybean and maize, and legume seed inoculant. Technical advice, mostly given through farmer training and demonstrations, featured the use of inoculants to boost soybean productivity; crop planting techniques, such as line sowing and seed spacing; use of mineral and organic fertilisers; use of plants to combat erosion; soybean processing; harvest management; and seed conservation.

Two complementary studies were carried out. One looked at the impacts of different packages of extension and inputs allocated randomly across 92 villages. In 31 villages, participating farmers were given extension messages and training, plus the offer of seed, fertiliser and inoculum sold with a 25% subsidy on their actual cost. Another 33 villages just got extension. The remaining 28 villages received nothing, acting as controls.

Other studies were qualitative enquiries in six villages, focused on social networks and how information and fertiliser packs flowed between households.

The survey showed that farmers who had been in contact with the N2Africa programme knew more about crop management, fertilisation and use of inoculants than those in control villages. They obtained higher bean yields – worth about \$40 a hectare – and felt less anxious about their food security. Higher yields, however, were not related to any significant increase in use of fertiliser or other inputs: they came from better crop management.

Little evidence was seen of consistent differences in effects by gender of household head or by security of land tenure. Villages distant from markets seemed to value information more than those close to markets. This may have been because the better-connected villages could buy and apply more inputs, while more remote settlements had to make do with their local resources, making technical knowledge to make use of them all the more valuable.

While some knowledge did spill over from treated to nearby untreated villages, this had little impact on practice or production in the latter. Because the messages being transmitted were quite complicated, they were only likely to be internalised by those who had not only heard the messages and seen the demonstrations, but had also tried out new techniques on their own fields.

The qualitative studies showed that all six NGOs working with N2Africa disseminated advice by first passing information to contact or 'master' farmers, who were then expected to share knowledge and any inputs with satellite farmers. Although the NGOs thought that this model worked, not surprisingly there were reports that a few master farmers had hoarded inputs or only allowed others access in return for labour.

Box 8 Lessons from the Kivus on farmer-to-farmer dissemination (continued)

While knowledge was shared, people were reluctant to advocate and recommend; that, they said, would be too forward, too arrogant, and meant carrying some responsibility for someone else's harvest. If asked, one shared, but only if asked.

The farmers interviewed appreciated and shared messages about line sowing – even those who had not seen demonstration plots picked up the idea after seeing it applied on neighbours' fields; on making and applying compost; and on the processing and benefits of soybean, valued for its protein.

Farmers reported that they could see that the inoculum was working, but few understood how it worked. Manufactured fertiliser was appreciated, but few farmers used it on their field crops owing to cost or unavailability. They understood the economics, however. Fertiliser was almost always applied to small plots for aubergine, cabbage, tomato, as was pesticide.

Those NGOs that had encouraged participation, built capacity locally and empowered women seemed to get a better spread of innovations. The farmers they worked with were more confident in discussing their experiences both with the researchers and among themselves.

Studies of social networks showed that messages and fertiliser packs were shared most when the contact farmers were central to networks and were sociable people. While contact farmers did pass on information and fertiliser to others in their network, the latter passed on rather little, so there was limited spread of advice and inputs.

Broader lessons from this research include:

- Passing messages to contact farmers selected by communities works, but incompletely. If the programme is to reach marginalised households on the periphery of social networks, more has to be done.
- Getting relatively complicated technical messages to farmers, such as those about inoculum, requires sustained extension. Otherwise messages barely get past the contact farmers, and may be altered as they pass among farmers.
- NGOs who had worked to build the capacity of farmer groups saw more results than others.
- The interventions studied were many and diverse. It is very difficult to assess their impacts through experimental trials. The qualitative studies were valuable in gaining insight into social processes that affected the use of farm innovations.

SOURCES: KENDZIOR ET AL. (2015); HOFMAN ET AL. (2017); LEUVELD ET AL. (2017); ROSS (2017); ROSS ET AL. (2017); LEUVELD ET AL. (2018); HOFMAN ET AL. (2019).

Another challenge to learning is that the performance, and hence impacts, of using technology are often not linear or consistent over time (Bridle et al., 2019). Learning can also be challenging when introduced technologies

are very novel, counter-intuitive, or when the realisation of a successful outcome depends on making several changes in complementary practices at the same time (Bridle et al., 2019). In these kinds of situations, simple tools, such

as leaf-colour charts and timely communication of advice and regular reminders, using direct channels such as SMS texting, can increase uptake of new practices and improve farmers' outcomes (Bridle et al., 2019).

DEGRP-supported research led by Arjunan Subramanian studied an intervention in Karnataka, India, where farmers were offered information via various channels, including a helpline. The service proved its value in providing timely and effective advice to help farmers cope with and recover from disease in a legume crop (see Box 9).

When the benefits of adopting new technology are not readily apparent to passive observers, theory suggests that farmers usually need to receive confirmatory information from multiple sources before adopting the new practices. This

implies that, in cases of complex learning, it is more efficient to encourage the spread of new practices by targeting interventions to a cluster of farmers who share connections in a social network. If the technology has more visible pay-offs, efficient interventions should be spread more distantly across a social network (Beaman et al., 2018).

Nonetheless, in spite of these challenges and obstacles, profitable technologies tend to spread through a community quite fast. There appears to be an association between education and the adoption of new technologies, which may have to do with the rapidity and ease with which better-educated farmers can acquire and process useful information about the performance of new technologies (Foster and Rosenzweig, 2010; Rosenzweig and Udry, 2020).

Box 9 The value of timely advice in coping with agricultural problems

Information, market creation and agricultural growth, led by Subramanian Arjunan

The research aimed to examine the impact on farm production and profitability of providing farmers with new information on weather, input and output prices, and cultivation practices through tele-centres and other electronic means. To do so, randomised trials were carried out in two districts of Karnataka, India, where from a pool of more than 1,300 farmers, 600 were selected for treatments. Six sets of interventions were trialled over two years. Focus group discussions complemented the trials and their associated household surveys.

One trial showed that regular provision of information was highly valued by farmers, especially younger farmers with little experience and farmers from scheduled castes.

In late 2013 sterility mosaic virus hit the redgram (pigeon pea) crop. In response, some 67 farmers were given details of a public helpline that they could call for advice on how to respond. Another 33 farmers were taken as controls, and not told of the helpline. Only about one-third of the farmers informed of the helpline actually called it; others said they were thinking about it, or that they doubted the value of any advice offered.

Treated and control groups were balanced. A battery of econometric tests showed that those who got the helpline numbers and made use of them recovered faster and better than control farmers. The helpline proved to be an effective way to help farmers deal with the crop virus.

SOURCES: PUROHIT ET AL. (2015); SUBRAMANIAN ET AL. (2016).

Box 10 Testing better ways to provide information to farmers in northern Ghana

Disseminating Innovative Resources and Technologies to Smallholders (DIRTS) in Northern Region, Ghana, led by Chris Udry

The study asked if farmers in northern Ghana would be encouraged to take up modern agricultural technologies if they had better access to information, farm inputs and rainfall index insurance. Randomised trials were used to test the effects of such interventions.

SMS messages were sent to randomly selected farmers with daily local forecasts of weather – to 80% or higher accuracy – for the next two days. Those farmers who got the messages were more likely to plant and fertilise on days predicted to have light rains. Messages spread across the community. Although the forecasts seemed to help farmers, the impact on farm returns was too small to detect.

Community extension agents were trained in randomly selected villages. In communities treated, farmers scored a little better in their knowledge of best agricultural practice, farmers were more likely not to burn their plots, to test seeds for germination, to plant in rows and to fertilise using manure and manufactured fertiliser. The trial, however, did not lead farmers to invest more in improved seeds or land preparation. Effects, while statistically significant, were minor; agricultural output did not increase, nor did farm profits.

In another trial, farmers were asked to grow their local open-pollinated variety of maize, Obaatanpa, alongside two imported hybrid varieties. In the season observed, one of the latter, Adikanfo, produced yields 57% higher than Obaatanpa – a gain of 1.9 tonnes per hectare, with economic margins 57% greater, amounting to a gain of just over \$360 per hectare. The season observed had ample rain. It remains to be seen how the hybrid performs when rains are poor.

SOURCES: BRIEFING PAPERS FROM THE PROJECT: [HTTPS://WWW.POVERTY-ACTION.ORG/STUDY/DISSEMINATING-INNOVATIVE-RESOURCES-AND-TECHNOLOGIES-SMALLHOLDER-FARMERS-GHANA](https://www.poverty-action.org/study/disseminating-innovative-resources-and-technologies-smallholder-farmers-ghana)

3.2 Social, economic and institutional challenges

For farmers to be able to make use of innovations, they need to know about them and how to use them; innovations need to be profitable at local prices; markets need to function to allow farmers to choose wisely among inputs on sale, to insure against risks and to obtain credit; and tenure needs to be secure enough that farmers feel confident that they will be able to realise the value of their investments and innovations.

3.2.1 Dissemination of information, farmer knowledge and skills

Beyond the simple metric of technology ‘adoption’, embedding a new technology within a transformed agricultural system requires institution building, behavioural change and the

forging of new relationships between multiple players in a value chain, including market actors upstream and downstream of farmers, as well as ancillary services. Approaches such as multi-stakeholder innovation platforms and FFS can be successful among direct participants and within the scope of a short-term project or programme, but embedding change that spreads beyond the circle of ‘contact farmers’, and endures beyond the end of funding, usually requires a longer-term and concerted effort, which is often lacking (see sections 3.1.3–3.1.4).

There is a great deal of effort invested globally by private actors, large and small, in agricultural technology promotion and dissemination. This includes the sophisticated marketing programmes of large transnational agribusiness companies and the efforts of the local sales representatives of national and regional firms that market seeds, fertilisers, machinery and other inputs. Naturally,

these efforts are concentrated in markets where there are profits to be made; they focus on cash crops and commodities, in regions where farmers are connected to input and output markets. In such areas, small- and medium-scale enterprises (SMEs) in rural towns sell and distribute commercial inputs directly to farmers.

Improved farming technologies may also be promoted by private enterprises, of various sizes, that are involved in businesses such as contract farming or certification of production standards (e.g. fair trade, organic or other quality standards). These businesses involve monitoring and even directing which cultivation technologies, methods and practices are used on farms to ensure and verify that they comply with product or process standards required by processors, retailers or consumers.

These commercially oriented technology-promotion activities undertaken by private sector agribusiness companies are much less studied by academic researchers than are public agricultural extension services or agricultural development undertaken by public and philanthropic programmes and projects. Private actors play central roles in disseminating improved farming technologies in some regions, markets, crops and value chains. Large agribusinesses typically focus on commodity crops such as rice and maize, on proprietary hybrids and on branded agricultural chemicals. Through marketing, field demonstrations, farm visits and farmer meetings, enterprises provide information, training and advice to farmers about technologies such as improved seeds, fertilisers and pesticides. The advice is often free of charge at the point of delivery (with the cost accounted for in marketing and sales budgets and/or wrapped up within the purchase price farmers pay for commercial farming inputs).

Many farmers also receive advice about inputs and agronomic problems from the people and enterprises with whom they do business. A remarkable recent study by Liverpool-Tasie et al. (2020b) has found that it is common for SME input suppliers and output purchasers to support farmers with ancillary services, such as agricultural information and extension, help with logistics (e.g. transportation and storage

services) and credit. Despite these arrangements rarely depending on formal contracts, the authors found that the various complementary services significantly helped transactions flow and the building of business relations. They increased the likelihood that the farmers would benefit from the commercial relationship.

There thus appears to be a substantial, emerging commercial sector, successfully but informally linking small-scale producers to small- and medium-scale input suppliers, processors and output traders, thereby providing valuable services to smallholders – including extension and access to improved technologies. Yet this is largely unrecognised by governments, policy-makers and academic researchers. Instead, policy and research usually focus on developing and strengthening formal agri-food businesses and value chains. Here, the emphasis usually is to build private input supply chains, especially seed systems, more than client-focused private advisory services (Louwaars et al, 2013; Spielman and Kennedy, 2016; Zwane and Davis, 2017; Ariga et al., 2019).

3.2.2 Economic conditions

If innovations neither increase the value of output nor reduce costs of production, they are unlikely to be adopted and sustained. While increased yields per hectare tend to correlate with increased profit, the relation is not automatic. A couple of examples make the point. In southern Mali, women farmers were given free mineral fertiliser to encourage them to use it. Not only did they use the fertiliser given, they also applied more herbicide and hired more labour, and output increased considerably. Profits, however, barely increased. The extra value of outputs was almost entirely matched by the rising costs of inputs and labour (Beaman et al., 2013). A technical improvement was no economic improvement.

The reverse was seen in Ethiopia, where an improved variety of chickpea was taken up by 80% of farmers, yet the variety provided no yield advantages over local cultivars. Adoption, however, not only reduced production costs (slightly), but also led to large increases in revenues because the new variety attracted a price premium compared to older varieties (Michler et al., 2019).

Transport costs can be an important deterrent to innovation. Farms distant from markets, with high transport costs to points of sale and input dealers, face a double hit on their farm-gate prices and costs. Costly transport reduces the effective price of produce at the farm gate, while raising that of any purchased. For Uganda, Gollin and Rogerson (2010) document the very high costs of rural transport that depress farm-gate prices, then consider the consequences of reducing these costs through building and maintaining more and better roads. Their model predicts sizeable increases in both agricultural productivity and production.

For northern Tanzania, Aggarwal et al. (2018a) estimated transport costs for farmers as equivalent to 6% of the value of produce per kilometre, typically 40% in total when travelling to the nearest dealer. Farmers in villages more distant from markets faced prices for outputs and inputs 40%–55% less favourable than those in villages close to markets. This fed through to less adoption of purchased inputs and lower outputs sales (by 20%–25%) for each additional standard deviation in the transport cost distribution. If costs of transport could be reduced by half, roughly the effect of paving rural roads, their analysis showed adoption would double.

This agrees with other observations in Tanzania, as for example in the remote Rukwa Valley of the southwest. By 2006 a new road into the valley had greatly reduced transport costs. Consequently, traders ventured to hitherto isolated villages to encourage farmers to grow sesame for sale, a new crop. Many farmers did so. As a result, cash has been earned in this remote area as never before, with around \$5 million a year paid to sesame farmers in Rukwa District since 2006 (Brockington and Noe, 2021).

Improving roads to reduce transport costs can stimulate agricultural production. Despite that, studies that assess this in detail – by, for example,

comparing costs of roads to the net returns to additional production, or by examining the conditions under which the returns outstrip the costs – seem to be surprisingly rare.¹⁰

3.2.3 Market failures

A longstanding concern in rural Africa has been that markets do not work well in rural areas, and especially do not work well for farm inputs and financial services such as insurance and credit. Were markets for inputs, insurance and credit in rural areas better developed,¹¹ farmers would be better placed to take the risk of adopting innovations and paying for the seeds, inputs and tools necessary. Instead, shortcomings in these markets can constitute major deterrents to investment and innovation.

Governments as far back as the 1930s tried to overcome these problems by setting up state enterprises – commodity boards and the like – to provide farmers with essential inputs of seed, planting materials, fertiliser and chemicals, usually advanced on credit, and then to buy up the resulting harvests. Most parastatals were set up for specific crops, above all the export crops of cocoa, coffee, cotton and tea. Since the boards were under political control, ministers were tempted to use them to subsidise costs of inputs, to pay standard prices for outputs even when these had to be transported from remote regions at high cost, to create jobs, and in some cases to manipulate prices to generate a profit to cover government spending in general. All of these factors, plus managers having little incentive to economise given their typical monopoly on marketing, resulted in the boards operating at high cost, some running up very high debts with the central bank – most notably in Tanzania (Ellis, 1983). Consequently, many of these boards were closed down or had their remit much trimmed under the structural adjustment programmes of the 1980s and 1990s (Barrett and Mutambatsere, 2008).¹²

10 The literature search was not specifically looking for these studies, but the more generalised search for publications on innovation could have been expected to detect at least some of them, if they existed.

