Received: 10 August 2019 | Revised: 11 September 2019 | Accepted: 17 September 2019
DOI: 10.1111/agec.12539

ORIGINAL ARTICLE

AGRICULTURAL ECONOMICS
The Journal of the International Association of Agricultural Economists
IAAE
WILEY

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Technology adoption, impact, and extension in developing countries' agriculture: A review of the recent literature

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Abstract
Given the stagnant agricultural productivity and persistent food insecurity in low-income countries—notably in sub-Saharan Africa (SSA)—there has been continued interest in the adoption of new technology and its impact on productivity in these regions. To increase crop yields and sustain yield gains, recent case studies of technology adoption unanimously recommend the adoption of integrated farm management systems, particularly in SSA. On the other hand, there have been increasing numbers of studies on social network or farmer-to-farmer technology extension. These studies explore more efficient extension systems than traditional public-sector extension approaches. This article reviews both recent case studies of technology adoption and its productivity impacts as well as studies on agricultural extension to identify common findings, shortcomings, and major remaining issues.

KEYWORDS
agricultural extension, productivity impact, technology adoption, technological diffusion

JEL CLASSIFICATION
O13, O33, Q16

1 | INTRODUCTION

Given the stagnant agricultural productivity and persistent food insecurity in low-income countries—notably in sub-Saharan Africa (SSA)—there has been continued interest in the adoption of new technology and its impact on productivity. In particular, how to increase maize yield and sustain its yield gain are major issues of agricultural development in SSA. Such interests are supported by changes in favor of the adoption of new agricultural technologies, such as the release of improved crop varieties; widespread use of mobile phones, which is expected to reduce transaction costs (Aker, 2011; Aker & Mbiti, 2010); and buoyant use of microcredit and index-based weather insurance, which would help to remove cash constraints and excessive exposure to production risk (de Janvry, Sadoulet, & Suri, 2017; Magruder, 2018). In fact, there are signs of Green Revolution in maize and rice in SSA, reflected in sharply increasing yield trends in the advanced regions of Africa (Otsuka & Muraoka, 2017).

A widely observed puzzling phenomenon in SSA is the low adoption rate of seemingly profitable technology (Macours, 2019; Sheahan & Barrett, 2017). The first major question that the literature on technology adoption ought to ask is whether truly productive and profitable technologies are available in SSA and other low-income countries. The related question is what the appropriate agricultural technologies are that can bring about significant and sustainable improvement in productivity.

The first purpose of this review article is to identify common findings of the studies on technology adoption regarding its determinants, impacts, and shortcomings. We put emphasis on maize and lowland rice, which attract considerable attention in the developing countries' literature and are considered the most promising staple crops in SSA (Otsuka & Larson, 2013, 2016).[1] A major and common argument in recent studies is that, in addition to the use of modern inputs, integrated farm management systems could lead to significant and sustained gains in productivity. These systems include application of organic fertilizer and intercropping or rotation with leguminous crops in the case of maize and application of bund construction, leveling, and straight-row transplanting in the case of rice.

Even if profitable technologies are potentially available, they may not be diffused widely, partly because of credit, insurance, and other market-related constraints and partly because of the ineffective information dissemination system, largely arising from the absence of effective agricultural extension systems.[2] The extension system is particularly weak in SSA because of the structural adjustment policies implemented in the 1980s and 1990s, which suppressed public-sector activities. To uncover efficient technology extension systems, the 2010s witnessed a surge in studies on social network or farmer-to-farmer technology dissemination. These works were triggered by Foster and Rosenzweig (1995) and Conley and Udry's (2001, 2010) pioneering studies. Whereas these studies have relied on observational data, the recent trend has moved toward the use of experimental data based on the randomized controlled trial (RCT). This technique has been applied to various fields of development economics to rigorously examine the causal impact of interventions such as roles of credit, index-based weather insurance, and contract farming. Because other review articles are available on other issues,[3] the second purpose of this article is to review recent articles on technology diffusion through farmer-to-farmer extension (F2FE).[4] More specifically, we will examine the effectiveness of F2FE systems, qualification of appropriate farmer-trainers, and incentivization of farmer-trainers. Although the available evidence is inadequate, we will attempt to speculate an efficient extension system that combines the traditional public-sector extension with the effective farmer-trainer systems.

The rest of the article is structured as follows. Section 2 reviews the case studies of technology adoption and Section 3 reviews recent studies of technology diffusion. Section 4 concludes the study.

[1] See the online appendix for the recent trend of maize and rice yield by region and distribution of topics related to technology adoption by crop and region in leading journals of development economics and agricultural economics.

[2] In this article, "technology adoption" refers to the adoption of new improved technologies by individual farmers in a certain area, whereas "technology diffusion" refers to widespread adoption of new technologies by a larger number of farmers in wider areas.

[3] See de Janvry et al. (2017), Magruder (2018), Otsuka, Nakano, and Takahashi (2016), and Macours (2019) for related reviews.

[4] Feder, Just, and Zilberman (1985) and Foster and Rosenzweig (2010) provide excellent reviews on the earlier literature on technology adoption.

2 | CASE STUDIES OF TECHNOLOGY ADOPTION

Because the adoption of modern agricultural technologies (improved varieties and inorganic fertilizer) and integrated farm management system is considered an essential component of productivity growth in the literature, we review determinants of such adoptions and their impact in order to understand sustainable farming technologies in developing countries.

2.1 | Adoption of improved varieties

The effort of research and development of new improved varieties suitable for local agroclimatic environments and their diffusion are considered the most important means to boost crop yield and improve the well-being of farmers in developing countries (Evenson & Gollin, 2003). We observe striking heterogeneity among developing countries upon examining the adoption rate of improved crop varieties. For example, using the Living Standards Measurement Study–Integrated Surveys on Agriculture (LSMS-ISA) data set, Sheahan and Barrett (2017) show the percentages of land under improved maize varieties by countries in SSA around 2010–2012 as follows: 28% in Ethiopia, 43% in Malawi, 95% in Nigeria, 35% in Tanzania, and 54% in Uganda.

Adoption of improved varieties generally has positive effects on yield and farmers' welfare. Specifically, the adoption of improved maize, legume, and other cereal varieties significantly increases yield (Villano, Bravo-Ureta, Solís, & Fleming, 2015; Zeng et al., 2015), crop and household income (Bezu, Kassie, Shiferaw, & Ricker-Gilbert, 2014; Kassie, Shiferaw, & Muricho, 2011; Khonje, Manda, Alene, & Kassie, 2015; Manda et al., 2019; Mathenge, Smale, & Olwande, 2014; Smale & Mason, 2014; Verkaart, Munyua, Mausch, & Michler, 2017; Villano et al., 2015), consumption (Asfaw, Kassie, Simtowe, & Lipper, 2012a; Asfaw, Shiferaw, Simtowe, & Lipper, 2012b; Bercerril & Abdulai, 2010; Bezu et al., 2014), nonland asset or wealth (Bezu et al., 2014; Manda et al., 2019; Mathenge et al., 2014; Smale & Mason, 2014), and child nutrition (Zeng et al., 2017). It particularly reduces poverty (Asfaw et al., 2012a; Becerril & Abdulai, 2010; Kassie et al., 2011; Khonje et al., 2015; Manda et al., 2019; Mathenge et al., 2014; Smale & Mason, 2014; Verkaart et al., 2017; Zeng et al., 2015).

Nevertheless, a large number of farmers does not adopt these seemingly promising and welfare-enhancing technologies. Studies note that poor access to information through extension services and inadequate seed supply constrain the adoption of improved crop varieties (Asfaw et al., 2012a, 2012b; Kassie et al., 2011; Khonje et al., 2015; Shiferaw, Kebede, Kassie, & Fisher, 2015; Suri, 2011; Villano et al., 2015). Shiferaw et al. (2015) demonstrate from

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their study of improved groundnut adoption in Uganda that, out of 41% of nonadopters, only 10% of farmers do not want to adopt, whereas 31% of farmers who do, face constraints that impede them from adoption. They empirically show that slow uptake of improved groundnut can be attributed to lack of technological information, seed supply, and credits.