11 This is not an argument about perfect markets, the ideal of most economists. In high-income countries, markets are usually sufficiently developed that there are agents and institutions that largely (but not necessarily completely) resolve the obstacles faced by farmers in rural Africa. Hence it is not perfection that is required, just development of markets to the point where the obstacles become minor considerations.

12 A parallel experience was seen where the state had provided credit to farmers through state banks or cooperatives: high costs led to such lending being ended or substantially reduced in the 1980s and 1990s.

Since then, most farmers in rural Africa have had to rely on private dealers in markets to provide them with inputs and technical advice, and to buy up their crops and livestock. Those who recommended privatising marketing hoped this would lead to farmers paying less for inputs and getting better prices for their outputs. But after 10 or so years, it was clear that the results had been mixed (Jayne and Jones, 1997; Dorward et al., 1998; Kydd and Dorward, 2004). Many farmers struggled to access reliable inputs at prices that reflect costs plus reasonable margins for distribution and trader profit. They rarely were able to obtain credit for inputs or longer-term investments. Only in selling crops had private traders usually filled the breach left by state enterprises.

Subsequently in the new century, attempts have been made to improve farmers' access to inputs and finance. In some countries, the state has returned to subsidising fertiliser and seed, with Malawi being the best-known example (Chirwa and Dorward, 2013). Private companies, agro-dealers, farmer associations, government and NGO projects have tried to find ways to improve farmer access through schemes such as contract farming, training of agro-dealers, using local agents to distribute inputs on credit, and so on (Wiggins and Keats, 2013). While some local schemes have succeeded, adapting to the specific crops and regions, few working models have been taken to scale.

As noted in the introduction, however, there are some promising signs that, since the 2010s, private traders in supply chains are starting to provide farmers with a wider range of services (Liverpool-Tasie et al., 2020b). An increase in the number of medium-scale farms in the 2010s may also encourage innovation as technical lessons, inputs and marketing spill-over from larger to neighbouring smaller holdings. (Box 11)

Access to reliable, quality inputs

Private provision of farm inputs was limited and flawed across much of rural SSA in the 1990s and 2000s. Private agro-dealers could

only be found in some market centres, often far from their potential customers, and they carried limited stocks.

Subsequently, it seems that availability of dealers has increased and distances from farm to dealer have diminished. For example, in Kenya the government liberalised sales of fertiliser in the early 1990s. Private firms responded: by the mid-2000s, 500 wholesalers and 7,000 retailers dealt in fertiliser. Distance from farmer to dealer fell on average from 8.4 to 4.1 km between 1997 and 2004. Moreover, transport and handling costs were cut in real terms, so the margins for moving fertiliser from the port of Mombasa to Nakuru in the heart of the commercial maize farming zone fell by around 40% in the 1990s. Not surprisingly, smallholders increasingly bought manufactured fertiliser, the share rising from 43% in 1995–1996 to 69% in 2003–2004. Rates of use rose by about 10%, typically reaching 190 kg per hectare or more – comparable to the levels seen in Asia (Ariga et al., 2006; Chamberlin and Jayne, 2009).

Yet, as commercial provision of inputs has increased, concern has emerged about the range of brands on offer (and their quality) above all for those inputs whose quality and effectiveness cannot be readily and swiftly judged by eye or any other sense – for example, seeds, fertiliser and agro-chemicals. Profusion of brands can present farmers with a bewildering choice. In West Africa in the 2010s, numerous small companies imported herbicide directly from Chinese factories labelling the chemicals with their own brands (Haggblade et al., 2021).

Registered generic formulations have driven the proliferation of pesticide products available for sale. For the top-selling active ingredient, glyphosate, pesticide suppliers in the Sahelian countries had registered a total of 39 different generic products for sale as of December 2016, while Ghana had registered 70 and Côte d'Ivoire had approved 147 different generic glyphosate products for sale. ... No wonder farmers complain of difficulties in deciding which brands to purchase (Haggblade et al., 2021).

Box 11 Do medium and large-scale farms encourage innovation by smallholders?

During the 2010s it became increasingly apparent that substantial areas in sub-Saharan Africa have come to be farmed in medium-size holdings of more than 10 and fewer than 100 hectares. Jayne et al. (2016: 197) compiled data from four countries showing that, 'Medium-scale farms control roughly 20% of total farmland (including large farms) in Kenya, 32% in Ghana, 39% in Tanzania, and over 50% in Zambia.'

In addition, some countries, such as Zambia, have for long had substantial areas under large-scale commercial farms even though most farms are much smaller. When the price of agricultural commodities rose dramatically in late 2007 and early 2008, large companies looked to acquire very large farms in Africa – notably in countries with relatively abundant land, such as Mozambique and Tanzania (von Braun and Meinzen-Dick, 2009; Deininger and Byerlee, 2011).

These developments prompt questions about interactions with neighbouring smallholdings, such as competition for land, building of roads and irrigation works, the potential for alliances in buying inputs and selling produce in bulk, jobs on larger holdings, and – of particular interest to this study – transfer of technical ideas from larger- to smaller-scale holdings. Studies have investigated these effects in Mozambique, Nigeria, Tanzania and Zambia.

In Mozambique, large farms did compete with smallholders for land, without generally creating much extra employment or contributing to local infrastructure, though in some cases technical ideas do seem to have transferred from the large to the smaller holdings. Interactions favoured smallholders more when formal links, such as outgrowing¹³ schemes, were in place (Baumert et al., 2019; Glover and Jones, 2019; Deininger and Xia, 2016).

In Kaduna and Ogun States, Nigeria, smallholders had learned better agricultural practices from medium-sized farms, and had bought inputs from the medium farms, leading to higher yields and crop incomes. They also benefitted from selling produce to the medium-scale farms at higher prices than they could get selling independently (Muyanga et al., 2019; Liverpool-Tasie et al., 2020a).

In Kilombero District, Tanzania, small-scale outgrowers producing sugar and rice benefitted from these arrangements more than their peers not in such schemes. Smallholders with more land benefitted more than those with little land, because the former were better placed to capture benefits than the latter (Herrmann, 2017).

Zambia's large-scale farms tend to be centrally located, close to road and rail and to have good soils. Smallholders close to large farms tend to cultivate more land and obtain better yields than other smallholders, even though they use less fertiliser. In areas with medium-scale farms, larger-scale traders had been attracted to come and buy produce, giving smallholders in those areas more opportunity to sell to the traders and to sell more (Lay et al., 2018; Burke, Jayne and Sitko, 2019)

Not surprisingly, given considerable variations of circumstances, findings are mixed – but with some evidence that medium- and large-scale farms can be a channel by which smallholders acquire information, skills and inputs by which to innovate and raise their productivity. Such effects are more likely when explicit arrangements, such as contracted outgrowing, are in place.

13 Where farmers are contracted by a processor, wholesaler or exporter to supply crops. Such arrangements often see farmers offered seed, fertiliser and other inputs on credit, and sometimes technical assistance as well.

Choice is one problem, but more serious is quality of products when materials have been adulterated or counterfeited, and are not what is claimed on the label.¹⁴

Evidence on the extent of this is mixed. Some reports are alarming. In Western and Central Kenya, returns to high quality fertiliser were high for most farmers, but some fertiliser bought from dealers was low quality, so farmers achieved low returns (Carter et al., 2015). In Uganda, analyses of herbicides sold in local markets showed that almost one-third of bottles contained less than 75% of the labelled concentration of active ingredient. Farmers reported they were aware of the problem. Their estimates of the degree and incidence of counterfeiting were similar to those found by laboratory analysis (Ashour et al., 2016). That knowledge would presumably have deterred use of herbicide. For West Africa, Haggblade et al. (2021) reported that fraudulent pesticides accounted for 34% of sales across countries in the region.

Poor quality and counterfeits do not just affect herbicide, either. In a separate study in Uganda, fertiliser and seed on offer in markets were tested. On average 30% of nutrients were missing from fertiliser, while hybrid maize seed contained under 50% of genuine seed (Bold et al., 2017).

Some reports, however, are more reassuring. In five West African countries, testing of fertilisers showed that, while as much of half of blended fertiliser was not up to standard, most single nutrient fertilisers were. Where problems arose, it was not usually the result of deliberate counterfeiting and deception – except for superphosphates in Nigeria that commonly contained quartz – but rather of bagging and storage.

Much variation in quality of fertiliser was seen across the five countries. Quality tended to be better in rural markets than urban, better

for permanent markets than periodic fairs, better in markets with plenty of dealers, and better when agro-dealers had been trained (Sanabria et al., 2013).

In Tanzania, lab testing of fertiliser sold by rural dealers showed the quality of most as meeting standards. Farmers, however, believed otherwise. They thought adulteration was common, they saw apparently degraded, unattractive-looking fertiliser and concluded it was low quality – although testing showed that it was still up to scratch. Consequently, farmers were not willing to pay for fertiliser (Michelson et al., 2021).¹⁵

When maize seeds were tested in Uganda, the seeds were usually found to be good quality. If there were problems, it was down to poor handling and storage of seed, rather than adulteration or counterfeiting (Barriga and Fiala, 2020).

To conclude, evidence of poor quality inputs is mixed, as might be expected given the wide range of inputs, countries and conditions that apply across SSA. One part of the problem is perceptions and credence. Labelling, certification and inspection need improvement so that farmers can be reassured that what is on sale is as it should be. While farmers cannot be sure what they are buying, the risks of adopting new technology rise, risks to which the discussion now turns.

Dealing with risks in innovation

Many innovations require spending more on purchased inputs or extra labour, exposing farmers to at least three risks: (1) the innovation does not work on their fields, in their conditions; (2) the crops or livestock are hit by bad weather, pests or disease; and (3) prices for additional output are lower than expected. Should any of these hazards materialise, the farmer faces lost output, or receives less income than expected. Costs of inputs or labour may not be covered. If

14 If product quality is poor on average, if adulteration and counterfeiting are prevalent, and if farmers switch randomly from one product or brand to another without systematically assessing performance – or if they engage in herds driven by advertising, social signals from rith and kin, or the dealer's advice (see Stone (2007) on Bt cotton seed in India), then quality products may not be distinguished nor bad ones driven out of the market.

15 While it was reassuring that the fertiliser was good, a market failure persisted if farmers could not be convinced of quality.

these have been acquired on credit, the farmer sinks into debt. For farmers on low incomes such risks may be unacceptable.

In years without serious hazards, innovations may pay off on average, sometimes handsomely so. But for those farmers on low incomes, with few assets and savings, and no insurance, the risk of the next season being bad after having spent on inputs can be too great to take.

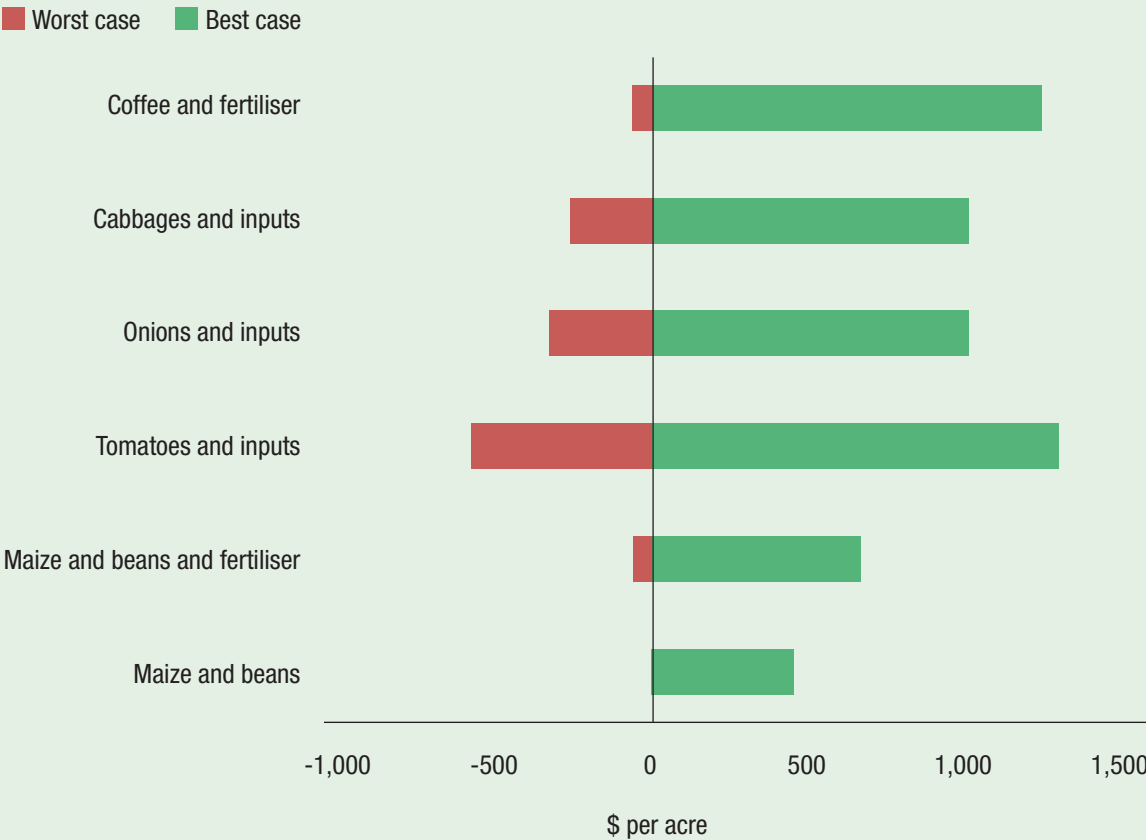
DEGRP research confirmed this for farmers in eastern Uganda. Despite average returns to growing coffee, cabbages, onions or tomatoes with fertiliser being far higher than growing maize and beans, the cash crops could fail, with financial losses to farmers, whereas at least with maize and beans it was only the harvest that was lost, not invested cash (see Box 12).

Box 12 Risk for farmers in eastern Uganda

A behavioural economic analysis of agricultural investment decisions in Uganda, led by Arjan Verschoor

The team studied the role of risk in eastern Uganda. Farmers’ options varied by returns and the risks of a poor harvest (Figure 4): the best-earning crops involved too much risk for most farmers, so they tended to choose maize and beans as a safe option

Figure 4
Expected returns to different crops in eastern Uganda, 2013



SOURCE: RESEARCH TEAM

Box 12 Risk for farmers in eastern Uganda (continued)

The team set two questions:

- How do farmers assess the risk level of investment prospects, and how does this influence their propensity to invest?
- Are farmers' investment decisions influenced by (anticipated) peer responses?

To this end, they conducted experiments with 1,803 smallholders in 100 villages in eastern Uganda. Participants played lottery games where funds were allocated to risky or safe options, outcomes depending on the luck of the draw. Different options were run, farmers played both individually and in pairs. Through repeated games, the following results became clear:

- Most farmers shied away from cash crops because of the risk of spending on fertiliser and not getting enough harvest to cover those costs. Farmers who did choose cash crops tended to downplay the risks of failed harvests – and they often had experience of growing them in real life.
- Farmers were influenced by expectations. They took more risks when risk-taking was suggested in the form of experiment, and took fewer risks when a prior exercise stressed their helplessness against fate.
- Farmers were strongly affected by working in pairs, which brought social obligations. They took fewer risks when losses were shared, more risks when profits were expected. Farmers, it seemed, were altruistic.
- Differences in acceptance of risk between farmers tended to lead to discord between them.