An explanation of nonadoption provided by Suri (2011) was based on the heterogeneous returns to the use of modern inputs among farmers. In a study on Kenya, she finds that farmers with high net returns adopted hybrid seeds, whereas farmers with low net returns did not. She suggests that removing supply and infrastructure constraints such as long travel time to seed and fertilizer distributors for farmers would be a cost-effective policy to raise hybrid seed adoption rates and maize yields. Michler, Tjernstrom, Verkaart, and Mausch (2018) extend Suri's analysis to improved chickpea production in Ethiopia and find that the adoption of improved chickpeas does not contribute to yield gain. However, it does decrease production costs, thereby leading to higher profitability than local varieties. They argue that this high profitability explains the rapid increase in adoption of improved chickpea seeds in Ethiopia. In addition, Kijima, Otsuka, and Sserunkuuma (2011) show that low profitability under the variable rainfall environment of NERICA rice in Uganda leads to the massive dropout. These studies commonly indicate the importance of analyzing profitability of improved varieties to understand the low adoption rate.

Lunduka, Fisher, and Snapp (2012) point out that the observed plateaus of adoption of modern maize varieties could be due to different traits of modern and traditional maize seeds and farmers' preference. They empirically show that, though farmers value high yield and early maturity of modern varieties, they also value the storability, taste, and processing traits of local varieties. This calls for seed breeding research to focus not only on crop yield, but also on ease of storage, high poundability, high flour–grain ratio, and favorable taste reflecting farmers' demand (Lunduka et al., 2012).

Bold, Kaizzi, Svensson, and Yanagizawa-Drott (2017) find that more than 50% of hybrid maize seeds are not authentic seeds and 30% of nutrients are missing in inorganic fertilizer in their survey areas in Uganda. This results in low return from hybrid seeds and inorganic fertilizer adoption, leading to low take-up of these modern inputs. Thus, we may need to develop inspection systems that assure quality of the modern inputs available to rural smallholders.

The recent development of improved storage technology could increase adoption of improved varieties. The kernels of hybrid maize varieties are softer and less protected from insect attacks than traditional varieties (Smale, Heisey, & Leathers, 1995). A study using Malawi's data collected by Ricker-Gilbert and Jones (2015) shows that acquiring chemical storage protectants after the previous harvest increases adoption of improved maize varieties. In addition, in Omotilewa, Ricker-Gilbert, Ainembabazi, and Shively's (2018) RCT in Uganda, the authors distributed improved hermetic storage bags for eliminating insect pests in storage to randomly selected households. They find that households that receive the improved bag more likely plant hybrid maize than control households by 10 percentage points. These studies show that newly developed technology, which could overcome the drawback of improved varieties, could improve adoption of improved seeds.

Generally, improved varieties are developed to enhance crop yields. In addition to the yield-enhancing trait, the development of abiotic stress-tolerant varieties, which could mitigate weather shocks affecting crop yield, has become especially important, possibly due to rapid climate change. In fact, Kostandini, La Rovere, and Abdoulaye (2013) estimate that adoption of drought-tolerant maize could generate gains of US$ 362–590 million and a 0.01–4.29% reduction in poverty by 2016. Emerick, de Janvry, Sadoulet, and Dar (2016) conduct an RCT to distribute a flood-tolerant rice variety randomly in India. They find that the use of this risk-reducing variety leads to higher adoption of other improved agricultural inputs and practices, such as adoption of a more labor-intensive planting, inorganic fertilizer application, and credit utilization. One issue of abiotic stress-tolerant varieties is that the benefits of adoption become visible only when the specific stress, which they are tolerant to, appears (Yamano, Luz, Habib, & Kumar, 2018; Yorobe et al., 2016). The study of submergence-tolerant rice variety adoption in Bangladesh shows that experience of submergence in the previous year increases adoption (Yamano et al., 2018). In addition, the study of drought-tolerant maize adoption in Malawi demonstrates that previous early season dry spells and access to seed subsidy increase adoption (Katengeza, Holden, & Lunduka, 2019). Thus, if normal seasons continued, we could predict that farmers tend to switch to other varieties. Therefore, Yamano et al. (2018) stress the importance of education for farmers about the benefits of stress-tolerant crop varieties through extension activities.

2.2 | Use of inorganic fertilizer

Adoption of improved varieties alone is not sufficient to boost crop yield. Application of inorganic fertilizer is necessary to exploit the full yield potential of improved varieties. In fact, simultaneous adoption of improved varieties and inorganic fertilizer is the core technology of Green Revolution in Asia and Latin America (Hayami & Ruttan, 1985). Therefore, inorganic fertilizer use, in addition to improved seed adoption, has been widely promoted to realize considerable yield growth, especially in SSA.

When we look at the inorganic fertilizer use by region, it is striking that inorganic fertilizer application is much lower in SSA compared with other regions. For example, nitrogen application in SSA is only 5–6% of that in South Asia and Southeast Asia (FAOSTAT, 2019). There is, however, heterogeneity in the use of inorganic fertilizer among countries and even within countries in SSA. Sheahan and Barrett (2017) demonstrate that the adoption rates of inorganic fertilizer in six countries range from 3.2% in Uganda to 64.3% in Nigeria; the mean nutrient usages range from 0.7 kg/ha in Uganda to 64.3 kg/ha in Nigeria. Heterogeneity of the yield response rate to inorganic fertilizer use and value-cost ratios is also surprisingly large, presumably due to heterogeneity in soil, rainfall, and market conditions in various countries (Jayne & Rashid, 2013).

How can we increase inorganic fertilizer application to boost crop yield, provided that its use is potentially profitable? Empirical studies indicate several constraints affecting inorganic fertilizer use. Capital and credit constraints impede farmers from continued adoption of inorganic fertilizers in DR Congo (Lambrecht, Vanlauwe, Merckx, & Maertens, 2014), and Malawi (Holden & Lunduka, 2013). Accessibility to inorganic fertilizer is another constraint. Minten, Koru, and Stifel (2013) show that transaction and transportation costs together add at least 20% costs to actual inorganic fertilizer price that farmers pay in the most convenient location and 50% in the most remote location. In addition, farmers who live in the most remote areas face not only higher input prices, but also lower output prices, resulting in 75% less inorganic fertilizer use and improved seeds compared with farmers in the most convenient location (Minten et al., 2013).

The other well-known constraint of inorganic fertilizer use is downside risk. Based on data from India, Dercon and Christiansen (2011) demonstrate that inorganic fertilizer application decreases when farmer faces downside risk in consumption. Similarly, Alem, Bezabih, Kassie, and Zikhali (2010) show that rainfall variability negatively affects inorganic fertilizer application decision indicating that risks and uncertainly constraint inorganic fertilizer use. These studies suggest that measures such as the adoption of abiotic stress-tolerant varieties and introduction of effective insurance program to remove downside risks could improve the adoption of yield-enhancing technologies (Alem et al., 2010; Dercon & Christiansen, 2011).

Farmers' motivation and procrastination may also matter. Duflo, Kremer, and Robinson (2011) find that willingness to purchase inorganic fertilizer is high at the time of harvest among farmers in Kenya, but they may procrastinate purchasing inorganic fertilizer and fail to save enough money for the next crop cycle. The authors experimentally show that small nudges, like providing vouchers to purchase inorganic fertilizer immediately after harvest, help present-biased farmers overcome procrastination problems and commit to fertilizer use. On the other hand, Holden and Lunduka (2013) find that some farmers in Malawi are willing to sell maize at the planting time when its price is higher, and then purchase inorganic fertilizer.

However, it may not be an appropriate strategy to increase inorganic fertilizer application alone without consideration of its profitability. The estimated yield response rate to inorganic fertilizer application in the trial plots managed by agronomic researchers in SSA ranges from 18 to 40 kg of maize per kilogram nitrogen applied (Vanlauwe, Kihara, Chivenge, Pypers, & Coe, 2011). At the prevailing market prices, these response rates to inorganic fertilizer use could result in high profitability of fertilizer application (Jayne, Mason, Burke, & Ariga, 2018). However, many empirical studies show that the average output computed from farmers' fields ranges from 7.6 to 21 kg of maize per kilogram of nitrogen (Burke, Jayne, & Black, 2017, Burke, Frossard, Kabwe, & Jayne, 2019; Liverpool-Tasie, 2017; Liverpool-Tasie, Omonona, Sanou, & Ogunleye, 2017; Sheahan, Black, & Jayne, 2013). These empirical analyses reveal that the low response rate to nitrogen application results in low profitability of inorganic fertilizer use. In fact, a significant portion of farmers in Kenya, Nigeria, and Zambia apply inorganic fertilizer at the economically optimum level, given the response rate to inorganic fertilizer use and prevailing prices (Burke et al., 2017, 2019; Liverpool-Tasie, 2017; Liverpool-Tasie et al., 2017; Sheahan et al., 2013). These studies emphasize that, to increase profitability of inorganic fertilizer use, it is important to improve the response rate of inorganic fertilizer application. This finding seems to imply that improvement of soil health is the key to achieving these objectives.

Marenya and Barrett (2009) empirically show the complementarities between soil organic matter (SOM) and applied nitrogen. Using data from western Kenya, they demonstrate that maize yield response to nitrogen application is low when SOM is low and increases rapidly with improvement of SOM. In their samples, one-third of the plots, which were mainly cultivated by the poorest farmers, suffered from degraded soil. This limits the crops' response rate and profitability of inorganic fertilizer application at the prevailing market prices. Soil degradation is a great challenge especially for SSA because increasing population pressure on the land leads to a reduction in fallows and more continuous farming without inorganic fertilizer and manure application, which, in turn, depletes soil nutrients (Drechsel, Gyiele, Kunze, & Cofie, 2001). Therefore, a means to replenish soil nutrients and improve soil health should be developed and diffused for farmers in order to maintain soil fertility, thereby achieving high yield response rate and profitability of inorganic fertilizer application.

Though there has been a revival of large-scale input subsidy programs (ISPs) for boosting inorganic fertilizer application and crop yield since the early 2000s, there exist strong empirical criticism against ISPs—because private sectors tend to be crowded out (Mason & Jayne, 2013; Ricker-Gilbert, Jayne,

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& Chirwa, 2011), and targeting generally does not work well (Kilic, Whitney, & Winters, 2015; Mason, Jayne, & Mofya-Mukuka, 2013; Pan & Christiaensen, 2012; Ricker-Gilbert et al., 2011). Hence, the impact is small compared with the large fiscal burden (Jayne & Rashid, 2013; Jayne et al., 2018). This large fiscal burden undermines the investment in agricultural research and extension services (Jayne & Rashid, 2013; Jayne et al., 2018). Today, it is imperative to build knowledge of farm management practices that could enhance soil health and sustainable yield growth suitable for local conditions (Burke et al., 2017, 2019).

2.3 | Integrated farm management system

As we discussed in the previous sub-section, soil erosion and nutrients depletion are becoming serious issues, especially in SSA, due to lack of appropriate soil management practices. For example, soil nutrients, measured in terms of nitrogen, phosphorus, and potassium (NPK), had been lost at a rate of more than 30 kg/ha per year from 2002 to 2004 in 85% of the African farmland (185 million ha) (Henao & Baanante, 2006). Therefore, it is essential to develop farm management practices that could enhance soil fertility and prevent soil erosion and land degradation. Such practices could sustainably improve crop yield and profitability of farming. In this sub-section, we would like to introduce the promising farm management practices for maize and rice, the two most important crops in developing countries, especially in SSA (Otsuka & Larson, 2013, 2016).

2.3.1 | Maize-based integrated farming system

In the recent literature, integrated soil fertility management (ISFM) is considered an important means to achieve sustainable crop yield and profitability through enhancing soil health (Jayne et al., 2018; Jayne, Snapp, Place, & Sitko, 2019; Larson, Muraoka, & Otsuka, 2016; Otsuka & Muraoka, 2017). Vanlauwe et al. (2010) define ISFM as "A set of soil fertility management practices that necessarily include the use of fertilizer, organic inputs, and improved germplasm combined with the knowledge on how to adapt these practices to local conditions, aiming at maximizing agronomic use efficiency of the applied nutrients and improving crop productivity. All inputs need to be managed following sound agronomic principles" (p. 195).

A typical way to implement ISFM is to simultaneously apply inorganic and organic fertilizers. It is well known that these two types of fertilizers have complementary effects because SOM supplemented by organic fertilizer makes external nutrients more absorbable to crops (Marenya & Barrett, 2009; Vanlauwe et al., 2010, 2015). Empirical analysis based on household panel data in India shows that application of organic fertilizer raises the marginal product of inorganic fertilizer, especially when soil fertility is low (Kajisa & Palanichamy, 2011).

Intercropping or rotation with legumes is another common practice under ISFM because the legumes fix nitrogen from the atmosphere and make it available in the soil. It could also enhance crop yield sustainably by reducing plant disease, weeds such as striga, and insects, and by increasing the soil carbon content (Hutchinson, Campbell, & Desjardins, 2007; Manda, Alene, Gardebroek, Kassie, & Tembo, 2016). In fact, empirical analysis using data from Tanzania indicates that maize–pigeonpea adoption significantly increases income and consumption among sample households (Amare, Asfaw, & Shiferaw, 2012).

Although sometimes conservation tillage is included as a component of ISFM, its effect on crop yield is controversial. It aims to minimize soil disturbance, reduce soil erosion, improve water filtration, and soil structure (Vanlauwe et al., 2015). However, reduction in crop yields under conservation tillage is commonly observed, especially when no mulch is applied (Vanlauwe et al., 2015). Rusinamhodzi et al. (2011) find that reduced tillage could bring a positive effect when it is combined with mulch in low rainfall environments on light-textured soil.[5,6]

Though considerable efforts have been made by national and international organizations to encourage farmers to disseminate ISFM, its adoption rate is still low (Arslan et al., 2015; Kassie, Jaleta, Shiferaw, Mmbando, & Mekuria, 2013; Teklewold, Kassie, & Shiferaw, 2013a). Empirical studies reveal that asset, labor availability, social capital and networks, access to extension services, market and credits, soil conditions, rainfall, tenure security, education, and experience affect the adoption of ISFM (Kassie et al., 2013; Kassie, Teklewold, & Marenya, 2015; Manda et al., 2016; Teklewold et al., 2013a; Zeweld, Van Huylenbroeck, Tesfay, Azadi, & Speelman, 2019). Adoption of ISFM requires up-front investments of substantial labor; it also takes several years to realize its benefits (Jayne et al., 2019). For example, Schmidt, Chinowsky, Robinson, and Strzepek (2017) show that soil

[5] There are strands of farming practices similar to ISFM, that is, sustainable agricultural practices (SAPs) and sustainable intensification practices (SIPs). Both aim to improve the underlying biophysical functioning of the farming system and enable crop production to withstand variation in moisture, temperature, and biotic conditions (Kassie, Teklewold, & Marenya, 2015; Teklewold, Kassie, Shiferaw, & Köhlin, 2013b). SAPs and SIPs generally include practices adopted in ISFM (Lee, 2005). Therefore, we categorize SAPs and SIP in the same group as ISFM.

[6] Conservation agriculture (CA) is another related practice for sustainable agricultural intensification which aims to mitigate the impact of rapid climate change. They have three key principles: minimum or zero tillage, permanent soil cover, and diversified crop rotation (Vanlauwe et al., 2014). However, Vanlauwe et al. (2014) argue that the fourth principle should be required in CA in SSA, which is use of inorganic fertilizer to enhance organic residue availability and crop yield.

and water management investment must be maintained for at least 7 years to achieve significant increases in value of production. Therefore, resource-rich farmers are more willing to make such investments than resource-poor farmers who tend to prioritize their immediate needs for sustenance (Jayne et al., 2019). Asfaw, Battista, and Lipper (2016) argue that adoption of crop residues and organic fertilizer can be characterized by low capital investments, high labor inputs, and long time to achieve results, whereas that of inorganic fertilizer and improved seeds requires higher capital investments, low labor inputs, and short times for results. Thus, the difference in resource endowments and needs of farmers is likely to result in different patterns of adoption of ISFM technologies. Aside from the location specificity, ISFM includes demonstrably knowledge- and management-intensive practices. Therefore, farmers' education and training through extension services is necessary for diffusion of ISFM.

What are then the effects of ISFM adoption? Kassie et al. (2018) report that adoption of improved maize seed, inorganic fertilizer, and legume intercropping increases maize yield significantly in Ethiopia. They also show that these improved maize production technologies reduce maize production costs because legume intercropping reduces fertilizer costs, leading to higher net crop income. Similarly, Teklewold et al. (2013b) find that, in Ethiopia, adoption of maize–legume rotation, improved maize varieties, and conservation tillage increases maize income, particularly when these practices are adopted in combination. In addition, based on data from Niger, Asfaw et al. (2016) show that adoption of inorganic fertilizer, improved seeds, and organic fertilizer is positively associated with crop productivity and income, but not crop residue. In the case of Zambia, Arslan et al. (2015) demonstrate that legume intercropping increases maize yields and reduces probability of low yield even under critical weather stress. They also find that reduced tillage and crop rotation have no significant effect on maize yield. These findings suggest that adoption of certain combination of ISFM brings positive effect on maize yields, but some components of ISFM do not work well. This is not surprising, given the heterogeneity in soil, agroclimate, and market conditions in various places. Therefore, it is necessary to develop localized ISFM technologies adjusted for specific agroecological and socioeconomic conditions.