The team fed these results back to farmers, the extension agents and other agricultural officers in the area, and later to a national meeting that brought ministry, NGO and commercial stakeholders together. The meetings produced proposals such as making fertiliser available in small packs, promoting exchanges between farmers to learn from those growing cash crops, and for insurance indexed on bad weather.

The team subsequently engaged with policy-makers, NGOs and commercial firms in Uganda to turn these suggestions into action. In 2020, their efforts to make a difference were recognised by an award from the ESRC.

SOURCE: CLIST ET AL. (2015); D'EXELLE AND VERSCHOOR (2015); LAHNO ET AL. (2015); VERSCHOOR ET AL. (2016).

Aggregate, covariate shocks can heavily reduce returns to agricultural investment, an impact that can be understated by observations at a single time.¹⁶ Analysing panel data on returns to additional crop investment by dryland farmers in Ghana and India, Rosenzweig and Udry (2020) found that investments were profitable on average,

but that year-to-year variations were so great that returns could be very far from the average:

the probability that any single year estimate of the rate of return is within 30 percentage points (on either side) of the expected value of the rate of return is only 5% in both Ghana and India (Rosenzweig and Udry, 2020).

16 Such observations show that using spatial variations of a shock like rainfall at a single time does not provide a reliable guide to variations through time.

They concluded:

Agents making investment decisions and policy-makers making policy decisions in a stochastic world face substantially more risk than measured by conventional estimates that ignore aggregate shocks (Rosenzweig and Udry, 2020).

Farmers typically react to such risks by investing less than they would if returns were more certain. For Ethiopia, dryland farmers facing variable weather spent less on fertiliser than is economically optimal on average, because in a bad year the losses were too hard to bear for households on low incomes. Risk in this case became a poverty trap (Dercon and Christiaensen, 2011).

Risk and its consequences can be mitigated by **technical innovations that reduce variance in yields**, such as crops resistant to drought, floods, pests or diseases. In Odisha, eastern India, researchers released a rice variety that could tolerate being submerged by flood waters – yielding 45% more than other varieties when under water for 10 days, yet which yielded as well as other varieties when there were no floods. Farmers offered minikits of the new variety in a trial were able to gain \$47 per hectare more than farmers without access to the flood-tolerant variety. The value of these extra returns outweighed extra costs of seed by 2.7 to 1. Farmers, moreover, then took more care with the less risky variety, transplanting their rice instead of broadcasting it, and applying more fertiliser (Dar et al., 2013; Emerick et al., 2016)

Despite the clear advantages of the flood-tolerant rice, adoption was slow by control farmers. Four years after the trial gave minikits to a random group of farmers, only 14% of those not treated had adopted. This was attributed to limited supply of seed, apparently the consequence of a monopoly of seed provision by a public corporation (de Janvry et al., 2016)

The other response to risk is to take out **insurance** against either crop losses or the hazards that lead to them. Crop insurance has existed in high-income countries since the nineteenth century and has been introduced in some low- and middle-income countries

within the last 40 or so years. The experience, however, has often been disappointing. When pay-outs depend on evidence of physical losses in the field, recurring problems include adverse selection (careless farmers may be more likely to take up insurance than careful farmers); moral hazard (once insured, farmers may take less care of their crops); and outright corruption (insurance company agents and farmers may falsify claims and share the pay-outs) (Hazell et al., 1986; Gates 1993).

Consequently, since the 1990s much interest has been shown in forms of insurance that avoid these three traps and which otherwise reduce transactions costs. **Index insurance** has been the leading candidate, where insurance is not an indemnity written against a specific hazard or crop losses, but instead pays out against a state of nature closely linked to crop losses. Proxies for crop damage include rainfall (measured by local rainfall gauges) and vegetation (measured by satellite images). When recorded levels of rain or vegetation fall below an advertised threshold, pay-outs are triggered irrespective of what has happened on individual farms. Indexing thus cuts out field inspections and removes the dangers of adverse selection, moral hazard and corruption.

Index insurance needs to be based on reliable measurements of conditions at local scale, to minimise the risk that farmers' losses do not correlate with the index measurement (basis risk). Farmers need to appreciate how the insurance works and how it would cover their risks, something that is probably best learned by experience. Psychological hurdles may apply; insurance premiums paid when hazards do not materialise seem a waste of money, even if the insured farmer understands their value in hard times.

The potential of (index) insurance has been seen in northern Ghana. In a randomised trial, farmers were offered either cash grants or rainfall index insurance. The cash grants made no difference to their farming, but those farmers given index insurance planted (profitable) crops with higher yield variance and invested more in their cultivation (Karlan et al., 2014). Similarly, in semi-arid India (Telangana and Andhra Pradesh)

a trial of rainfall insurance showed it encouraged farmers, especially the better educated, to invest in castor and groundnuts, crops with higher returns but sensitive to rainfall (Cole et al., 2017). In China, tobacco farmers had to take out compulsory insurance from a state bank. Thus insured, they increased their investment in tobacco and raised production (Cai, 2016).

DEGRP studies (see Box 13) also show how farmers offered index insurance expanded their operations, this time in Kenya. Despite this, only one in three farmers introduced to insurance was willing to pay a market premium.

Concern that formal insurance could simply displace informal assistance through social networks is not warranted, inferring from research in India into the effects of rainfall insurance (Mobarak and Rosenzweig, 2012).

They observed that formal insurance covered the aggregate shock, while informal assistance helped those hit by idiosyncratic shocks. That said, Jack et al. (2015) and Oliva et al. (2020) report that in Zambia the prevalence of idiosyncratic risks caused farmers to abandon an otherwise advantageous innovation: a tree that fixes nitrogen.

Despite some successes, take-up of formal insurance schemes has often disappointed – but for reasons that are not always clear. Low take-up can result from marginal defects in the design and execution of schemes, or from farmers not having the product sufficiently well explained to them (Carter et al., 2017). If that were so, improvements could be expected; insurance companies can fine-tune their offer; and in time farmers should come to appreciate how index insurance can work for their farm.

Box 13 Packaging insurance and credit for farmers in Kenya and Ethiopia

Optimal packaging of insurance and credit for smallholder farmers in Africa, led by Ana Marr

In Meru County, Kenya, a randomised control trial assessed the importance of risk for adoption of improved seed, use of fertiliser and chemicals. Some farmers intending to buy certified seed were chosen at random and offered free crop insurance against multiple perils, part indexed on rainfall and part on indemnity against actual losses. Farmers not chosen for insurance formed a control group.

Compared to the control group, those who accepted the free insurance tended to buy more seed, planted a greater area and correspondingly hired in more labour, and spent more on machine operations. They tended to extend their fields rather than intensify on their existing land, understandably, given that most of the farmers said they could get more land to plough.

The trial showed that risk was a deterrent to investment. Given insurance, they invested more on the farms. When asked, however, how much they would pay for insurance, most of those treated offered significantly less than the commercial premium charged – even if they were prepared to pay more than the control group. Just one-third were prepared to pay the market rate (Bulte et al., 2019).

A similar experiment was carried out in the Rift Valley of Ethiopia with 1,661 smallholders. They were offered, variously and randomly, index-based crop insurance; insurance with credit; insurance, credit and farm inputs; or nothing for the control group. Offering insurance alone led to very low uptake of insurance, just 9% of farmers. When linked to credit, however, uptake rose to 24.5%, and uptake rose further, to 32%, when linked to credit and inputs. Interlinking the provision of insurance with credit and inputs made the package more attractive to farmers – although adoption was still only by one-third of farmers (Marr et al. 2019).

SOURCES: BULTE ET AL. (2019); MARR ET AL. (2019).

A greater difficulty is that farmers may lack liquid capital to buy the insurance (Cole et al., 2012, 2013). Bundling insurance with farm credit may overcome liquidity obstacles (Hazell et al., 2010). Low take-up may, however, stem from deeper obstacles still. Farmers may simply not trust the companies and their schemes.

A radical solution to the problem of low uptake would be to treat insurance as a merit good,¹⁷ one that does more good for the persons concerned and society as a whole than the insured farmers realise. Simulating the effects of extending crop insurance to farmers in China at little or no cost to them, Cai (2016) found insurance to be 'both welfare improving and cost-effective'.

Subsidies might be given by publicly discounting reinsurance of insurance companies, allowing them to charge lower premiums for farmers (Bridle et al., 2019, reporting Carter et al., 2017).¹⁸ Indeed, agricultural insurance might be a form of social protection for farmers on low incomes who face substantial risks from bad weather, pests and disease (Bridle et al., 2019).

Liquidity and credit

Since much innovation requires farmers to spend on extra inputs, tools and machinery or labour, lack of capital is likely to deter innovation. Smallholders have little cash for much of the year, so liquidity can easily limit innovation. Savings or credit might be the answer.

Savings

Savings might overcome this, were farmers able to save, and able to discipline themselves to keep whatever they have saved to buy inputs when needed – given that rural households often face requests for financial help from family needing funds to cover school fees, medical bills and other emergencies.

In Kenya, schemes to help farmers save were tried. One scheme involved communal storage of

maize, assisted by the introduction of improved plastic bags to store the grain. Those responding – just over half the members of local savings and credit associations – were more likely to store maize, to sell maize and to sell it later at a better price. Encouraging farmers to save to spend on inputs made little difference to the amount spent on inputs, but probably only because inputs were already used far more than the researchers expected (Aggarwal et al., 2018b).

In Malawi, a trial offered randomly selected farmers the chance to deposit earnings from cash crops into bank savings accounts. Those taking up the offer accumulated more savings ready for next crop season, allowing them to spend more on inputs, consequently growing more, selling more and being able to consume more. The increased spend on inputs, however, was four times the value of savings. This remarkable outcome arose perhaps because savings were banked, and thus less vulnerable to family demands, or because saving focused the minds of farmers on investing in their crops so that additional cash was prioritised to buy inputs (Brune et al., 2015).

This result hints at nudges to change behaviour. In western Kenya, farmers were offered the chance to buy their fertiliser for the next season just after harvest when they had cash, at full price but with the small incentive of free delivery. This led to an increase of one-third or so of farmers taking up fertiliser (Duflo et al. 2008, 2011).

But savings do not always translate into increased investment on the farm. In a Mozambique trial, farmers given a subsidy on fertiliser may have increased their use of inputs, but those who were also encouraged to save – through financial education, introduction to bank branches, and in some cases having matched grants to add to their savings – did not increase their fertiliser use. Instead, they accumulated bank savings, presumably as self-insurance against hazards (Carter et al., 2014).

17 Public education and libraries are often seen as merit goods. Schoolchildren may not realise the lifelong benefits of literacy, numeracy and other skills; book borrowers may not fully appreciate the benefits of their reading. Everyone else in society probably benefits from having educated and well-read citizens around them.

18 Reduced premiums could be made a condition of access to subsidised reinsurance.

Credit

Credit could also provide capital, but formal credit is very hard to obtain for most smallholders in rural Africa. Banks are reluctant to offer credit to small-scale farmers, for three good reasons: (1) they know too little about the credit-worthiness of most farmers – is the applicant a competent farmer, and will they repay if able to do so? (2) administrative costs can be high when dealing with the comparatively small loans that smallholders need; and (3) bankers see considerable risks in farming, and fear involuntary default on loans (Meyer, 2015). Combine all three, and it is no surprise to see just how few smallholders get formal credit for farming.

This may not just be down to lack of supply from banks. Demand from farmers may be low, partly because they worry about the risks of not being able to repay loans, and partly because the paperwork to apply for a loan can be daunting.

Recent research has thus probed farmers' responses to grants of capital, or to savings schemes earmarked for investment in the farm. Trials show that, when farmers get a grant to obtain inputs, a gift of an input or a significant subsidy on the cost of the input, they apply more inputs, and do indeed benefit.

For example, in Mozambique, farmers offered a subsidy on fertiliser raised their use of the input for the season the subsidy was on offer – and for two more seasons after that. Farmers produced more, sold more and earned more (Carter et al., 2014). In Mali, farmers given grants responded by investing in their farms (Beaman et al., 2013). In Uganda, farmers offered free hybrid maize seed and fertiliser bought more of these in subsequent seasons. For the same farmers, availability of credit also increased use of modern inputs (Matsumoto et al., 2013).

Not only can providing working capital help raise production, it can also make markets more stable. In Kenya, farmers were offered credit to enable them to defer sales from immediately after harvest when prices were low until prices were higher. These farmers duly stored their grain, sold later at a better price and realised returns of 28% on the cost of credit. General equilibrium effects, however,

commuted this result. The more farmers stored grain and held off the market, the more prices after harvest improved while those just before the next harvest were reduced. This benefitted farmers who could not afford to wait before selling their maize, who were probably among the poorest. This socially desirable externality could thus justify a public subsidy on seasonal credit (Burke, Bergquist and Miguel, 2019).

Providing credit can also improve allocation of factors of production. In Zambia, for example, farmers offered seasonal credit were less likely to seek farm work to earn cash during the growing season. Seeking work on other farms when the home farm needed labour was a last resort to deal with lack of cash, rather than a rational allocation of household labour between labour market and home farm. Given credit, they withdrew from labouring, resulting in local farm wages rising – benefiting other households, probably poorer farm households who depended on paid farm work (Fink et al., 2014).

Making loan conditions more amenable to farmers can raise uptake of loans and increase investment. In Kenya, members of dairy cooperatives were offered loans to buy water tanks. Instead of insisting on down-payments and guarantors, the loans were secured against the value of the water tank. From a tiny 2.4% of members taking up loans, demand went up to 42% of cooperative members. Almost all borrowers repaid, so very few tanks were repossessed. With more water stored in tanks, children spent less time collecting water, and more girls were enrolled in school (Jack et al., 2016).

These encouraging results do not necessarily always apply, nor do they apply equitably between farmers. For example, in Mali, the farmers who made good use of grants were those who would have applied for credit in any case. This suggests that those farmers who benefitted most from capital, were the ones who tended to seek credit, reminding us that returns to innovations can vary substantially between farmers (Beaman et al., 2013).

When farming is particularly risky, as in semi-arid lands, farmers may be reluctant to invest, even when handed a grant that would allow them to do so. This applied in northern Ghana, as

mentioned earlier, where farmers only invested in crops when they were offered insurance (Karlan et al., 2014). Similarly, farmers in northern Haiti offered subsidies on inputs for rice, groundnuts and horticulture did not increase use of inputs or otherwise invest more in their crops – probably because of the high risks they faced in production (Macours et al., 2018).

Reflections on market failures

Linked problems, complementary solutions

The three obstacles reviewed are linked to some degree. Inputs whose quality is hard to know, which are often watered down or counterfeited, add to the risk of innovation. Hazards in farming and in markets are not only risks in themselves, but also make taking out credit risky, reducing demand for credit.

Measures to address these market failures may thus be complementary and synergistic. This is increasingly recognised in practice. For example, schemes to provide farmers with seasonal credit to buy seed and fertiliser often now incorporate insurance of the inputs. If the rains fail, the pay-out cancels the debt for the inputs. One Acre Fund, for example, has pioneered such packages in East Africa (One Acre Fund managers, pers. comm., since 2019).

Careful studies, limited knowledge

Since 2000 there has been a growing tendency to use experimental methods, including the gold standard of randomised controlled trials. These studies have high internal validity; they produce reliable insights into the effects of treatments offered to farmers in specific agro-ecological, social and economic circumstances. They are, however, nowhere near as valid externally. Without replicating studies in other circumstances, there is no proof that similar results would be obtained.

That is not to say that they do not provide lessons elsewhere. There are grounds, although largely those of specialist opinion rather than scientific proof, to extend the results. For example, lessons from a trial with groundnut farmers in a semi-arid zone, where access to markets is costly, may well apply to groundnut farmers in other dry areas with difficult market access.