Available evidence is generally limited to the impact of ISFM on yield or, at best, on income. There are very few studies analyzing of profitability of ISFM, which deducts not only the paid-out cost, but also the imputed cost of family-owned resources, such as labor and machine, from the gross output value. This is problematic because complex knowledge- and management-intensive technologies, like ISFM that requires care and judgment, are mainly performed by family labor. Though it is challenging to estimate profit because of the difficulty in imputing the cost of family labor, more research efforts need to be devoted to assessing the profitability of new package of technologies. Otherwise, we cannot judge the viability and scalability of new technology.

2.3.2 | Improved rice cultivation practices (IRCPs)

New labor-intensive management practices, such as system of rice intensification (SRI), have been proposed for lowland rice cultivation to improve the efficiency of natural resource use and prevent environmental degradation (Uphoff & Randriamiharisoa, 2002). SRI consists of four core components: early transplanting of seedlings, shallow planting of one or two seedlings per hill, sparse planting, and intermittent irrigation. However, some scholars question the yield and profitability impacts of SRI (Takahashi & Barrett, 2014). Though Noltze, Schwarze, and Qaim (2013) demonstrate that SRI in Timor Leste significantly increases crop yield and income, Takahashi and Barrett (2014) present contradicting evidence: SRI increased yield by about 64% on average, but did not increase household income because it required a shift of labor from other activities.

Recently, modified SRI (MSRI) has been introduced in some areas; this system includes not only farm management practices, but also modern inputs use. According to Nakano, Tanaka, and Otsuka (2018a), MSRI consists of practices such as seed selection in salty water, straight-raw dibbling or transplanting, wide spacing, application of inorganic fertilizer, and adoption of improved rice varieties. They examine the impact of the MSRI training in rural Tanzania and find that rice yield of MSRI plots is higher by 1.3–1.8 tons/ha, with profits increasing by US$ 119–137/ha compared with other plots.

IRCPs, which are similar to MSRI, have also been introduced in some areas in SSA. The major advantage of lowland rice is its high transferability of recommended practices developed and diffused widely in Asia to SSA (Otsuka & Larson, 2013). IRCPs include not only the application of modern inputs, such as improved lowland rice variety and inorganic fertilizer, but also improved management practices, such as leveling, bund construction, as well as straight-row transplanting for soil, water, and weed management (Kijima, Ito, & Otsuka, 2012; Takahashi, Mano, & Otsuka, 2019). Like ISFM for maize, IRCPs are knowledge- and management-intensive technologies based on the idea that, beyond adoption of modern inputs, even appropriate soil and water management practices are essential to boost lowland rice yields significantly and sustainably. The IRCP training was provided for rural farmers in some countries in SSA, followed by impact evaluation of the training by researchers. Studies find that the training encourages adoption of IRCPs (Kijima et al., 2012; Takahashi et al., 2019) and increases rice yield (deGraft-Johnson, Suzuki, Sakurai, & Otsuka, 2014; Nakano, Tsusaka, Aida, & Pede, 2018b), income (Takahashi et al., 2019), and profit (deGraft-Johnson et al., 2014; Kijima et al., 2012) significantly. Although empirical findings indicate that they have the potential to boost rice yield and profits in SSA, IRCPs are not prevalent in rice farming in this region presumably because of weak extension systems (Otsuka & Larson, 2013, 2016).

3 | TECHNOLOGY DIFFUSION AMONG FARMERS

The existing case studies clearly suggest that improved agricultural technologies, such as modern varieties, inorganic fertilizers, and improved management practices, are available. However, their adoption rates are not generally high, especially in SSA.

An increasing number of recent studies focus on failures that impede appropriate information flow from laboratories or experimental stations to farmers. Public extension workers have traditionally played a central role in the overall process of technology diffusion. However, it may be prohibitively costly to directly train all individual farmers to increase their awareness and knowledge of new technologies, and thus promote technology adoption and wider diffusion. This is especially true in many low-income countries where the dominant mode of agricultural production is small-scale farms that are located in geographically dispersed areas. In these regions, the quality of infrastructure is often low, which further increases the cost of disseminating information to them (Anderson & Feder, 2007). Also, extension workers sometimes feel unmotivated; as a result, information loss from extension agents to farmers becomes severe (Niu & Ragasa, 2018). To complement the extension system from public agents to farmers, the potential of the F2FE approach has been extensively investigated in recent years.

This section presents an overview of the literature on F2FE, focusing on the extent to which and under what conditions its approach is effective, how to best select farmer-trainers who play a major role in disseminating technological information, and whether monetary or other incentives are required to motivate farmer-trainers.

3.1 | Effectiveness of F2FE systems

Because learning new technologies is a complex process, farmers may need to rely on multiple sources of information before they adopt a new technology (Beaman, BenYishay, Magruder, & Mobarak, 2018; Fisher, Holden, Thierfelder, & Katengeza, 2018; Genius, Koundouri, Nauges, & Tzouvelekas, 2014). The importance of public extension services may be paramount at the initial stage of new technology diffusion—that is, when farmers have limited opportunities to learn from each other (Anderson & Feder, 2007). Over time, when an increasing number of farmers become aware of and start to adopt a specific technology, the impact of such an extension may diminish and the role of an F2FE system expands (Krishnan & Patnam, 2014).

The effectiveness of an F2FE system or social learning for the diffusion of agricultural technologies has been widely recognized since the pioneering works by Conley and Udry (2001, 2010) and Foster and Rosenzweig (1995), even though it sometimes fails to achieve the stated objectives (Kondylis, Mueller, & Zhu, 2017). Theories of social learning suggest that, when technologies are new, there is higher uncertainty about their expected returns and risks as well as the best practices (e.g., appropriate input levels). Farmers can update their beliefs by not only testing it themselves, but also observing peers' behavior or sharing knowledge with them. This learning process is effective especially when the information is reliable and there is no heterogeneity in farming conditions and technological parameters (Munshi, 2004; Tjernstrom, 2017). In such cases, information about early adopters provides appropriate signals; it increases knowledge about technologies and expected profits, thereby boosting subsequent adoption by others (Bardhan & Udry, 1999).

Empirically measuring the impact of social learning involves several challenges because of the difficulty in exactly defining the networks (Maertens & Barrett, 2012) and because of confounders that make geographically and socially proximate people behave similarly, aside from pure learning effects (Manski, 1993). With the availability of accurate network data and the spread of an experimental approach that creates exogenous variation in exposure to technology adoption, an increasing number of studies successfully identify the type of network and extension method most effective in disseminating agricultural technologies.

Some studies find various types of social networks, such as geographical neighbors and local risk-sharing partners, to be effective in exchanging information among members (Mekonnen, Gerber, & Matz, 2018). However, many other studies commonly illustrate that the learning effect is larger among members who are linked by kinships or voluntarily formed groups for exchanging agricultural information (Bandiera & Rasul, 2006; Conley & Udry, 2010; Liverpool-Tasie & Winter-Nelson, 2012; Matuschke & Qaim, 2009). These studies suggest that farmers do not rely on all members of the village for gathering agricultural information. Therefore, the use of the average community-level adoption rate as a proxy for an opportunity to learn would be misleading. In particular, having a benefiting adopter in a network is proven to be important in increasing adoption through productivity spillovers, especially for new and knowledge-intensive technologies (Conley & Udry, 2010; Magnan, Spielman, Lybbert, & Gulati, 2015; Van den Broeck & Dercon, 2011; Yamano et al., 2018). This finding is important in view of the argument that new desirable technologies in SSA, such as integrated farm management systems, are likely to be knowledge-intensive, and hence complex. Van den Broeck and Dercon (2011) find that positive productivity spillovers among farmers may arise among kinship groups, but not geographical neighbors or informal insurance network members, presumably because kinship among farmers ensures a conscious effort to explain complex technology compared with members in other network types.

To improve female learning, the existing studies underscore the importance of information linkages formed among female peers. For example, Vasilaky and Leonard (2018) conduct a field experiment in Uganda to create a new information link by randomly pairing female cotton farmers at a training session with whom they had not previously interacted. The authors encouraged them to share technological information in the production process. This intervention resulted in a significant increase in the productivity of the treated pair, signifying the importance of linking females who tend to be outside the agricultural information network. Similarly, having a female instructor reduces gender bias, creates awareness, and helps in the adoption of new technologies by female (Kondylis, Mueller, Sheriff, & Zhu, 2016; Shikuku, 2019), and such network effects are larger among female than male farmers (Mekonnen et al., 2018).

The significant gendered segmented network is observed partly because of cultural norms that prohibit women from interacting with men external to their family members (Kondylis et al., 2016). However, it may be also because individuals have a tendency to disproportionately learn from those who are similar to them. This is called homophily, which contrasts with heterophily, wherein knowledge diffusion takes places more often among people who are different from each other (Feder & Savastano, 2006; Shikuku, Pieters, Bulte, & Läderach, 2019). The relative importance of homophily and heterophily becomes an important issue not only to improve female productivity, but also to facilitate overall social learning.

The relevance of this argument is clear if we realize that, due to budgetary constraints, public extension agents can often train only a limited number of farmer-trainers or "contact farmers" who are later expected to share the information with other nontrained community members. This contact farmer approach is now widely used in many developing countries, including SSA. However, it is not entirely clear who should become the farmer-trainers. Specifically, the following question is left unanswered: Should those individuals be farmer-trainers who are influential in terms of network connectivity and opinion leadership, who are innovative with entrepreneurship ability, or who are ordinal and representative of the majority population in the community?

3.2 | Qualifications of appropriate farmer-trainers

The literature considers three types of potential farmer-trainers: (a) those who are at the center of the information network; (b) those who are innovative, eager to take risks associated with the adoption of new technologies, and often knowledgeable and productive; and (c) those who have socioeconomic and farm characteristics similar to the majority of farmers in a community. Whereas (a) and (b) are conceptually distinguishable, they often overlap and tend to have higher status in a society (hereafter called "lead farmer") (Dar, de Janvry, Emerick, Kelly, & Sadoulet, 2019; Feder & Savastano, 2006; Rogers, 1995).

The advantage of selecting types (a) and (b) is that the number of trainee farmers would increase because lead farmers have various connections with others, information would be more accurately disseminated because they are more knowledgeable, and demonstration effects in terms of productivity and profitability improvement would be larger because they are more productive. Moreover, such innovators would effectively integrate new knowledge into local practices when adaptation is required in the local context. By strategically delaying own adoption, peer farmers can free-ride and reduce the uncertainty associated with the adoption of new technologies (Bandiera & Rasul, 2006; Foster & Rosenzweig, 1995; Maertens, 2017).

On the other hand, if gains of new technology are heterogeneous, reflecting the variety in growing conditions and farmer characteristics, there is no guarantee that lead farmers' success can be replicated by other farmers (Magnan et al., 2015; Shikuku, 2019; Suri, 2011; Tjernstrom, 2017). In other words, better performance cannot be solely attributed to the advantages embedded in technology, but to observable and unobservable characteristics of lead farmers and their agricultural plots (Barrett, Moser, McHugh, & Barison, 2004). In this case, it would be easier for followers to learn from farmer-trainers who are endowed with similar, but not outstanding, characteristics.

The empirical findings of these competing views are mixed. Maertens (2017) provides evidence indicating that lead farmers play a more significant role than ordinary farmers when peer farmers learn about technological characteristics from their learning links. Similarly, the lead-farmer approach, implemented in SSA countries, has a positive impact on the uptake of new technologies among fellow farmers (Wellard, Rafanomezana, Nyirenda, Okotel, & Subbey, 2013). Dillon, Porter, and Ouedraogo (2018) compare the degree of technological diffusion by selecting farmer-trainers (a) randomly, (b) on network size, and (c) based on network centrality measured by Eigenvector centrality. The results suggest that the network-based targeting approach is more effective in encouraging broader adoption. Beaman et al. (2018) also find similar results, whereas Beaman and Dillon (2018) and Lee, Suzuki, and Nam (2019) show that the network-based targeting approach is not necessarily superior to random selection of entry points to improve the knowledge of other farmers.

The superiority of homophily is presented in an analysis by Matuschke and Qaim (2009) and Weimann (1994). They contend that vertical flow of information from the lead farmer to peer farmers often fails, and successful information exchange is likely to be based on horizontal, socially proximate relationships. Based on an RCT in Malawi, BenYishay and Mobarak (2019) demonstrate that ordinary farmers perform better than lead farmers as farmer-trainers in terms of efforts and resultant technology diffusion, especially when ordinary farmers are incentivized. Takahashi et al.'s (2019) RCT in Cote d'Ivoire also shows that randomly selected training participants, who are representative of the majority in a community, effectively work as a catalyst to disseminate information to nontraining participants. This F2FE approach is as effective in improving practices as the initial training provided by extension services.

Somewhere between these two views is the perspective provided by Feder and Savanstano (2006). These authors find that farmers are more inclined to learn from peer farmers who are slightly superior to them, but not excessively so. Referring to Rogers (1995), Fisher et al. (2018) also share this view and discuss the differential roles of homophily and heterophily networks as follows:

> *"[h]omophilous and heterophilous networks have distinct and complementary roles in the diffusion of innovations. Heterophilous networks, such as that between lead and follower farmers, are more important in triggering awareness of a new technology, because new ideas most often enter a system through individuals who have higher status and are more innovative. Homophilous networks are, however, more useful than heterophilous ties in persuading potential adopters of the merits of the innovation […] If F2FE is to have a greater role in encouraging follower farmers to adopt innovations it may be necessary to identify lead farmers that are capable and motivated to train other farmers but not too socially distant from the target population of farmers in terms of personal characteristics and innovativeness." (pp. 321–322)*

As discussed by Fisher et al. (2018), if lead farmers are more suitable as entry points to disseminate new information, but ordinary farmers are more suitable to the wider diffusion of a specific technology, compromising these two views would be potentially the most effective approach. That is, an approach wherein lead farmers receive initial training to train new technologies to socially proximate farmers who are slightly more capable than ordinary farmers. Then, the latter set of farmers teaches the same technologies to other farmers comprising the majority of the community. This argument can be reinforced if the new technology is complex, as discussed in the previous section. This stepwise approach is exactly the case presented by Nakano et al. (2018b) in Tanzania, where 20 lead farmers were initially selected and trained in IRCPs. The trained lead farmers were responsible for training five other farmers close to them, who were then encouraged to diffuse the improved practices to other ordinary farmers. The study found that the yield gap between lead and intermediary farmers, as well as other ordinary farmers, widened immediately after the training because the former had adopted new practices faster than the latter. However, intermediary farmers soon caught up with the lead farmers and ordinary farmers caught up belatedly with the lead and intermediate farmers. Eventually, the yield gap among these groups gradually declined.

Since Nakano et al.'s (2018b) study is based on the small sample size, the effectiveness of such a stepwise technological diffusion path would be worth investigating in other contexts to examine its external validity.

3.3 | Incentivizing farmer-trainers

Aside from the issue of selection of best farmer-trainers, increasing attention has been paid to the question of how to motivate farmer-trainers to maximize technology diffusion. Generally, in the lead-farmer approach, the selected farmer-trainers do not receive any monetary rewards. Because the training of other farmers entails a cost of efforts for communication and demonstration, the farmer-trainers sometimes fail to perform the expected role and function in disseminating information to other farmers. Regardless of whether they are lead or ordinary farmers, well-motivated farmer-trainers might be key to improving knowledge diffusion and adoption of new technologies and practices by fellow farmers (Fisher et al., 2018; Holden, Fisher, Katengeza, & Thierfelder, 2018). Recent studies also experimentally reveal the relevance of the provision of material and financial incentives.

For example, Shikuku et al. (2019) investigate the role of private and social material rewards in improving the efforts of farmer-trainers and whether their behavior changes by prosocial preferences. A private reward (e.g., a weighing scale) is secretly provided to a farmer-trainer if the technical knowledge of other farmers surpasses the threshold level. A social reward (the same weighing scale) is provided to a village chief with a public announcement that the device is gifted in recognition of a farmer-trainer's performance. The results show that the provision of social rewards has a positive and significant impact on farmer-trainers' experimentation and diffusion efforts, which has a larger impact than the provision of private rewards. These effects remain, regardless of the prosocial preference of farmer-trainers. Note that because this study assumes farmer-trainers are better extension agents if they are similar to other farmers, they are selected from among farmers who are not starkly different from ordinary farmers in terms of wealth, education, and landholdings.