Moreover, the experimental studies accumulate to provide valuable insights into processes and factors that affect farmer decisions, some of which must surely apply more widely than the immediate context of the trial. For example, some of the trials – above all those performed in western Kenya referenced above – have made clear just how much conditions can vary from farm to farm, even within the same community, and how much the abilities and resources of neighbouring farmers can vary. It is hard to believe that what has been observed in detail in western Kenya does not apply across parts of, or much of, rural Africa.

For practitioners – government staff designing farm extension, bank managers considering credit lines to farmers, NGO leaders planning projects, input dealers contemplating what to stock, etc. – the increasingly rich picture being developed provides useful guidance on what they might consider. Perhaps an overall lesson is that farmers face multiple obstacles, so that agents of change need to see their efforts as part contributions to improvement, rather than the overall solution – contributions that should be undertaken in the light of, or coordinated with, other similar interventions that tackle related obstacles.

3.2.4 Insecurity of tenure and incentives to innovate

Tenure and incentive to invest

A longstanding concern is that insecure property rights could deter innovation because farmers cannot be sure they will recoup the value of their improvements. Meanwhile logical questions arise over what makes property more or less secure, and how much this affects decisions to innovate.

Much of the land farmed by smallholders in Africa is cultivated under some form of collective tenure where farmers have usufruct rights that apply so long as they are resident and use the land, but they do not have rights to dispose of the land, since ultimate ownership resides with the community (Berry, 1993). To some observers, the lack of the absolute ownership of the land implies insecurity. It is far from clear, however, that those farming with usufruct rights feel their rights to be insecure.



This question has been much studied. Typically, studies examine the apparent consequences of different forms of tenure on innovation and investment, and particularly on conservation measures that pay off over the medium-to-long term. Security of tenure in these studies is not measured, but is just assumed from the form of tenure – since insecurity can hardly be measured by anything other than perceptions. Empirically, most such tests pit farmers with land under collective tenure against those with individual freeholder rights. A certain circularity applies in such studies; if farmers under a particular form of tenure invest, it is inferred that they must perforce feel secure in their tenure – which is what allowed them to invest. The possibility that they take a chance on investing when unsure of their tenure is rarely entertained.

The studies produce a mixed picture. Some do not see collective tenure as deterring investment. For example, Migot-Adholla et al. (1991) and

Place and Hazell (1993) on Ghana, Kenya and Rwanda; Besley (1995) on Ghana; Brasselle et al. (2002) on Burkina Faso; and Place and Otsuka (2002) on Uganda. Others, however, report collective tenure to be an obstacle. In southern Ghana, for instance, farmers were reluctant to leave land fallow to restore soil fertility, owing to fears of loss of rights to land not being actively farmed (Goldstein and Udry, 2008). Farmers in Uganda have invested more on the plots they own outright, compared to those for which they have only usufruct rights (Deininger and Ali, 2008).

Since collective land rights vary from place to place in the security they offer, diverging observations are probably to be expected.

During the 2010s, further studies have reported on relations between land tenure and adoption of innovations and associated investments. Many of these studies (see Table 2) do not set out

Table 2
Studies in the 2010s of land tenure and innovation

Reference	Location, methods	Key findings
Asaaga et al. (2020)	Ghana, southern, econometric analysis of data from 796 plots to explore relation of tenure to investments in sustainable practices	Tenure of land had little influence on uses of inorganic fertiliser or retaining natural trees on land. More secure tenure, however, was associated with the planting of trees. Relation between tenure security and sustainable was also mediated by other important factors including access to credit, modernised agricultural inputs and targeted extension.
Asfaw et al. (2016)	Malawi, modelling farmers' adoption of risk-reducing practices	Some evidence that households were more likely to use sustainable practices on plots under greater tenure security.
Belay and Bewket (2013)	Ethiopia, NW. Regression to explain use of cattle manure on fields using data from 201 households	Plot distance from residence, number of livestock owned, use of dung for fuel, maize–vegetable–fruit intercropping, land to man ratio and perception of land tenure security were important determinants of manure use among the farmers.
Etongo et al. (2018)	Burkina Faso. Probit models of adoption of land management practices, 220 households	Although authors argue that more secure tenure should lead to more adoption of sustainable methods of farming, statistical analysis shows that tenure security is only associated with improved fallowing, but not with zai pits, stone bunds, composting and use of live hedges.
Kassie et al. (2013)	Tanzania, four districts, 60 villages. Probit model of adoption of sustainable practices	Among other factors, plots that were owned and not rented were more likely to see adoption of conservation tillage and soil and water conservation.
Lawin and Tamini (2019)	Benin, econometrics with propensity score matching using data from 2,800 smallholders	Land tenure significantly influences farmer decisions to invest in agri-environmental practices. Intensity of adoption of agri-environmental practices is consistently higher on owned plots than borrowed, rented or share-cropped plots.
Lokonon and Mbaye (2018)	Benin, Niger basin, regression of factors affecting perceptions of climate change and adoption of sustainable land practices, using data from 545 households	Land being owned or family land, and not rented, leased or community land, was associated with legume intercrops – but not with rotations, stone bunds or planting trees.
Paltasingh (2018)	India, Odisha. Tobit regression of effects of tenure on adoption of improved rice technology	Owner operators, with more secure tenurial rights, are more likely to adopt modern varieties than (partial and pure) tenant cultivators. Tenants with long-term tenure adopt more modern varieties than those with shorter tenure.
Turinawe et al. (2015)	Uganda, Kabale District, Tobit model of factors behind adoption of soil and water conservation measures on plots of 338 households	Adoption enhanced by having more labour, better education, higher age, more livestock, soil fertility, training in soil and water conservation, neighbours adopting ... and expected access to parcels.

to determine the role of tenure alone. Instead, they explore the determinants of adoption, typically running models where half a dozen or more hypothesised causes, including some measure of tenure, are regressed on the adoption of one or several different innovations – very often measures to conserve resources and make farming more sustainable. Because tenure is not the focus, measures of tenure security can become simplified to categories such as owned or rented, in situations where gradations of tenure are probably far more varied.

Moreover, such studies are usually observational rather than experimental. They do not necessarily probe for the potential endogeneity of tenure – that is, tenure may be made more secure by some land investments such as planting a tree crop (see Besley, 1995).¹⁹

With those qualifications, the nine studies summarised show in some cases that plots owned, as opposed to rented or share-cropped, were more likely to see adoption of conservation and sustainable practices – but equally, in other studies, similar tenure was shown to make little difference. Given the range of contexts, the different measures of tenure, the different innovations and investments observed, general conclusions about the influence of tenure on innovation cannot be drawn from these recent studies. As Asaaga et al. (2020) conclude in their study in Ghana, tenure is but one of several influences on farmers' decisions, some of them more powerful than tenure, so the impact of tenure on any one investment appears inconsistent when more important determinants vary.

Tenure and credit

A second concern about collective tenure is that land cannot be pledged – because the user only has usufruct or has no formal title – against a bank loan, thereby reducing potential access to formal credit. Although logical, whether this actually hinders obtaining loans is not clear. We

have not come across recent evidence that formal lenders would advance credit if they were able to take title to the land as a guarantee, all other things being equal.²⁰

Whether land as collateral is desirable is questionable. When farming involves taking risks, then pledging land against loans could mean loss of land – and with it the basis of smallholder livelihoods – simply because of bad weather and a poor harvest.

Tenure, efficiency and productivity

DEGRP research has explored another potential path from tenure to agricultural innovation and productivity, taking the case of collective tenure, where land sales are prohibited, renting is discouraged and land may be periodically redistributed to the net benefit of those with little land. This could encourage farmers to remain on their land and not seek potentially higher-paying jobs in towns and cities, hindering a better match between the farmers' skills and aptitudes and land access.

A model of this for Ethiopia initially showed collective tenure could bottle up labour on the land, probably leading to increased agricultural production, but at low labour productivity, with very large losses to the economy as a whole. When, however, general equilibrium effects were modelled, price movements meant economic losses were far less, and relatively few people remained on the land who would otherwise have moved to cities (Gottlieb and Grobovšek, 2019; see Box 14).

In China, the effects of a 2003 reform allowing farmers to lease land were analysed (see Box 15). In villages that had implemented the reform, farmers had more flexibility to respond to changes in cotton prices. When cotton prices rose, farmers were able to expand the area sown and encouraged to apply more fertiliser, thereby growing more. Overall, it seemed that leasing had led to a 7% increase in farm output.

19 Meinzen-Dick et al. (2019) survey the impact of stronger land rights for women farmers, but lament the lack of reliable evidence.

20 In India bankers have been reluctant to take land as a pledge, since costs of enforcing the pledge if the borrower defaults are high – indeed, it is not always possible to take possession of the land, since other villagers may prevent this (Rural bankers, pers. comm., Tamil Nadu, 1984 and 1985).

Box 14 Collective tenure in Ethiopia

Agricultural misallocation, occupational choice and aggregate productivity – the role of insecure land rights and missing financial markets, led by Jan Grobovšek

The study addressed the effects of collective tenure on agricultural productivity. It modelled the consequences of collective tenure where individual farmers are allocated land, but where this land may be taken back and given to others. In effect, renting out land increases the chances that land rented is taken away, while periodic land redistribution favours those with less land. Land sales are not allowed. This is based on tenure observed in Ethiopia, with insights drawn from surveys of farmers.

Collective tenure encourages people to remain on the land, and to work it themselves – regardless of their skills, aptitude or resources to farm. Two potential distortions to an ideal matching of farmers to land then arise: (1) more people will remain in agriculture because they will potentially be allocated land; and (2) farming skills and resources will not be matched to the amount of land operated. The latter effect should reduce the productivity of farming, while the former effect lowers productivity in the overall economy, because people remain in low productivity farming instead of moving to higher productivity jobs in industry and services.

These effects could be strong, the model shows. Agricultural productivity relative to that in other sectors could fall by 25%, and 62% of farmers might remain on the land compared to what would happen with individual tenure with no limits to renting and sales.

Effects are much less strong, however, because prices adjust. As more farmers stay on the land, output rises and pushes down the prices of farm produce. If there were individual tenure with an active land market, farm output prices would rise, as would agricultural productivity raising the incentive to stay on the land.

When price adjustments are factored in, real relative agricultural productivity only falls by 4%; agricultural employment is only 1.5% more than it might be; only 9% of farmers remain on the land; and the loss to gross domestic product (GDP) is just 2%. Hence the outcomes of the two tenure regimes differ less than might first be imagined.

SOURCE: GOTTLIEB AND GROBOVŠEK (2019).

Box 15 Land reform in China: allowing farmers to lease land

Rural property rights, returns to scale and contracts, led by Elaine Liu

In 2003 a land reform act allowed farmers in China to lease out their land.

The research planned to examine the effects of allowing land leasing on farm practice and production, migration, and the potential contracts between agribusiness firms and small family farms. Large-scale national household surveys were used to address these questions, focusing on households growing cotton, using econometric models. The model exploited variations between provinces in the speed with which they implemented the reform.

Where cotton prices had risen, and land was being leased, more land was sown to cotton, more fertiliser was applied, more cotton was harvested and more land was leased out. The reform gave farmers more flexibility to respond to price changes. Leasing had led to a 7% in agricultural output.

SOURCES: LIU (2013); CHARI ET AL. (2017).

4 Conclusions

4.1 Summary of main points

4.1.1 Concepts

Stark differences can be seen in the way that innovation on farms is conceived. Some see most innovation as arising from when farmers adopt technical improvements that have been created by scientists and disseminated to farmers through extension agents – a linear TOT, from the top down. It assumes that leaders of public research are well informed about farmers' priorities, field conditions and the resources they command – which they often are not.

This has been criticised for ignoring that farmers get messages about potential improvements from other sources, including agricultural dealers, radio, social media and other sources, not least from other farmers. Farmers do not simply adopt or not. Rather, they evaluate new ideas, test them on their fields – thereby sometimes finding better ways to apply them – and only then change their farm practice.

One topic where the different conceptions clash arises with gaps between the yield per hectare that researchers can achieve with optimal conditions and management of a crop, and the yields realised by the average farmer – gaps where the latter are often half or less of the former. Yield gaps are often cited to show how much formal research can contribute to development, and so to encourage policy-makers to invest in research.

Yield gaps, however, are not just the result of farmers not making best use of existing technology. Farmer priorities may not be the highest yields per hectare. The technical maximum is usually higher than would make economic sense. Farmers additionally face considerable social, economic and institutional obstacles in raising their yields. Such considerations complicate a simple interpretation of yield gaps to guide innovation, public research and extension.

It is thus no surprise that specialist opinion is divided on the question of whether suitable

technology has been developed for most crops, livestock and AEZs in SSA – and that consequently the main challenge is to encourage farmers to make use of this existing technology, removing the barriers that prevent them from doing so. Some crop scientists and economists would claim that this is broadly the case. Others, including sociologists and anthropologists, prefer to see technical ideas from public research as one element in systems within which processes of innovation arise. Interventions thus need to be suitably nuanced to appreciate the multiple factors that facilitate innovation.

This debate may seem abstract and conceptual, but as we shall see, it has considerable practical implications.

4.1.2 Disseminating technical ideas

Agricultural extension – getting appropriate messages to farmers about potential technical improvements – is a longstanding challenge in agricultural development. More than one model for public extension has been proposed, then found to be flawed, to be replaced with a new model.

Broadly the trajectory of thinking has been from extension as a top-down exercise in telling farmers how they should farm according to standardised recommendations, to more participatory methods where extensionists work alongside farmers to test options that may be effective for different farmers in different conditions. FFS, where groups of farmers facing common problems can come together to share ideas, to try them out and discuss the results, are one way this ideal might be achieved. Innovation platforms – bringing together not just the agricultural world of agronomists and farmers, but also buyers, transporters, input suppliers, bankers and others in supply chains to solve whatever are the most pressing problems affecting farmers – is another, more ambitious model.

Research in the 2010s has helped inform this debate. Studies show just how much

variation exists between farmers' fields in soil fertility and topography, even within villages. Those differences mean that a standard recommendation for, say, seed rates and fertiliser application, cannot be formed at the village level, still less for larger units – such as AEZs. Instead, farmers need to try out potential improvements, to adapt principles to fit their farms and their fields. This is powerful support for more participatory forms of extension.

Moreover, those same studies show that farmers can learn effectively, especially if given some support, but that the transmission from farmer to farmer of what has been learned, including principles behind specific practices, is limited. Ideas may pass along family lines, between close friends, but not generally among all in the local community. That is an equally powerful argument in favour of FFS to target disadvantaged farmers such as women or poorer households.

4.1.3 Economic conditions and market failures

Some innovations promoted may not be profitable for farmers in rural Africa. Above all, when roads are poor and transport costs are high, effective prices at the farm gate for inputs (inflated by haulage rates) and for produce (discounted by freight rates) mean that intensification of production simply does not pay. Fortunately, in parts of Africa it seems roads are being improved and transport costs are falling – thereby widening the range of technical options that pay off.

It is not just transport costs that hinder farmers. Rural markets for inputs and financial systems too often fail. Although inputs such as seed, fertiliser, agro-chemicals and veterinary drugs are now much more commonly available in local market centres than they were in say, the 1990s, the profusion of brands and labels confronts farmers with a bewildering choice. Worse, some inputs are either adulterated or fake, characteristics that cannot readily be detected when buying them, only becoming evident after they have been applied. Evidence of the degree and extent of poor quality inputs is mixed. In some cases it seems farmers are unduly wary of the quality of seed, fertiliser and chemicals, believing inputs are more often poor quality than they actually are.