BenYishay and Mobarak (2019) provide another experimental evidence to prove that offering small incentives to farmer-trainers based on knowledge and the adoption rate of other farmers significantly increases farmer-trainers' efforts to communicate with other farmers. Moreover, it also improves their own experimentation to demonstrate the input level and yield outcomes. Interestingly, this incentive scheme works only for farmer-trainers who are selected from among ordinary farmers, but it does not work well for farmer-trainers selected from lead farmers. According to the authors, ordinary farmers are more sensitive to incentives because it is easier for them to convince other farmers owing to similarities among them. Thus, it is easier to reach the required number of adopters to receive the incentives. Though not mentioned in their study, another interpretation can be that ordinary farmers would be better extrinsically incentivized to increase their efforts, whereas such extrinsic incentives may not be effective or may even hurt lead farmers when they are already intrinsically motivated. Indeed, motivation of lead farmers selected by communities is generally not financial rewards, but to improve their own farming knowledge and to help others based on altruism (Kiptot, Karuhanga, Franzel, & Nzigamasabo, 2016).

Though the provision of material and financial incentives can increase the effectiveness of F2FE systems, how such extension systems attain scalability is disputed. As Shikuku et al. (2019) note, collection of data on others' knowledge of new technology and its adoption is likely to be prohibitively expensive. Given the counterevidence that F2FE systems can potentially work without any incentive (e.g., Takahashi et al., 2019), its cost-effectiveness must be rigorously examined in the future research.[7]

4 | CONCLUDING REMARKS

A review of the case studies on technology adoption provides support for the hypothesis that there are profitable technologies that are not diffused widely because of a weak extension system. Recent case studies commonly argue that desirable improved technologies, particularly in SSA, are knowledge- and management-intensive. They require integrated management of soil, nutrient, and water. Such technologies are likely to be complicated and their impacts are likely to be heterogeneous depending on agroclimates, soil quality, and farmers' abilities. For successful diffusion of new agricultural technology, effective extension systems are indispensable. For this reason, a surge in extension studies is warranted.

One shortcoming of the studies on technology adoption is the lack of analysis of profitability of new technologies, especially in maize-based ISFM. Notably, it is extremely difficult to measure profit—that is, the return on the fixed factor of production—primarily because of the difficulty in imputing the value of unpaid family labor. It is often observed, particularly in the context of SSA, that when family labor cost is imputed by the prevailing market wage rate, the estimated residual profit is negative, indicating that this imputation method is inappropriate. This does not imply, however, that we do not have to estimate profit, because we cannot judge the viability and scalability of new technology without estimating profits. A practical solution is to assume that the estimated profit is not a cardinal, but an ordinal number. That is, it is not its absolute value, but its relative values that may be useful for assessing changes and differences in profitability. Another solution is a collaboration between agricultural economists and scientists, particularly agronomists, to experiment combinations of technologies and input uses in order to estimate the profits of various technologies under a variety of external environments.

Diffusion studies in general do not carefully assess the profitability of a technology under examination, except with a few exceptions. Yet, it is absurd to examine the adoption of new technology and the role of social information network if the technology itself is not profitable. Another difficulty is the absence of interactions with case studies of technology adoption. Though case studies recommend integrated farming systems or "packages" of new inputs and management practices, still many diffusion studies focus only on a single technology, such as improved seed variety, improved planting method, and use of compost. We recommend closer collaborations between the two groups of economists interested in these intimately related issues.

However, criticisms against the diffusion studies discussed above do not deny their significant contributions to the literature on technology adoption and diffusion. The question raised by these studies about the information channels has been neglected for long in the economics literature, yet it is pertinent for the establishment of effective extension systems. Because information on new technology is a "local public good," we believe that a public-sector extension system is needed. Because the public extension system is often inefficient, it is desirable to use farmer-trainers who are trained by extension workers. The critical questions are what types of

[7] The same applies to the case wherein farmer-trainers are selected through network-based targeting. Though this approach has potential, collecting detailed network data is expensive. Hence, its scalability and cost-effectiveness can be questioned.

farmers are appropriate for farmer-trainers and whether incentives should be given to them.

Given the heterogeneous impacts of new technology, providing training to outstanding lead farmers may not lead to wider adoption of new technology by ordinary farmers. However, although ordinary farmers have many peers who are willing to use the same technology, they are less capable than lead farmers in learning new and complicated technology. If desirable technology is complicated, as is likely to be the case in SSA, it may well be that farmer-trainers ought to be entrepreneurial lead farmers. They are likely to disseminate new information to their peers, whose ability may be above the average in the rural community, even if they do not receive particular rewards. These peers may, in turn, further disseminate new information to less capable peers. On the other hand, if the desirable technology is simple and the identification of "ordinary farmers" with relatively large network connectivity is not costly, the best strategy may be to select ordinary farmers as farmer-trainers. Note, however, that ordinary farmers may have to be incentivized to serve as effective extension agents. Judging from the extant literature, it is too hasty to present an optimum extension system with finality. Further research on the role and effectiveness of trainer-farmers in the diffusion of new technologies in a variety of contexts is thus necessary.

ACKNOWLEDGMENTS

We thank Yuma Noritomo for excellent research assistance and Mushfiq Mobarak for useful comments. Financial support for this research by National Graduate Institute for Policy Studies (G192RP108) is gratefully acknowledged. The remaining errors are the sole responsibility of the authors.

REFERENCES

Aker, J. C. (2011). Dial "A" for agriculture: A review of information and communication technologies for agricultural extension in developing countries. *Agricultural Economics*, *42*, 631–647.

Aker, J. C., & Mbiti, I. M. (2010). Mobile phones and economic development in Africa. *Journal of Economic Perspectives*, *24*(3), 207–232.

Alem, Y., Bezabih, M., Kassie, M., & Zikhali, P. (2010). Does fertilizer use respond to rainfall variability? Panel data evidence from Ethiopia. *Agricultural Economics*, *41*, 165–175.

Amare, M., Asfaw, S., & Shiferaw, B. (2012). Welfare impacts of maize-pigeonpea intensification in Tanzania. *Agricultural Economics*, *43*(1), 27–43.

Anderson, J. R., & Feder, G. (2007). Agricultural extension. In R. Evenson & P. Pingali (Eds.), *Handbook of agricultural economics* (Vol. 3, pp. 2343–2378). Amsterdam: Elsevier.

Arslan, A., McCarthy, N., Lipper, L., Asfaw, S., Cattaneo, A., & Kokwe, M. (2015). Climate smart agriculture? Assessing the adaptation implications in Zambia. *Journal of Agricultural Economics*, *66*(3), 753–780.

Asfaw, S., Battista, F. D., & Lipper, L. (2016). Agricultural technology adoption under climate change in the Sahel: Micro-evidence from Niger. *Journal of African Economies*, *25*(5), 637–669.

Asfaw, S., Kassie, M., Simtowe, F., & Lipper, L. (2012a). Poverty reduction effects of agricultural technology adoption: A micro-evidence from rural Tanzania. *Journal of Development Studies*, *48*(9), 1288–1305.

Asfaw, S., Shiferaw, B., Simtowe, F., & Lipper, L. (2012b). Impact of modern agricultural technologies on smallholder welfare: Evidence from Tanzania and Ethiopia. *Food Policy*, *37*(3), 283–295.

Bandiera, O., & Rasul, I. (2006). Social networks and technology adoption in Northern Mozambique. *Economic Journal*, *116*(514), 869–902.

Bardhan, P., & Udry, C. (1999). *Development microeconomics*. Oxford: Oxford University Press.

Barrett, C. B., Moser, C. M., McHugh, O. V., & Barison, J. (2004). Better technology, better plots, or better farmers? Identifying changes in productivity and risk among Malagasy rice farmers. *American Journal of Agricultural Economics*, *86*(4), 869–888.

Beaman, L. A., BenYishay, A., Magruder, J., & Mobarak, A. M. (2018). *Can network theory-based targeting increase technology adoption*? NBER Working Paper 24912.

Beaman, L. A., & Dillon, A. (2018). Diffusion of agricultural information within social networks: Evidence on gender inequalities from Mali. *Journal of Development Economics*, *133*, 147–161.

Becerril, J., & Abdulai, A. (2010). The impact of improved maize varieties on poverty in Mexico: A propensity score-matching approach. *World Development*, *38*(7), 1024–1035.