This contributes to the second problem, that of risk. Most farmers in Africa, not having irrigation, face considerable risks in production – bad weather, pests and disease – as well as in markets for produce where unstable prices may be low when it is time to sell. To those can now be added the risk of buying fake inputs.

Ideally, risk can be mitigated if research can generate seeds and practices that reduce their vulnerability to bad weather, pests and disease. Some innovations do just that, with the much cited example of the flood resistant (Swarna-Sub 1) rice variety developed for Odisha, India. But such innovations are not always available, and they do not necessarily remove all risks.

Hence, much research has gone into how to supply farmers with affordable insurance. Indemnity insurance tends to be costly, in part to offset moral hazard and adverse selection. Much effort has thus gone into index insurance to overcome these by linking pay-outs to a proxy measure, such as rainfall, that may apply across a district, thereby removing the need to assess crop loss field by field. Studies have shown that farmers given such insurance do indeed respond by investing more in their crops and growing more.

But those studies also reveal stumbling blocks. One is the basis risk that the proxy may not correspond to conditions on individual farmers' fields. Given variations from field to field seen in other studies, this risk may be high. Although farmers appreciate index insurance when offered it free or at highly subsidised rates, most are not prepared to pay a market premium for it. On the other hand, insurance can generate benefits for others in the community who are not insured, often people on low incomes. This becomes a strong argument for public subsidy of insurance.

A third significant market failure is that few farmers can obtain formal finance for working capital, and still less investment capital. It is a moot point as to how much this hinders innovation. Some studies, for example, show that, when risk is reduced by insurance, farmers invest more. Capital, it seems in such cases, can be found when risks are removed.

Much has been attempted over the last few decades by governments, NGOs, aid agencies and private banks to make credit available to informal enterprises in Africa by reducing transactions costs and risks – but mainly to traders, manufacturers and service providers, rather than to farmers. A large literature on developing rural financial systems exists, but to date this has not produced solutions to the difficulties of linking creditworthy farmers to formal lenders. Nor have attempts to develop local financial institutions, such as village savings and loans groups, made the difference for farmers, either.

4.1.4 Institutional barriers to innovation: land tenure

In the past, above all in the 1970s, 1980s and 1990s, many observers were concerned that collective tenure regimes – so prevalent for smallholders – would discourage farmers from investing in or conserving the land they farmed (which belonged to the community at large). Given the great variety of ways such collective regimes operate to allocate land, it was no surprise that studies in particular localities came to different conclusions about tenure's effects on investment. If that debate tended to conclude that it all depended on local circumstances, it did arrest the enthusiasm of some policy advocates, notable in aid agencies, for converting collective into individual freehold tenure. From the 1990s onwards, practitioners have been looking for alternative – cheaper and speedier (and sometimes fairer) – ways to strengthen land rights, rather than surveying each field, documenting rights and issuing legal certificates.

In the 2010s, relatively few researchers reported on the relation of tenure to innovation. And even those few studies reviewed here were not concerned with tenure as their prime aim. Tenure was just one condition they observed when looking at factors for innovation.

Concerns over tenure have continued, with one being the economic efficiency of collective tenure. If such tenure means that land cannot readily be transferred between farmers – and this may only apply in some unusual cases, such as the

very particular case of Ethiopia – then there is likely to be a mismatch between farmer skills and aspirations and the land they have to operate. DEGRP research on Ethiopia shows this would be serious, causing massive misallocation of labour and labour with substantial economic losses – were it not for general equilibrium effects of price movements. Factor these in, and effects become minor.

DEGRP studies in China similarly show that allowing more flexible tenure, in this case through leasing of land, can stimulate farmers to invest.

4.2 Reflections and implications

4.2.1 On innovation

Many of the studies reviewed address just some of the many questions that can be asked about innovation, drawing on detailed evidence from small areas – a district or a few villages. Even so, the accumulation of (micro) insights does help to illuminate the bigger picture.

Systems views of innovation, rather than linear TOT, seem a realistic way to frame agricultural innovation. The initial framing used to synthesise these insights (section 2.2) may therefore have been simplistic – although it proved useful to categorise practical responses to obstacles.

A systems view should remind us that:

- (a) Farmers need technical options and they are the best placed to assess them. They may not always have the skills, information and techniques to assess them to best effect. But they can be assisted to do so.
- (b) Their options are not just restricted to what formal public research generates. They get other ideas from private goods on sale in local dealers, some of them – especially seeds and chemicals – the result of formal private research. They also get equipment and tools from engineering allied to the best practice of manufacturing and logistics; for example, cheap irrigation pumps from China. And they may get fake options as well.²¹

21 Not just the counterfeit inputs documented in this report, but also snake-oil messages about too-good-to-be-true farming methods – see Andersson and Giller (2012) on conservation tillage.

(c) Smallholders in SSA, like their counterparts in Asia, are increasingly part-time farmers. The household has other activities, other sources of income. This can limit what household members can do on the farm, it can change their priorities for their farm and, by providing cash, may enable more investment.

A systems view should teach some humility in public policy. We should not imagine that what makes a difference to the lives and livelihoods of farmers comes entirely from public efforts, we should not feel we need to solve all problems, and we should not despair if we cannot do so. We should acknowledge the limits of public endeavours. If these can be allied with those coming from the private sector, both formal and informal, and above all with the agency of farmers – who are not always waiting for others to sort out the problems they face, or to help them seize opportunities – then much may be achieved.²²

While SSA faces some daunting challenges – providing jobs and livelihoods to populations that uniquely in the world are still growing quickly, remedying environmental harm, making sure that farming from now on is sustainable, and adapting

to climate change – **some circumstances are far more favourable than in the past.** Urbanisation and the rise of a middle class means a swelling demand for higher-value foods. Asian industrial success brings cheap tools and machines: motorcycles, pumps, solar panels. Better education and improving health mean the new generation of farmers can work and interact with the rest of the economy more effectively. Agricultural supply chains are being upgraded by enterprises within them, even informal businesses, faster than might have been hoped a decade ago. Private firms are finding ways to help farmers access inputs, advice, credit – because they need the farmers to produce the goods that they can then sell to their customers.

One might also mention **the promise of the new and emerging technologies**, the gene-edited crops, drones, data and artificial intelligence – so long as these are seen for what they are. They are not silver bullets, but rather options for tomorrow’s farmers, for them to assess and incorporate as suits them. We can expect, from past experience, that farmers will take up some of these options, reject others and adapt some for uses that will surprise us.



SOLAR PANEL TECHNOLOGY ON A RURAL FARM IN BENIN. SUPPLIES ENERGY FOR A PUMPING SYSTEM. CREDIT BOULENGER XAVIER SHUTTERSTOCK.COM

22 This represents a challenge to public sector evaluation. When the public project is just one element leading to an outcome, how do we apportion contributions? The public contribution may be overstated or understated.

4.2.2 On policy

Some pointers to public policies, programmes and investments emerge:

Innovation matters, invest in it. Innovation is the only way to conserve resources while producing more for growing populations that increase the demands for food. It is the best way to raise labour productivity on farms and so raise farm incomes and eradicate poverty. It can even be socially progressive, by liberating rural populations from the stranglehold that some landlords have over land and water. Some innovation will come from the private sector, some from informal processes in villages, but some can and must come from formal public research and extension.²³

Steer concepts and practice towards more participation. In a world where private enterprise is a major player, where many farmers have more agency than before, it makes sense to find ways for public actors to work with multiple actors, rather than imagining that all depends on their efforts. Extension in forms such as FFS and innovation platforms are indicated, even if the very best way to implement these may be in debate. In working with farmers to evaluate their options, methods that actively engage and enable them to join in innovation are needed.

Work hard to resolve market failures. If risk can be reduced by insurance, and if, as some studies suggest, there are considerable positive externalities that also benefit those on low incomes, then subsidise insurance. Make it part of social protection. Investigate how to do this, how much it would cost and compare it to the likely benefits.

Great efforts are being made by many actors to improve **rural financial systems**. Ideal models may not yet exist, but the many pilots must surely pay off – so long as pilots and trials are reviewed and evaluated.

Dealing with **variable and fake inputs** – where they exist – presents a new policy challenge, but one for which social scientists should be able

to assist policy-makers. It does not necessarily require new discoveries. Some countries have better ways than others of dealing with this. We need to know those experiences and understand how they work, and in what conditions.

In addressing market failures in isolation, it is easy to become discouraged. Some evidence suggests that bundling inputs with credit and insurance reduces transaction costs and overcomes market failures. That applies most clearly with contract farming, but it is an option that is open to only a minority of farmers. Other actors – input dealers, NGOs, farmer cooperatives, etc. – are finding ways to bundle their offers to help farmers overcome the risks and lack of liquidity that confront them.

Do not worry too much about the interactions between land tenure and innovation. Innovation is not the best reason to address tenure issues. Reasons of equity and protecting the rights of vulnerable farmers to their land are more important – as long as tenure is not ossified – allowing land to move to those who want to farm from those who have better options.

4.2.3 On research

Much of the research reviewed here has been detailed studies covering small areas, using rigorous (sometimes experimental) methods with high internal validity. They often produce invaluable insights. They can be expensive, however. Often researchers create new experiments, rather than examining accidental, natural and less formal experiments.

Yet, across rural Africa many informal pilots and trials are underway to get information, advice and technology to farmers, to improve marketing, to overcome risk, to supply capital, etc. – some by businesses to make profit (see Liverpool-Tasie et al., 2020b), others by more altruistic NGOs and farmer associations. These initiatives offer a rich opportunity for study to learn practical lessons about how they work and with what outcomes and for whom – and to test theories and expectations against such observations.

23 Not reviewed in this synthesis are the many studies (for example, Alston et al., 2009; Fuglie and Rada, 2011) that demonstrate the high pay-offs to public investment in research.

References

- AfDB – African Development Bank (2016) *African development report 2015. Growth, poverty and inequality nexus: overcoming barriers to sustainable development*. Abidjan: AfDB (www.afdb.org/fileadmin/uploads/afdb/Documents/Publications/ADRI5_UK.pdf).
- Affholder, F., Poeydebat, C., Corbeels, M. et al. (2013) 'The yield gap of major food crops in family agriculture in the tropics: assessment and analysis through field surveys and modelling' *Field Crops Research* 143: 106–118 (<https://doi.org/10.1016/j.fcr.2012.10.021>).
- Aggarwal, S., Giera, B., Jeong, D., Robinson, J., and Spearot, A. (2018a) 'Market Access, Trade Costs, and Technology Adoption: Evidence from Northern Tanzania', Working Paper No. 25253, National Bureau of Economic Research Working Paper Series (<https://doi.org/10.3386/w25253>).
- Aggarwal, S., Francis, E. and Robinson, J. (2018b) 'Grain today, gain tomorrow: evidence from a storage experiment with savings clubs in Kenya' *Journal of Development Economics* 134: 1–15 (<https://doi.org/10.1016/j.jdevco.2018.04.001>).
- AGRA – Alliance for a Green Revolution in Africa (2017) *Africa agriculture status report: the business of smallholder agriculture in sub-Saharan Africa* (Issue 5). Nairobi: AGRA (<https://agra.org/wp-content/uploads/2017/09/Final-AASR-2017-Aug-28.pdf>).
- AGRA (2019) *Africa agriculture status report: the hidden middle: a quiet revolution in the private sector driving agricultural transformation* (Issue 7). Nairobi, Kenya: AGRA.
- Alston, J.M., Beddow, J.M. and Pardey, P.G. (2009) 'Agricultural research, productivity, and food prices in the long run' *Science* 325(5945): 1209–1210.
- Anderson, J.R., Feder, G. and Ganguly, S. (2006) *The rise and fall of training and visit extension: an Asian mini-drama with an African epilogue*. World Bank Policy Research Working Paper 3928. Washington DC: World Bank (<https://openknowledge.worldbank.org/handle/10986/8447>).
- Andersson, J.A. and Giller, K.E. (2012) 'On heretics and God's blanket salesmen: contested claims for conservation agriculture and the politics of its promotion in African smallholder farming' in J. Sumberg and J. Thompson (eds) *Contested agronomy: agricultural research in a changing world*. Abingdon: Routledge.
- Andres, C., Mandloi, L.S. and Bhullar G.S. (2016) 'Sustaining the supply of White Gold: the case of SysCom innovation platforms in India' in I. Dror, J.J. Cadilhon, M. Schut et al. (eds) *Innovation platforms for agricultural development: evaluating the mature innovation platforms landscape*. Abingdon: Routledge.
- Ariga, J., Jayne, T.S. and Nyoro, J. (2006) *Factors driving the growth in fertilizer consumption in Kenya, 1990–2005: sustaining the momentum in Kenya and lessons for broader replicability in sub-Saharan Africa*. Working Paper, Tegemeo Institute of Agricultural Policy and Development, Egerton University (<https://ageconsearch.umn.edu/record/55167/?ln=en>).
- Ariga, J., Mabaya, E., Waithaka, M. et al. (2019) 'Can improved agricultural technologies spur a green revolution in Africa? A multicountry analysis of seed and fertilizer delivery systems' *Agricultural Economics* 50(51): 63–74.
- Asaaga, F.A., Hirons, M.A. and Malhi, Y. (2020) 'Questioning the link between tenure security and sustainable land management in cocoa landscapes in Ghana' *World Development*, 130 (<https://doi.org/10.1016/j.worlddev.2020.104913>).
- Ashour, M., Billings, L., Gilligan, D., Hoel, J.B. and Karachiwalla, N. (2017) 'Do beliefs about agricultural inputs counterfeiting correspond to actual rates of counterfeiting? Evidence from Uganda', International Food Policy Research Institute (IFPRI) Discussion Paper 01552 (<https://www.ifpri.org/publication/do-beliefs-about-agricultural-inputs-counterfeiting-correspond-actual-rates>).
- Asfaw, S., McCarthy, N., Lipper, L. et al. (2016) 'What determines farmers' adaptive capacity? Empirical evidence from Malawi' *Food Security*, 8(3): 643–664 (<https://link.springer.com/article/10.1007/s12571-016-0571-0>).
- Assunção, J., Bragança, A. and Hemsley, P. (2013) *High productivity agricultural techniques in Brazil: adoption barriers and potential solutions*. Rio de Janeiro: Climate Policy Initiative (www.climatepolicyinitiative.org/publication/high-productivity-agricultural-techniques-in-brazil-adoption-barriers-and-potential-solutions/).
- AUC/OECD – African Union Commission and OECD (2018) *Africa's development dynamics 2018: growth, jobs and inequalities*. Addis Ababa and Paris: African Union Commission and OECD Publishing.
- Audouin, S., Gazull, L. and Gautier, D. (2018) 'Territory matters: exploring the functioning of an innovation system through the filter of local territorial practices. The example of the adoption of cashew trees in Burkina Faso' *Journal of Rural Studies* 63: 130–140.
- Bakker, T., Dugué, P. and de Tourdonnet, S. (2021) 'Assessing the effects of Farmer Field Schools on farmers' trajectories of change in practices' *Agronomy for Sustainable Development* 41(2): 18.
- Barrett, C.B. and Mutambatsere, E. (2008) 'Marketing boards' in L.E. Blume and S.N. Durlauf (eds) *The new Palgrave dictionary of economics*, 2nd edition. Basingstoke: Palgrave Macmillan.
- Barriga, A. and Fiala, N. (2020) 'The supply chain for seed in Uganda: where does it go wrong?' *World Development* 130: 104928 (<https://doi.org/10.1016/j.worlddev.2020.104928>).
- Barzola Iza, C.L., Dentoni, D. and Omta, O.S.W.F. (2020) 'The influence of multi-stakeholder platforms on farmers' innovation and rural development in emerging economies: a systematic literature review' *Journal of Agribusiness in Developing and Emerging Economies* 10(1): 13–39.
- Baumert, S., Fisher, J., Ryan, C. et al. (2019) 'Forgone opportunities of large-scale agricultural investment: a comparison of three models of soya production in Central Mozambique' *World Development Perspectives* 16: 100145 (<https://doi.org/10.1016/j.wdp.2019.100145>).
-