BenYishay, A., & Mobarak, A. M. (2019). Social learning and incentives for experimentation and communication. *Review of Economic Studies*, *86*, 976–1009.

Bezu, S., Kassie, G. T., Shiferaw, B., & Ricker-Gilbert, J. (2014). Impact of improved maize adoption on welfare of farm households in Malawi: A panel data analysis. *World Development*, *59*, 120–131.

Bold, T., Kaizzi, K. C., Svensson, J., & Yanagizawa-Drott, D. (2017). Lemon technologies and adoption: Measurement, theory and evidence from agricultural markets in Uganda. *Quarterly Journal of Economics*, *132*(3), 1055–1100.

Burke, W. J., Frossard, E., Kabwe, S., & Jayne, T. S. (2019). Understanding fertilizer adoption and effectiveness on maize in Zambia. *Food Policy*, *86*, 101721.

Burke, W. J., Jayne, T. S., & Black, J. R. (2017). Factors explaining the low and variable profitability of fertilizer application to maize in Zambia. *Agricultural Economics*, *48*(1), 115–126.

Conley, T.G., & Udry, C. R. (2001). Social learning through networks: The adoption of new agricultural technologies in Ghana. *American Journal of Agricultural Economics*, *83*(3), 663–673.

Conley, T. G., & Udry, C. R. (2010). Learning about a new technology: Pineapple in Ghana. *American Economic Review*, *100*(1), 35–69.

Dar, M. H., de Janvry, A., Emerick, K., Kelly, E. M., & Sadoulet, E. (2019). *Endogenous information sharing and the gains from using network information to maximize technology adoption* (CEPR Discussion Paper DP13507).

de Janvry, A., Sadoulet, E., & Suri, T. (2017). Field experiments in developing country agriculture. In A. V. Banerjee & E. Duflo (Eds.), *Handbook of field experiments* (Vol. 2, pp. 427–466). North Holland: Elsevier.

deGraft-Johnson, M., Suzuki, A., Sakurai, T., & Otsuka, K. (2014). On the transferability of the Asian rice green revolution to rainfed areas

in sub-Saharan Africa: An assessment of technology intervention in Northern Ghana. *Agricultural Economics*, *45*(5), 555–570.
Dercon, S., & Christiaensen, L. (2011). Consumption risk, technology adoption and poverty traps: Evidence from Ethiopia. *Journal of Development Economics*, *96*(2), 159–173.
Dillon, A., Porter, M., & Ouedraogo, A. (2018). *Social network targeting of agricultural technology: Adoption, input substitution and yield effects*. Selected Paper prepared for presentation at the Agricultural & Applied Economics Association Annual Meeting, Washington, DC., August 5–7.
Drechsel, P., Gyiele, L., Kunze, D., & Cofie, O. (2001). Population density, soil nutrient depletion, and economic growth in sub-Saharan Africa. *Ecological Economics*, *38*, 251–258.
Duflo, E., Kremer, M., & Robinson, J. (2011). Nudging farmers to use fertilizer: Evidence from Kenya. *American Economic Review*, *101*(6), 2350–2390.
Emerick, K., de Janvry, A., Sadoulet, E., & Dar, M. H. (2016). Technological innovations, downside risk, and the modernization of agriculture. *American Economic Review*, *106*(6), 1537–1561.
Evenson, R. E., & Gollin, D. (Eds.). (2003). *Crop variety improvement and its effect on productivity: The impact of international agricultural research*. Wallingford, UK: CABI Publishing.
FAOSTAT. (2019). Retrieved from http://www.fao.org/faostat/en/#data
Feder, G., Just, R. E., & Zilberman, D. (1985). Adoption of agricultural innovations in developing countries: A survey. *Economic Development and Cultural Change*, *33*(2), 255–298.
Feder, G., & Savastano, S. (2006). The role of opinion leaders in the diffusion of new knowledge: The case of integrated pest management. *World Development*, *34*(7), 1287–1300.
Fisher, M., Holden, S. T., Thierfelder, C., & Katengeza, S. P. (2018). Awareness and adoption of conservation agriculture in Malawi: What difference can farmer-to-farmer extension make? *International Journal of Agricultural Sustainability*, *16*(3), 310–325.
Foster, A. D., & Rosenzweig, M. R. (1995). Learning by doing and learning from others: Human capital and technical change in agriculture. *Journal of Political Economy*, *103*(6), 1176–1209.
Foster, A. D., & Rosenzweig, M. R. (2010). Microeconomics of technology adoption. *Annual Review of Economics*, *2*, 395–424.
Genius, M., Koundouri, P., Nauges, C., & Tzouvelekas, V. (2014). Information transmission in irrigation technology adoption and diffusion: Social learning, extension services, and spatial effects. *American Journal of Agricultural Economics*, *96*(1), 328–344.
Hayami, Y., & Ruttan, V. W. (1985). *Agricultural development: An international Perspective*. Baltimore, MD: Johns Hopkins University Press.
Henao, J., & Baanante, C. (2006). *Agricultural production and soil nutrient mining in Africa: Implications for resource conservation and policy development*. Muscle Shoals, AL: The International Fertilizer Development Center.
Holden, S. T., Fisher, M., Katengeza, S. P., & Thierfelder, C. (2018). Can lead farmers reveal the adoption potential of conservation agriculture? The case of Malawi. *Land Use Policy*, *76*, 113–123.
Holden, S. T., & Lunduka, R. W. (2013). Input subsidies, cash constraints, and timing of input supply. *American Journal of Agricultural Economics*, *96*(1), 290–307.
Hutchinson, J. J., Campbell, A., & Desjardins, R. L. (2007). Some perspectives on carbon sequestration in agriculture. *Agricultural and Forest Meteorology*, *142*(2–4), 288–302.
Jayne, T. S., Mason, N. M., Burke, W. J., & Ariga, J. (2018). Review: Taking stock of Africa's second-generation agricultural input subsidy programs. *Food Policy*, *75*, 1–14.
Jayne, T. S., & Rashid, S. (2013). Input subsidy programs in sub-Saharan Africa: A synthesis of recent evidence. *Agricultural Economics*, *44*(6), 547–562.
Jayne, T. S., Snapp, S., Place, F., & Sitko, N. (2019). Sustainable agricultural intensification in an era of rural transformation in Africa. *Global Food Security*, *20*, 105–113.
Kajisa, K., & Palanichamy, N. V. (2011). Potential and limitation of an organic fertilizer-based development strategy: Evidence from Tamil Nadu, India, from 1993 to 2003. *Agricultural Economics*, *42*(6), 715–725.
Kassie, M., Jaleta, M., Shiferaw, B., Mmbando, F., & Mekuria, M. (2013). Adoption of interrelated sustainable agricultural practices in smallholder systems: Evidence from rural Tanzania. *Technological Forecasting and Social Change*, *80*(3), 525–540.
Kassie, M., Marenya, P., Tessema, Y., Jaleta, M., Zeng, D., Erenstein, O., & Rahut, D. (2018). Measuring farm and market level economic impacts of improved maize production technologies in Ethiopia: Evidence from panel data. *Journal of Agricultural Economics*, *69*(1), 76–95.
Kassie, M., Shiferaw, B., & Muricho, G. (2011). Agricultural technology, crop income, and poverty alleviation in Uganda. *World Development*, *39*(10), 1784–1795.
Kassie, M., Teklewold, H., & Marenya, P. (2015). Production risks and food security under alternative technology choices in Malawi: Application of a multinomial endogenous switching regression. *Journal of Agricultural Economics*, *66*(3), 640–659.
Katengeza, S. P., Holden, S. T., & Lunduka, R. W. (2019). Adoption of drought tolerant maize varieties under rainfall stress in Malawi. *Journal of Agricultural Economics*, *70*(1), 198–214.
Khonje, M., Manda, J., Alene, A. D., & Kassie, M. (2015). Analysis of adoption and impacts of improved maize varieties in Eastern Zambia. *World Development*, *66*, 695–706.
Kijima, Y., Ito, Y., & Otsuka, K. (2012). Assessing the impact of training on lowland rice productivity in an African setting: Evidence from Uganda. *World Development*, *40*(8), 1610–1618.
Kijima, Y., Otsuka, K., & Sserunkuuma, D. (2011). An inquiry into constraints on a green revolution in sub-Saharan Africa: The case of NERICA Rice in Uganda. *World Development*, *39*(1), 77–86.
Kilic, T., Whitney, E., & Winters, P. (2015). Decentralised beneficiary targeting in large-scale development programmes: Insights from the Malawi farm input. *Journal of African Economies*, *24*(1), 26–56.
Kiptot, E., Karuhanga, M., Franzel, S., & Nzigamasabo, P. B. (2016). Volunteer farmer-trainer motivations in East Africa: Practical implications for enhancing farmer-to-farmer extension. *International Journal of Agricultural Sustainability*, *14*(3), 339–356.
Kondylis, F., Mueller, V., Sheriff, G., & Zhu, J. (2016). Do female instructors reduce gender bias in diffusion of sustainable land management techniques? Experimental evidence from Mozambique. *World Development*, *78*, 436–449.
Kondylis, F., Mueller, V., & Zhu, J. (2017). Seeing is believing? Evidence from an extension network experiment. *Journal of Development Economics*, *125*, 1–20.
Kostandini, G., La Rovere, R., & Abdoulaye, T. (2013). Potential impacts of increasing average yields and reducing maize yield variability in Africa. *Food Policy*, *43*, 213–226.