- Beaman, L. and Dillon, A. (2018) 'Diffusion of agricultural information within social networks: evidence on gender inequalities from Mali' *Journal of Development Economics* 133: 147–161.
- Beaman, L., BenYishay, A., Magruder, J. et al. (2018) *Can network theory-based targeting increase technology adoption?* NBER Working Paper 24912. Cambridge MA: National Bureau of Economic Research (<https://doi.org/10.3386/w24912>).
- Beaman, L., Karlan, D., Thuysbaert, B. et al. (2013) 'Profitability of fertilizer: experimental evidence from female rice farmers in Mali' *American Economic Review* 103(3): 381–386.
- Belay, M. and Bewket, W. (2013) 'Farmers' livelihood assets and adoption of sustainable land management practices in north-western highlands of Ethiopia' *International Journal of Environmental Studies* 70(2), 284–301.
- Berry, S. (1993) *No condition is permanent: the social dynamics of agrarian change in sub-Saharan Africa*. Madison WI: The University of Wisconsin Press.
- Besley, T. (1995) 'Property rights and investment incentives: theory and evidence from Ghana' *Journal of Political Economy* 103(5): 903–937.
- Biggs, S.D. (1995) 'Farming systems research and rural poverty: relationships between context and content' *Agricultural Systems* 47(2), 161–174.
- Bold, T., Kaizzi, K.C., Svensson, J. and Yanagizawa-Drott, D. (2017) 'Lemon technologies and adoption: measurement, theory and evidence from agricultural markets in Uganda' *The Quarterly Journal of Economics* 132(3): 1055–1100.
- Bonny, S. (2016) 'Genetically modified herbicide-tolerant crops, weeds, and herbicides: overview and impact' *Environmental Management* 57(1): 31–48.
- Bortesi, L. and Fischer, R. (2015) 'The CRISPR/Cas9 system for plant genome editing and beyond' *Biotechnology Advances* 33(1): 41–52.
- Bottazzi, P., Goguen, A. and Rist, S. (2016) 'Conflicts of customary land tenure in rural Africa: Is large-scale land acquisition a driver of "institutional innovation"?' *Journal of Peasant Studies* 43(5): 971–988.
- Brasselle, A., Gaspard, F. and Platteau, J. (2002) 'Land tenure security and investment incentives: puzzling evidence from Burkina Faso' *Journal of Development Economics* 67(2): 373–418.
- Braun, A., Jiggins, J., Röling, N. et al. (2006) *A global survey and review of farmer field school experiences*. The Hague: International Livestock Research Institute (www.researchgate.net/publication/228343459_A_Global_Survey_and_Review_of_Farmer_Field_School_Experiences).
- Bridle, L., Magruder, J., McIntosh, C. et al. (2019) *Experimental insights on the constraints to agricultural technology adoption*. ATA, J-PAL, CEGA Working Paper. Cambridge MA and Berkeley CA: MIT and UC Berkeley (www.atai-research.org/experimental-insights-on-the-constraints-to-agricultural-technology-adoption/).
- Brockington, D. and Noe, C. (eds) (2021) *Prosperity in rural Africa? Insights into wealth, assets and poverty from longitudinal studies in Tanzania*. Oxford: Oxford University Press.
- Brune, L., Giné, X., Goldberg, J. and Yang, D. (2015) 'Facilitating savings for agriculture: field experimental evidence from Malawi' *Economic Development and Cultural Change* 64(2), 187–220.
- Bulte, E., Cecchi, F., Lensink, R. et al. (2019) 'Does bundling crop insurance with certified seeds crowd-in investments? Experimental evidence from Kenya' *Journal of Economic Behavior & Organization* 180: 744–757.
- Burke, M., Bergquist, L. F. and Miguel, E. (2019) 'Sell low and buy high: arbitrage and local price effects in Kenyan markets' *The Quarterly Journal of Economics* 134(2): 785–842.
- Burke, W.J., Jayne, T.S. and Sitko, N.J. (2019) 'Do medium-scale farms improve market access conditions for Zambian smallholders?' *Journal of Agricultural Economics* 71(2): 517–533 (<https://doi.org/10.1111/1477-9552.12360>).
- Cai, J. (2016) 'The impact of insurance provision on household production and financial decisions' *American Economic Journal: Economic Policy* 8(2): 44–88.
- Carter, M.R., Laajaj, R. and Yang, D. (2014) *Subsidies and the persistence of technology adoption: field experimental evidence from Mozambique*. Working Paper. National Bureau of Economic Research (<https://doi.org/10.3386/w20465>).
- Carter, M.R., Lybbert, T. and Tjernström, E. (2015) *The dirt on dirt: soil characteristics and variable fertilizer returns in Kenyan maize systems*. Working Paper. University of California Davis.
- Carter, M., de Janvry, A., Sadoulet, E. and Sarris, A. (2017) 'Index insurance for developing country agriculture: a reassessment' *Annual Review of Resource Economics* 9(1): 421–38 (<https://doi.org/10.1146/annurev-resource-100516-053352>).
- Cassman, K.G. and Grassini, P. (2020) 'A global perspective on sustainable intensification research' *Nature Sustainability* 3(4): 262–268.
- Catacora-Vargas, G., Binimelis, R., Myhr, A.I. et al. (2017) 'Socio-economic research on genetically modified crops: a study of the literature' *Agriculture and Human Values* 35(2): 489–513.
- Chamberlin, J. and Jayne, T. (2009) *Has Kenyan farmers' access to markets and services improved? Panel survey evidence, 1997–2007*. Working Paper 33/2009, October. Kenya: Tegemeo Institute of Agricultural Policy and Development, Egerton University.
- Chambers, R. and Jiggins, J. (1987a) 'Agricultural research for resource-poor farmers. Part I: transfer-of-technology and farming systems research' *Agricultural Administration and Extension* 27(1): 35–52.
- Chambers, R. and Jiggins, J. (1987b) 'Agricultural research for resource-poor farmers. Part II: a parsimonious paradigm' *Agricultural Administration and Extension* 27(2): 109–128.
- Chambers, R., Pacey, A. and Thrupp, L.A. (eds) (1989) *Farmer first: farmer innovation and agricultural research*. London: Intermediate Technology Publications.
- Chari, A.V., Liu, E.M., Wang, S.Y. et al. (2017) *Property rights, land misallocation and agricultural efficiency in China*. NBER Working Paper W24099. Cambridge MA: National Bureau of Economic Research (www.nber.org/papers/w24099).

- Chirwa, E. and Dorward, A. (2013) *Agricultural input subsidies: the recent Malawi experience*. Oxford: Oxford University Press.
- Clist, P., D'Exelle, B. and Verschoor, A. (2015) *Nature's frames, reference lotteries and truly risky choice: evidence from a Ugandan field lab*. Norwich: University of East Anglia.
- Cole, S., Bastian, G., Vyas, S. et al. (2012) *The effectiveness of index-based micro-insurance in helping smallholders manage weather-related risks*. London: EPPi-Centre, Social Science Research Unit, Institute of Education, University of London.
- Cole, S., Giné, X., Tobacman, J. et al. (2013) 'Barriers to household risk management: evidence from India' *American Economic Journal: Applied Economics* 5(1): 104–35.
- Cole, S., Giné, X. and Vickery, J. (2017) 'How does risk management influence production decisions? Evidence from a field experiment' *The Review of Financial Studies* 30(6): 1935–70..
- Commission for Africa (2005) *Our common interest*. Report of the Commission for Africa. London: Commission for Africa (<https://reliefweb.int/report/world/our-common-interest-report-commission-africa>).
- Comptour, M., Cosiaux, A., Coomes, O.T. et al. (2020) 'Agricultural innovation and environmental change on the floodplains of the Congo River' *The Geographical Journal* 186(1): 16–30.
- Cong, L., Ran, F.A., Cox, D. et al. (2013) 'Multiplex genome engineering using CRISPR/Cas systems' *Science* 339(6121): 819–823.
- Dar, M.H., de Janvry, A., Emerick, K. et al. (2013) 'Flood-tolerant rice reduces yield variability and raises expected yield, differentially benefitting socially disadvantaged groups' *Scientific Reports* 3(1): 3315.
- De Clercq, M., Vats, A. and Biel, A. (2018) *Agriculture 4.0: the future of farming technology*. Dubai: World Government Summit in collaboration with Oliver Wyman (www.worldgovernmentsummit.org/api/publications/document?id=95df8ac4-e97c-6578-b2f8-ff0000a7ddb6).
- D'Exelle, B. and Verschoor, A. (2015) *Investment behaviour and network centrality: evidence from rural Uganda*.
- de Janvry, A. and Sadoulet, E. (2020) 'Using agriculture for development: supply- and demand-side approaches' *World Development* 133: 105003 (<https://doi.org/10.1016/j.worlddev.2020.105003>).
- de Janvry, A., Sadoulet, E., Dar, M. et al. (2016) *The agricultural technology adoption puzzle: what can we learn from field experiments?* FERDI Working Paper 178. Clermont-Ferrand: Fondation pour les Etudes et Recherches sur le Développement International (<https://ferdi.fr/dl/df-fp2tipEP79TxRtujbBYbr5lKe/ferdi-pl178-the-agricultural-technology-adoption-puzzle-what-can-we-learn.pdf>).
- de Roo, N., Almekinders, C., Leeuwis, C. et al. (2019) 'Scaling modern technology or scaling exclusion? The socio-political dynamics of accessing in malt barley innovation in two highland communities in Southern Ethiopia' *Agricultural Systems* 174: 52–62.
- Deininger, K. Ayalew Ali, D. (2008) 'Do overlapping land rights reduce agricultural investment? Evidence from Uganda' *American Journal of Agricultural Economics* 90(4) 869–882.
- Deininger, K. and Byerlee, D. with Lindsay, J., Norton, A., Selod, H. and Stickler, M. (2011) *Rising global interest in farmland. Can it yield sustainable and equitable benefits?* Washington DC: World Bank.
- Deininger, K. and Xia, F. (2016) 'Quantifying spill over effects from large land- based investment: the case of Mozambique' *World Development* 87: 227–241.
- Dercon, S. and Christiaensen, L. (2011) 'Consumption risk, technology adoption and poverty traps: evidence from Ethiopia' *Journal of Development Economics* 96(2): 159–173.
- Descheemaeker, K., Ronner, E., Ollenburger, M. et al. (2019) 'Which options fit best? Operationalizing the socio-ecological niche concept' *Experimental Agriculture* 55(S1): 169–190.
- Dorward, A., Kydd, J. and Poulton, C. (eds) (1998) *Smallholder cash crop production under market liberalisation: a new institutional economic perspective*. Wallingford: CAB International.
- Duflo, E., Kremer, M. and Robinson, J. (2008) 'How high are rates of return to fertilizer? Evidence from field experiments in Kenya' *American Economic Review* 98(2): 482–88.
- Duflo, E., Kremer, M. and Robinson, J. (2011) 'Nudging farmers to use fertilizer: theory and experimental evidence from Kenya' *American Economic Review* 101(6): 2350–90.
- Egelie, K.J., Graff, G.D., Strand, S.P. et al. (2016) 'The emerging patent landscape of CRISPR-Cas gene editing technology' *Nature Biotechnology* 34(10): 1025–1031.
- Ellis, F. (1983) 'Agricultural marketing and peasant-state transfers in Tanzania' *The Journal of Peasant Studies* 10(4): 214–242.
- Emerick, K., de Janvry, A., Sadoulet, E. et al. (2017) *Enhancing the diffusion of information about agricultural technology*. Working Paper. Boston: Boston University (www.bu.edu/econ/files/2017/03/Emerick_Agricultural_Technology.pdf).
- Emerick, K., de Janvry, A., Sadoulet, E. and Dar M.H. (2016) 'Technological innovations, downside risk, and the modernization of agriculture' *American Economic Review* 106(6): 1537–1561.
- Etongo, D., Epule, T.E., Djenontin, I.N.S. and Kanninen, M. (2018) 'Land management in rural Burkina Faso: the role of socio-cultural and institutional factors' *Natural Resources Forum* 42(3), 201–213.
- Falconnier, G.N., Descheemaeker, K., Van Mourik, T.A. et al. (2016) 'Unravelling the causes of variability in crop yields and treatment responses for better tailoring of options for sustainable intensification in southern Mali' *Field Crops Research* 187: 113–126.
- Falconnier, G.N., Descheemaeker, K., Van Mourik, T.A. et al. (2017) 'Co-learning cycles to support the design of innovative farm systems in southern Mali' *European Journal of Agronomy* 89: 61–74.
- Fink, G., Jack, K. and Masiye, F. (2014) *Seasonal credit constraints and agricultural labor supply: evidence from Zambia*. Working Paper. National Bureau of Economic Research, June (<https://doi.org/10.3386/w20218>).
- Fischer, K., Ekener-Petersen, E., Rydhmer, L. et al. (2015) 'Social impacts of GM crops in agriculture: a systematic literature review' *Sustainability* 7(7): 8598–8620.

- Foster, A.D. and Rosenzweig, M.R. (2010) 'Microeconomics of technology adoption' *Annual Review of Economics* 2(1): 395–424.
- Fresco, L.O., Huizing, H., Van Keulen, H. et al. (1994) *Land evaluation and farming systems analysis for land use planning*. Rome: FAO.
- Fuglie, K., Gautam, M., Goyal, A. et al. (2020) *Harvesting prosperity: technology and productivity growth in agriculture*. Washington DC: World Bank. (<https://openknowledge.worldbank.org/handle/10986/32350>).
- Fuglie, K.O. and Rada, N. (2011) *Policies and productivity growth in African agriculture*. ASTI/IFPRI-FARA Conference Working Paper 19. Accra: ASTI (www.asti.cgiar.org/pdf/conference/Themel/Fuglie.pdf).
- Gao, Y., Liu, B., Yu, L. et al. (2019) 'Social capital, land tenure and the adoption of green control techniques by family farms: evidence from Shandong and Henan Provinces of China' *Land Use Policy* 89.
- Gates, M. (1993) *In default: peasants, the debt crisis, and the agricultural challenge in Mexico*. Boulder CO: Westview Press.
- Girard, N. (2015) 'Knowledge at the boundary between science and society: a review of the use of farmers' knowledge in agricultural development' *Journal of Knowledge Management* 19(5): 949–967.
- Glover, D. (2010) 'Is Bt cotton a pro-poor technology? A review and critique of the empirical record' *Journal of Agrarian Change* 10(4): 482–509.
- Glover, D. (2014) 'Of yield gaps and yield ceilings: making plants grow in particular places' *Geoforum* 53: 184–194.
- Glover, D., Sumberg, J. and Andersson, J.A. (2016) 'The adoption problem; or why we still understand so little about technological change in African agriculture' *Outlook on Agriculture* 45(1): 3–6.
- Glover, D., Sumberg, J., Ton, G. et al. (2019) 'Rethinking technological change in smallholder agriculture' *Outlook on Agriculture* 48(3): 169–180.
- Glover, D., Venot, J.-P. and Maat, H. (2017) 'On the movement of agricultural technologies: packaging, unpacking and situated reconfiguration' in J. Sumberg (ed.) *Agronomy for development: the politics of knowledge in agricultural research*. Abingdon: Routledge.
- Glover, S. and Jones, S. (2019) 'Can commercial farming promote rural dynamism in sub-Saharan Africa? Evidence from Mozambique' *World Development* 114: 110–121.
- Goldstein, M. and Udry, C. (2008) 'The profits of power: land rights and agricultural investment in Ghana' *Journal of Political Economy* 116(6): 981–1022.
- Gollin, D. and Rogerson, R. (2010) *Agriculture, roads, and economic development in Uganda* (No. w15863). National Bureau of Economic Research (www.nber.org/chapters/c13433.pdf).
- Gottlieb, C. and Grobovšek, J. (2019) 'Communal land and agricultural productivity' *Journal of Development Economics* 138: 135–152.
- Haggblade, S., Diarra, A. and Traoré, A. (2021) 'Regulating agricultural intensification: lessons from West Africa's rapidly growing pesticide markets' *Development Policy Review* 12 January (<https://doi.org/10.1111/dpr.12545>).
- Hall, A. and Dorai, K. (2020) 'Agricultural research, technology and innovation in Africa: issues and options' *International Journal of Technology Management & Sustainable Development* 19(1): 3–22.
- Hall, A., Sulaiman, R., Clark, N. et al. (2003) 'From measuring impact to learning institutional lessons: an innovation systems perspective on improving the management of international agricultural research' *Agricultural Systems* 78(2): 213–241.
- Harou, A., Liu, Y., Barrett, C.B. and You, L. (2014) *Variable returns to fertilizer use and its relationship to poverty: experimental and simulation evidence from Malawi*. IFPRI Discussion Paper No. 01373. Washington, DC: IFPRI.
- Hazell, P., Anderson, J., Balzer, N. et al. (2010) *Potential for scale and sustainability in weather index insurance for agriculture and rural livelihoods*. Rome: IFAD and WFP.
- Hazell, P., Pomareda, C. and Valdés, A. (eds) (1986) *Crop insurance for agricultural development: issues and experience*. Baltimore MD: The Johns Hopkins University Press.
- Heap, I. (2014) 'Global perspective of herbicide-resistant weeds' *Pest Management Science* 70(9): 1306–1315.
- Hermans, T.D.G., Whitfield, S., Dougill, A.J. and Thierfelder, C. (2020) 'Bridging the disciplinary gap in conservation agriculture research, in Malawi. A review' *Agronomy for Sustainable Development* 40(1): 1–15.
- Herrmann, R.T. (2017) 'Large-scale agricultural investments and smallholder welfare: a comparison of wage labor and out grower channels in Tanzania' *World Development* 90: 294–310.
- Hofman, P., Larson, J., Ross, M. et al. (2017) *Social networks and social preferences: a lab-in-field experiment in eastern DRC*. Working Paper.
- Hofman, P., Larson, J., Ross, M. et al. (2019) 'The importance of initial recipients for technology diffusion: evidence from a field experiment in the Congo'. Draft paper (www.semanticscholar.org/paper/The-Importance-of-Initial-Recipients-for-Technology-Hofman-Larson/b80e1465fa4aa2a42c662ceaab980f3b7fe06f75).
- Ivanic, M. and Martin, W. (2018) 'Sectoral productivity growth and poverty reduction: national and global impacts' *World Development* 109: 429–439.
- Jack, B., Kelsey, P.O., Severen, C. et al. (2015) *Technology adoption under uncertainty: take-up and subsequent investment in Zambia*. Working Paper. National Bureau of Economic Research, July (<https://doi.org/10.3386/w21414>).
- Jack, W., Kremer, M., de Laet, J. and Suri, T. (2016) *Borrowing requirements, credit access, and adverse selection: evidence from Kenya*. Cambridge, MA: National Bureau of Economic Research, September (<https://doi.org/10.3386/w22686>).
- Jacobson, K. (2013) 'From betterment to Bt maize: agricultural development and the introduction of genetically modified maize to South African smallholders'. PhD thesis, Swedish University of Agricultural Sciences, Uppsala (http://pub.epsilon.slu.se/10406/1/Jacobson_k_130507.pdf).
- Jama, B., Kimani, D., Harawa, R. et al. (2017) 'Maize yield response, nitrogen use efficiency and financial returns to fertilizer on smallholder farms in southern Africa' *Food Security* 9: 577–593.

- Jayne, T.S., Chamberlin, J., Traub, L., et al. (2016) 'Africa's changing farm size distribution patterns: the rise of medium-scale farms' *Agricultural economics* 47, no. 51 (2016): 197-214.
- Jayne, T.S., Adelaja, A. and Mkandawire, R. (2020) 'Africa's rapid economic transformation' *Rural 21* 54(2): 14-17 (www.rural21.com/english/archive/2020/02/detail/article/africas-rapid-economic-transformation.html).
- Jinek, M., Chylinski, K., Fonfara, I. et al. (2012) 'A programmable dual-RNA-guided DNA endonuclease in adaptive bacterial immunity' *Science* 337(6096): 816-821.
- Kamanga, B.C.G., Waddington, S.R., Whitbread, A.M. et al. (2014) 'Improving the efficiency of use of small amounts of nitrogen and phosphorus fertilizer on smallholder maize in central Malawi' *Experimental Agriculture* 50(2): 229-249.
- Karlan, D., Osei, R., Osei-Akoto, I. and Udry, C. (2014) 'Agricultural decisions after relaxing credit and risk constraints' *The Quarterly Journal of Economics* 129(2): 597-652.
- Kassie, M., Jaleta, M., Shiferaw, B. et al. (2013) 'Adoption of interrelated sustainable agricultural practices in smallholder systems: evidence from rural Tanzania' *Technological Forecasting & Social Change* 80(3): 525-540.
- Kathage, J. and Qaim, M. (2012) 'Economic impacts and impact dynamics of Bt (*Bacillus thuringiensis*) cotton in India' *Proceedings of the National Academy of Sciences* 109(29): 11652-11656.
- Kendzior, J., Zibika, J.-P., Voors, M. et al. (2015) *Social relationships, local institutions, and the diffusion of improved variety seed and field management techniques in rural communities: six case studies in South Kivu, DRC*. Wageningen: Wageningen University (<https://n2africa.org/sites/default/files/inline-images/Kendzior%20et%20all%20qualitative%20report.pdf>).
- Khatodia, S., Bhatotia, K., Passricha, N. et al. (2016) 'The CRISPR/Cas genome-editing tool: application in improvement of crops' *Frontiers in Plant Science* 7: 506.
- King, A. (2017) 'Technology: the future of agriculture' *Nature* 544(7651): 521-523.
- Kingiri, A.N. (2013) 'A review of innovation systems framework as a tool for gendering agricultural innovations: exploring gender learning and system empowerment' *The Journal of Agricultural Education and Extension* 19(5): 521-541.
- Klümper, W. and Qaim, M. (2014) 'A meta-analysis of the impacts of genetically modified crops' *PLoS ONE* 9(11): e111629.
- Kondylis, F., Mueller, V. and Zhu, J. (2017) 'Seeing is believing? Evidence from an extension network experiment' *Journal of Development Economics* 125: 1-20.
- Kosmowski, F., Alemu, S., Mallia, P. et al. (2020) *Shining a brighter light: comprehensive evidence on adoption and diffusion of CGIAR-related Innovations in Ethiopia*. Rome: Standing Panel on Impact Assessment (<https://cas.cgiar.org/spia/publications/shining-brighter-light-comprehensive-evidence-adoption-and-diffusion-cgiar>).
- Kranthi, K.R. and Stone, G.D. (2020) 'Long-term impacts of Bt cotton in India' *Nature Plants* 6(3): 188-196.
- Krishna, V.V., Aravalath, L.M. and Vikraman, S. (2019) 'Does caste determine farmer access to quality information?' *PLoS ONE* 14(1): e0210721.
- Kuehne, G., Llewellyn, R., Pannell, D.J. et al. (2017) 'Predicting farmer uptake of new agricultural practices: a tool for research, extension and policy' *Agricultural Systems* 156: 115-125.
- Kydd, J. and Dorward, A. (2004) 'Implications of market and coordination failures for rural development in least developed countries' *Journal of International Development* 16(7): 951-970.
- Laajaj, R. and Macours, K. (2016) 'Learning-by-doing and learning-from-others: evidence from agronomical trials in Kenya'. Ferdi Policy Brief B156. Clermont-Ferrand: Fondation pour les Etudes et Recherches sur le Développement International (<https://ferdi.fr/en/publications/learning-by-doing-and-learning-from-others-evidence-from-agronomical-trials-in-kenya>).
- Laajaj, R., Macours, K., Masso, C. et al. (2020) 'Reconciling yield gains in agronomic trials with returns under African smallholder conditions' *Scientific Reports* 10(1): 14286.
- Lahno, A.M., Serra-Garcia, M., D'Exelle, B. et al. (2015) 'Conflicting risk attitudes' *Journal of Economic Behavior & Organization* 118: 136-149.
- Lawin, K.G. and Tamini, L.D. (2019) 'Land tenure differences and adoption of agri-environmental practices: evidence from Benin' *Journal of Development Studies* 55(2), 177-190.
- Lay, J., Nolte, K. and Sipangule, K. (2018) *Large-scale farms and smallholders: evidence from Zambia*. Kiel Working Papers 2098. Kiel Institute for the World Economy.
- Ledford, H. (2015) 'CRISPR, the disruptor' *Nature* 522(7554): 20-24.
- Leuvel, K., Nillesen, E., Pieters, J. et al. (2017) *The impact of agricultural extension and input subsidies on knowledge, input use and food security in Eastern DRC*. Maastricht: UNU-MERIT (<https://www.merit.unu.edu/publications/uploads/1494255082.pdf>).
- Leuvel, K., Nillesen, E., Pieters, J. et al. (2018) *Agricultural extension and input subsidies to reduce food insecurity. Evidence from a field experiment in the Congo*. UNU-MERIT Working Paper 009. Maastricht: UNU-MERIT (www.merit.unu.edu/publications/working-papers/abstract/?id=7635).
- Liu, E. (2013) 'Time to change what to sow: risk preferences and technology adoption decisions of cotton farmers in China' *The Review of Economics and Statistics* 95(4): 1386-1403.
- Liverpool-Tasie, L.S.O. (2016) 'Is fertilizer use inconsistent with expected profit maximization in sub-Saharan Africa?' The case of rice in Nigeria' *Journal of Agricultural Economics* 68(1): 22-44.
- Liverpool-Tasie, L.S.O., Nuhu, A.S., Awokuse, T. et al. (2020a) *Spillover effects of medium-scale farms on smallholder behaviour and welfare: evidence from Nigeria*. APRA Working Paper 38. Brighton: Future Agricultures Consortium (<https://opendocs.ids.ac.uk/opendocs/handle/20.500.12413/15712>).
- Liverpool-Tasie, L.S.O., Omonona, B.T., Sanou, A. et al. (2016) 'Is increasing inorganic fertilizer use in sub-Saharan Africa a profitable proposition? Evidence from Nigeria' *Food Policy* 67: 41-51.

- Liverpool-Tasie, L.S.O., Wineman, A., Young, S. et al. (2020b) 'A scoping review of market links between value chain actors and small-scale producers in developing regions' *Nature Sustainability* 3(10): 799–808.
- Lobell, D.B., Cassman, K.G. and Field, C.B. (2009) 'Crop yield gaps: their importance, magnitudes, and causes' *Annual Review of Environment and Resources* 34(1): 179–204.
- Lokonon, B.O.K. and Mbaye, A.A. (2018) 'Climate change and adoption of sustainable land management practices in the Niger basin of Benin' *Natural Resources Forum* 42(1): 42–53.
- Louwaars, N.P., de Boef, W.S. and Edeme, J. (2013) 'Integrated seed sector development in Africa: a basis for seed policy and law' *Journal of Crop Improvement* 27(2): 186–214.
- Maat, H. and Glover, D. (2012) 'Alternative configurations of agricultural experimentation' in J. Sumberg and J. Thompson (eds) *Contested agronomy: agricultural research in a changing world*. London: Routledge.
- Macours, K. (2019) 'Farmers' demand and the traits and diffusion of agricultural innovations in developing countries' *Annual Review of Resource Economics* 11(1): 483–499.
- Macours, K. and Laajaj, R. (2016) 'Learning-by-doing and learning from others: evidence from agronomical trials in Kenya'. Policy brief prepared for the Ferdi and SPIA workshop 'Learning for adopting: technology adoption in developing country agriculture', Clermont-Ferrand, France, 1–2 June.
- Macours, K., Stein, D., Salazar, L. et al. (2018) *Technology transfer to small farmers program (PTTA) in Haiti: implementation, evaluation and lessons learned* ([https://publications.iadb.org/publications/english/document/Technology-Transfer-to-Small-Farmers-Program-\(PTTA\)-in-Haiti-Implementation-Evaluation-and-Lessons-Learned.pdf](https://publications.iadb.org/publications/english/document/Technology-Transfer-to-Small-Farmers-Program-(PTTA)-in-Haiti-Implementation-Evaluation-and-Lessons-Learned.pdf)).
- Magala, D.B., Mangheni, M.N. and Miir, R.F. (2019) 'Actor social networks as knowledge sharing mechanisms in multi-stakeholder processes: a case of coffee innovation platforms of Uganda' *The Journal of Agricultural Education and Extension* 25(4): 323–336.
- Marenja, P.P. and Barrett, C.B. (2009) 'Soil quality and fertilizer use rates among smallholder farmers in western Kenya' *Agricultural Economics* 40(5): 561–572.
- Marr, A., Belissa, T. and Lensink, R. (2019) *Uptake and impact of interlinked index-based insurance with credit and agricultural inputs: experimental evidence from Ethiopia*. Greenwich Papers in Political Economy 23810. London: University of Greenwich (<https://gala.gre.ac.uk/id/eprint/23810/>).
- Mather, D., Waized, B. Ndyetabula, D. et al. (2016) *The profitability of inorganic fertilizer use in smallholder maize production in Tanzania: implications for alternative strategies to improve smallholder maize productivity*. GISAIA Working Paper No. 4. Dar es Salaam, Tanzania: GISAIA.
- Matsumoto, T., Yamano, T. and Sserunkuuma, D. (2013) *Technology adoption and dissemination in agriculture: evidence from sequential intervention in maize production in Uganda*. GRIPS Discussion Paper. National Graduate Institute for Policy Studies, July (<https://econpapers.repec.org/paper/ngidpaper/13-14.htm>).
- Maxwell, S. (1986) 'Farming systems research: hitting a moving target' *World Development* 14(1): 65–77.
- Meinzen-Dick, R., Quisumbing, A., Doss, C. et al. (2019) 'Women's land rights as a pathway to poverty reduction: framework and review of available evidence' *Agricultural Systems* 172: 72–82.
- Meyer, R.L. (2015) *Financing agriculture and rural areas in sub-Saharan Africa: Progress, challenges and the way forward*. IIED Working Paper. London: IIED.
- Michelson, H., Fairbairn, A., Ellison, B. et al. (2021) 'Misperceived quality: fertilizer in Tanzania' *Journal of Development Economics* 148: 102579.
- Michler, J.D., Tjernström, E., Verkaart, S. and Mauscher, K. (2019) 'Money matters: the role of yields and profits in agricultural technology adoption' *American Journal of Agricultural Economics* 101(3): 710–731.
- Migot-Adholla, S., Hazell, P. Blarel, B. and Place, F. (1991) 'Indigenous land rights systems in sub-Saharan Africa: a constraint on productivity?' *The World Bank Economic Review* 5 (1): 155–175.
- Mobarak, A.M. and Rosenzweig, M. (2012) *Selling formal insurance to the informally insured*. Working Paper No. 1007. Economic Growth Center, Yale University. (<https://ideas.repec.org/p/egc/wpaper/1007.html>).
- Montenegro, M. (2016) 'CRISPR is coming to agriculture – with big implications for food, farmers, consumers and nature'. ENSIA, 28 January (<https://ensia.com/voices/crispr-is-coming-to-agriculture-with-big-implications-for-food-farmers-consumers-and-nature/>).
- Muyanga, M., Aromolaran, A., Jayne, T. et al. (2019) *Changing farm structure and agricultural commercialisation in Nigeria* (<https://opendocs.ids.ac.uk/opendocs/handle/20.500.12413/14576>).
- NAS – National Academy of Science (2016) *Genetically engineered crops: experiences and prospects*. Washington DC: The National Academies Press (<https://doi.org/10.17226/23395>).
- Ngome, A.F., M. Becker, M.K. Mtei, and F. Mussngug. (2013) 'Maize productivity and nutrient use efficiency in western Kenya as affected by soil type and crop management' *International Journal of Plant Production* 7(3): 517–536.
- Nin-Pratt, A., Johnson, M., Magalhaes, E. et al. (2011) *Yield gaps and potential agricultural growth in west and central Africa*. Washington DC: International Food Policy Research Institute.
- Nourani, V. (2018) 'The nuanced role of social relationships in sub-Saharan village economies'. PhD thesis, Cornell University (<https://doi.org/10.7298/X4B275JD>).
- Nyaga, J., Barrios, E., Muthuri, C.W. (2015) 'Evaluating factors influencing heterogeneity in agroforestry adoption and practices within smallholder farms in Rift Valley, Kenya' *Agriculture, Ecosystems & Environment* 212: 106–118.
- Okali, C., Sumberg, J. and Farrington, J. (1994) *Farmer participatory research: rhetoric and reality*. London: Intermediate Technology.
- Oliva, P., Kelsey Jack, B., Bell, S. et al. (2020) 'Technology adoption under uncertainty: take-up and subsequent investment in Zambia' *The Review of Economics and Statistics* 102(3): 617–32.

- Omonona, B.T., Liverpool-Tasie, L.S.O., Sanou, A. and Ogunleye, W. (2020) 'Is fertilizer use inconsistent with profitability? Evidence from Sorghum Production in Nigeria' *Nigerian Journal of Agricultural Economics* 9(1) (DOI: 10.22004/ag.econ.304676).
- Orr, A. (2012) 'Why were so many social scientists wrong about the Green Revolution? Learning from Bangladesh' *Journal of Development Studies* 48(11): 1565–1586.
- Paltasingh, K.R. (2018) 'Land tenure security and adoption of modern rice technology in Odisha, Eastern India: revisiting Besley's hypothesis' *Land Use Policy* 78: 236–244.
- Pamuk, H., Bulte, E. and Adekunle, A.A. (2014) 'Do decentralized innovation systems promote agricultural technology adoption? Experimental evidence from Africa' *Food Policy* 44: 227–236
- Perry, E.D., Ciliberto, F., Hennessy, D.A. et al. (2016) 'Genetically engineered crops and pesticide use in U.S. maize and soybeans' *Science Advances* 2(8): e1600850.
- Pingali, P.L. (2012) 'Green revolution: impacts, limits, and the path ahead' *Proceedings of the National Academy of Sciences* 109(31): 12302–12308.
- Place, F. and Hazell, P. (1993) 'Productivity effects of indigenous land tenure systems in sub-Saharan Africa' *American Journal of Agricultural Economics* 75(1), 10–19.
- Place, F. and Otsuka, K. (2002) 'Land tenure systems and their impacts on agricultural investments and productivity in Uganda' *Journal of Development Studies* 38 (6): 105–128.
- Purohit, P., Subramanian, A., Nair, G. et al. (2015) 'What is information worth for an extra quintal of grain? Randomised experimental evidence from farmers in India'. Presentation at the 89th Agricultural Economics Society Conference, 13–15 April, Warwick (<http://eprints.gla.ac.uk/118997/>).
- Richards, P. (1985) *Indigenous agricultural revolution: ecology and food production in West Africa*. London: Hutchinson.
- Ronner, E., Descheemaeker, K., Almekinders, C.J.M. et al. (2018) 'Farmers' use and adaptation of improved climbing bean production practices in the highlands of Uganda' *Agriculture, Ecosystems & Environment* 261: 186–200.
- Rosenzweig, M.R. and Udry, C. (2020) 'External validity in a stochastic world: evidence from low-income countries' *The Review of Economic Studies* 87(1): 343–381.
- Ross, M. (2017) 'Raising farmer yields in Eastern D.R. Congo: social learning and reduced cost experiential learning on farmer productivity'. PhD thesis, Wageningen University (<https://library.net/document/y9Owp5wy-leveraging-social-networks-for-agricultural-development-in-africa.html>).
- Ross, M., Hofman, P., Van der Windt, P. et al. (2017) *Selection of targets in network diffusion interventions*. Working Paper. Netherlands: Wageningen University.
- Sanabria, J., Dimithe, G. and Alognikou, E.K.M. (2013) *The quality of fertilizer traded in West Africa: evidence for stronger control*. A Joint ECOWAS, UEMOA and IFDC Report. Muscle Shoals AL: International Fertilizer Development Center (<https://africafertilizer.org/wp-content/uploads/2017/04/The-Quality-of-Fertilizer-Traded-in-West-Africa-Evidence-for-Stronger-Control.pdf>).
- Sanyang, S., Taonda, S.J.-B., Kuiseu, J. et al. (2016) 'A paradigm shift in African agricultural research for development: the role of innovation platforms' *International Journal of Agricultural Sustainability* 14(2): 187–213.
- Sartas, M., Schut, M., Proietti, C. et al. (2020) 'Scaling readiness: science and practice of an approach to enhance impact of research for development' *Agricultural Systems* 183: 102874.
- Schnurr, M.A. (2016) 'GMOs and poverty: yield gaps, differentiated impacts and the search for alternative questions' *Canadian Journal of Development Studies/Revue canadienne d'études du développement* 38(1): 149–157.
- Schut, A.G.T. and Giller, K.E. (2020) 'Soil-based, field-specific fertilizer recommendations are a pipe-dream' *Geoderma* 380: 114680.
- Schut, M., Leeuwis, C. and Thiele, G. (2020) 'Science of scaling: understanding and guiding the scaling of innovation for societal outcomes' *Agricultural Systems* 184: 102908.
- Sell, M. (2018) 'Innovation capacity and women empowerment: identifying constraints and pathways toward sustainability, improved productivity and livelihoods of small-scale farmers in Africa'. PhD thesis, University of Helsinki (<https://helda.helsinki.fi/handle/10138/262135>).
- Séogo, W. and Zahonogo, P. (2019) 'Land tenure system innovation and agricultural technology adoption in Burkina Faso: comparing empirical evidence to the worsening situation of both rural people vulnerability and vulnerable groups' access to land' *African Journal of Science, Technology, Innovation & Development* 11(7): 833–842.
- Shan, Q., Wang, Y., Li, J. et al. (2013) 'Targeted genome modification of crop plants using a CRISPR-Cas system' *Nature Biotechnology* 31(8): 686–688.
- Sheahan, M. and Barrett, C.B. (2014) *Understanding the agricultural input landscape in sub-Saharan Africa: recent plot, household, and community-level evidence*. Policy Research Working Paper 7014. Washington DC: World Bank (<https://openknowledge.worldbank.org/handle/10986/20346>).
- Sheahan, M., Black, R. and Jayne, T.S. (2013) 'Are Kenyan farmers under-utilizing fertilizer? Implications for intensification strategies and research' *Food Policy* 41: 39–52.
- Simmonds, N. (1986) 'A short review of farming systems research in the tropics' *Experimental Agriculture* 22(1): 1–13.
- Smale, M. (2016) 'GMOs and poverty: the relationship between improved seeds and rural transformations' *Canadian Journal of Development Studies/Revue canadienne d'études du développement* 38(1): 139–148.
- Snapp, S., Jayne, T.S., Mhango, W. (2014) *Maize yield response to nitrogen in Malawi's smallholder production systems*. IFPRI Working Paper No. 9. Malawi Strategy Support Program. Washington, DC: International Food Policy Research Institute.
- Sparrow, A.D. and Traoré, A. (2018) 'Limits to the applicability of the innovation platform approach for agricultural development in West Africa: socio-economic factors constrain stakeholder engagement and confidence' *Agricultural Systems* 165: 335–343.

- Spielman, D.J. and Kennedy, A. (2016) 'Towards better metrics and policymaking for seed system development: insights from Asia's seed industry' *Agricultural Systems* 147: 111–122.
- Stone, G. D. (2007) 'Agricultural deskilling and the spread of genetically modified cotton in Warangal' *Current Anthropology* 48(1): 67–103.
- Subramanian, A., Purohit P. and Echavarrri, R. (2016) 'Dial helpline "H" for help'. Presentation at European Winter Meeting of the Econometric Society, 10–11 December, University of Edinburgh, Edinburgh.
- Sumberg, J. (2012) 'Mind the (yield) gap(s)' *Food Security* 4(4): 509–518.
- Suri, T. (2011) 'Selection and comparative advantage in technology adoption' *Econometrica* 79(1): 159–209.
- Tabashnik, B.E. and Carrière, Y. (2017) 'Surge in insect resistance to transgenic crops and prospects for sustainability' *Nature Biotechnology* 35(10): 926–935.
- Tabashnik, B.E., Brévault, T. and Carrière, Y. (2013) 'Insect resistance to Bt crops: lessons from the first billion acres' *Nature Biotechnology* 31(6): 510–521.
- Tittonell, P. and Giller, K.E. (2013) 'When yield gaps are poverty traps: the paradigm of ecological intensification in African smallholder agriculture' *Field Crops Research* 143: 76–90.
- Totin, E., van Mierlo, B. and Klerkx, L. (2020) 'Scaling practices within agricultural innovation platforms: between pushing and pulling' *Agricultural Systems* 179: 102764.
- Tubb, C. and Seba, T. (2019) *Rethinking food and agriculture 2020–2030. The second domestication of plants and animals, the disruption of the cow, and the collapse of industrial livestock farming*. RethinkX Sector Disruption Report. San Francisco CA: RethinkX (www.rethinkx.com/food-and-agriculture#food-and-agriculture-download).
- Turinawe, A., Drake, L. and Mugisha, J. (2015) 'Adoption intensity of soil and water conservation technologies: a case of South Western Uganda' *Environment, Development & Sustainability* 17(4): 711–730.
- Turyahikayo, W., Matsiko, F.B., Okiror, J.J. et al. (2018) 'The perceived role of innovation platforms in addressing the agricultural value chain collective problems: an empirical application of transaction cost theory' *International Journal of Agricultural Research, Innovation and Technology* 8(2): 1–12.
- Valdés, A., Hazell, P.B.R. and Pomareda, C. (1986) 'Crop insurance for agricultural development: Issues and experience'. Instituto Interamericano de Cooperación para la Agricultura Biblioteca Venezuela.
- van Dijk, M., Morley, T., van Loon, M. et al. (2020) 'Reducing the maize yield gap in Ethiopia: decomposition and policy simulation' *Agricultural Systems* 183: 102828.
- van Ittersum, M.K., Cassman, K.G., Grassini, P. et al. (2013) 'Yield gap analysis with local to global relevance: a review' *Field Crops Research* 143: 4–17.
- van Ittersum, M.K., van Bussel, L.G., Wolf, J. et al. (2016) 'Can sub-Saharan Africa feed itself?' *Proceedings of the National Academy of Sciences* 113(52): 14964–14969.
- van Loon, M.P., Adjei-Nsiah, S., Descheemaeker, K. et al. (2019) 'Can yield variability be explained? Integrated assessment of maize yield gaps across smallholders in Ghana' *Field Crops Research* 236: 132–144.
- Vanlauwe, B., Kihara, J., Chivenge, P. et al. (2011) 'Agronomic use efficiency of N fertilizer in maize-based systems in sub-Saharan Africa within the context of integrated soil fertility management' *Plant and Soil* 339(1–2): 35–50.
- Vasco Silva, J. and Ramisch, J.J. (2019) 'Whose gap counts? The role of yield gap analysis within a development-oriented agronomy' *Experimental Agriculture* 55(2): 311–338.
- Vasco Silva, J., Reidsma, P., Laborte, A.G. et al. (2016) 'Explaining rice yields and yield gaps in Central Luzon, Philippines: an application of stochastic frontier analysis and crop modelling' *European Journal of Agronomy* 82(B): 223–241.
- Verschoor, A., D'Exelle, B. and Perez-Viana, B. (2016) 'Lab and life: does risky choice behaviour observed in experiments reflect that in the real world?' *Journal of Economic Behavior & Organization* 128 (2016): 134–148.
- von Braun, J. and Ruth Meinzen-Dick, R. (2009) "'Land Grabbing" by foreign investors in developing countries: risks and opportunities', Policy Brief 13, Washington DC: IFPRI.
- Waddington, H., Snilstveit, B., Hombrados, J. et al. (2014) 'Farmer field schools for improving farming practices and farmer outcomes: a systematic review' *Campbell Systematic Reviews* 10(1): i-335.
- Walker, L.P. and Buhler, D. (2020) 'Catalyzing holistic agriculture innovation through industrial biotechnology' *Industrial Biotechnology* 16(4): 189–208.
- Wigboldus, S. (2018) 'To scale, or not to scale—that is not the only question: rethinking the idea and practice of scaling innovations for development and progress'. PhD thesis, Wageningen University (<https://library.wur.nl/WebQuery/wurpubs/fulltext/449586>).
- Wigboldus, S., Klerkx, L. and Leeuwis, C. (2020) 'Making scale work for sustainable development: a framework for responsible scaling of agricultural innovations' in A.A. Adenle, M.R. Chertow, E.H.M. Moors et al. (eds) *Science, technology, and innovation for Sustainable Development Goals*. Oxford: Oxford University Press.
- Wigboldus, S., Klerkx, L., Leeuwis, C. et al. (2016) 'Systemic perspectives on scaling agricultural innovations: a review' *Agronomy for Sustainable Development* 36(3): 46.
- Wiggins, S. and Keats, S. (2013) *Leaping and learning: linking smallholders to markets in Africa*. London: Agriculture for Impact, Imperial College and ODI (<https://odi.org/en/publications/leaping-and-learning-linking-smallholders-to-markets/>).
- Wiggins, S. and Lankford, B. (2019) *Farmer-led irrigation in sub-Saharan Africa: synthesis of current understandings*. London: Evidence & Policy Group of the DFID-ESRC Growth Research Programme, ODI (<https://degrp.odi.org/publication/farmer-led-irrigation-in-sub-saharan-africa-synthesis-of-current-understandings/>).
- Woltering, L., Fehlenberg, K., Gerard, B. et al. (2019) 'Scaling – from "reaching many" to sustainable systems change at scale: a critical shift in mindset' *Agricultural Systems* 176: 102652.

Woodhouse, P. (1989) 'From green revolution to food security in sub-Saharan Africa: issues in research and technology development' *Food Policy*, 14(1): 7–12.

Zinck, J. A., Berroteràn, J. L., Farshad, A. et al. (2004) 'Approaches to assessing sustainable agriculture' *Journal of Sustainable Agriculture* 23(4): 87–109.

Zwane, E.M. and Davis, K.E. (2017) 'Extension and advisory services: the African renaissance' *South African Journal of Agricultural Extension* 45(1): 78–89.

The views presented in this publication are those of the author(s) and do not necessarily represent the views of FCDO, ESRC or ODI..

© DEGRP 2021

degrp.odi.org



Research jointly supported by the ESRC and FCDO