Krishnan, P., & Patnam, M. (2014). Neighbors and extension agents in Ethiopia: Who matters more for technology adoption? *American Journal of Agricultural Economics*, *96*(1), 308–327.

Lambrecht, I., Vanlauwe, B., Merckx, R., & Maertens, M. (2014). Understanding the process of agricultural technology adoption: Mineral fertilizer in Eastern DR Congo. *World Development*, *59*, 132–146.

Larson, D. F., Muraoka, R., & Otsuka, K. (2016). Why African rural development strategies must depend on small farms. *Global Food Security*, *10*, 39–51.

Lee, D. R. (2005). Agricultural sustainability and technology adoption: Issues and policies for developing countries. *American Journal of Agricultural Economics*, *87*(5), 1325–1334.

Lee, G., Suzuki, A., & Nam, V. H. (2019). Effect of network-based targeting on the diffusion of good aquaculture practices among shrimp producers in Vietnam. *Word Development*, *124*, 104641.

Liverpool-Tasie, L. S. O. (2017). Is fertiliser use inconsistent with expected profit maximization in sub-Saharan Africa? "Evidence from Nigeria". *Journal of Agricultural Economics*, *68*(1), 22–44.

Liverpool-Tasie, L. S. O., Omonona, B. T., Sanou, A., & Ogunleye, W. O. (2017). Is increasing inorganic fertilizer use for maize production in SSA a profitable proposition? Evidence from Nigeria. *Food Policy*, *67*, 41–51.

Liverpool-Tasie, L. S. O., & Winter-Nelson, A. (2012). Social learning and farm technology in Ethiopia: Impacts by technology, network type, and poverty status. *Journal of Development Studies*, *48*(10), 1505–1521.

Lunduka, R., Fisher, M., & Snapp, S. (2012). Could farmer interest in a diversity of seed attributes explain adoption plateaus for modern maize varieties in Malawi? *Food Policy*, *37*(5), 504–510.

Macours, K. (2019). Farmers' demand and the traits and diffusion of agricultural innovations in developing countries. *Annual Review of Resource Economics*, *11*, 483–499.

Maertens, A. (2017). Who cares what others think (or do)? Social learning and social pressures in cotton farming in India. *American Journal of Agricultural Economics*, *99*(4), 988–1007.

Maertens, A., & Barrett, C. B. (2012). Measuring social networks' effects on agricultural technology adoption. *American Journal of Agricultural Economics*, *95*(2), 353–359.

Magnan, N., Spielman, D. J., Lybbert, T. J., & Gulati, K. (2015). Leveling with friends: Social networks and Indian farmers' demand for a technology with heterogeneous benefits. *Journal of Development Economics*, *116*, 223–251.

Magruder, J. R. (2018). An assessment of experimental evidence on agricultural technology adoption in developing countries. *Annual Review of Resource Economics*, *10*, 299–316.

Manda, J., Alene, A. D., Gardebroek, C., Kassie, M., & Tembo, G. (2016). Adoption and impacts of sustainable agricultural practices on maize yields and incomes: Evidence from rural Zambia. *Journal of Agricultural Economics*, *67*(1), 130–153.

Manda, J., Alene, A. D., Tufa, A. H., Abdoulaye, T., Wossen, T., Chikoye, D., & Manyong, V. (2019). The poverty impacts of improved cowpea varieties in Nigeria: A counterfactual analysis. *World Development*, *122*, 261–271.

Manski, C. F. (1993). Identification of endogenous social effects: The reflection problem. *Review of Economics Studies*, *60*(3), 531–542.

Marenya, P. P., & Barrett, C. B. (2009). State-conditional fertilizer yield response on Western Kenyan farms. *American Journal of Agricultural Economics*, *91*(4), 991–1006.

Mason, N. M., & Jayne, T. S. (2013). Fertiliser subsidies and smallholder commercial fertiliser purchases: Crowding out, leakage and policy implications for Zambia. *Journal of Agricultural Economics*, *64*(3), 558–582.

Mason, N. M., Jayne, T. S., & Mofya-Mukuka, R. (2013). Zambia's input subsidy programs. *Agricultural Economics*, *44*, 613–628.

Mathenge, M. K., Smale, M., & Olwande, J. (2014). The impacts of hybrid maize seed on the welfare of farming households in Kenya. *Food Policy*, *44*, 262–271.

Matuschke, I., & Qaim, M. (2009). The impact of social networks on hybrid seed adoption in India. *Agricultural Economics*, *40*(5), 493–505.

Mekonnen, D. A., Gerber, N., & Matz, J. A. (2018). Gendered social networks, agricultural innovations, and farm productivity in Ethiopia. *World Development*, *105*, 321–335.

Michler, J., Tjernstrom, E., Verkaart, S., & Mausch, K. (2018). Money matters: The role of yields and profits in agricultural technology adoption. *American Journal of Agricultural Economics*, *101*(3), 710–731.

Minten, B., Koru, B., & Stifel, D. (2013). The last mile(s) in modern input distribution: Pricing, profitability, and adoption. *Agricultural Economics*, *44*(6), 629–646.

Munshi, K. (2004). Social learning in a heterogeneous population: Technology diffusion in the Indian Green Revolution. *Journal of Development Economics*, *73*(1), 185–213.

Nakano, Y., Tanaka, Y., & Otsuka, K. (2018a). Impact of training on the intensification of rice farming: Evidence from rainfed areas in Tanzania. *Agricultural Economics*, *49*(2), 193–202.

Nakano, Y., Tsusaka, T. W., Aida, T., & Pede, V. O. (2018b). Is farmer-to-farmer extension effective? The impact of training on technology adoption and rice farming productivity in Tanzania. *World Development*, *105*, 336–351.

Niu, C., & Ragasa, C. (2018). Selective attention and information loss in the lab-to-farm knowledge chain: The case of Malawian agricultural extension programs. *Agricultural Systems*, *165*, 147–163.

Noltze, M., Schwarze, S., & Qaim, M. (2013). Impacts of natural resource management technologies on agricultural yield and household income: The system of rice intensification in Timor Leste. *Ecological Economics*, *85*, 59–68.

Omotilewa, O. J., Ricker-Gilbert, J., Ainembabazi, J. H., & Shively, G. E. (2018). Does improved storage technology promote modern input use and food security? Evidence from a randomized trial in Uganda. *Journal of Development Economics*, *135*, 176–198.

Otsuka, K., & Larson, D. F. (Eds.). (2013). *An African Green Revolution: Finding ways to boost productivity on small farms*. Dordrecht, The Netherlands: Springer.

Otsuka, K., & Larson, D. F. (Eds.). (2016). *In pursuit of an African Green Revolution: Views from rice and maize farmers' fields*. Dordrecht, The Netherlands: Springer.

Otsuka, K., & Muraoka, R. (2017). A Green Revolution for sub-Saharan Africa: Past failures and future prospects. *Journal of African Economies*, *26*(S1), i73–i98.

Otsuka, K., Nakano, Y., & Takahashi, K. (2016). Contract farming in developed and developing countries. *Annual Review of Resource Economics*, *8*, 353–376.

Pan, L., & Christiaensen, L. (2012). Who is vouching for the input voucher? Decentralized targeting and elite capture in Tanzania. *World Development*, *40*(8), 1619–1633.

Ricker-Gilbert, J., Jayne, T. S., & Chirwa, E. (2011). Subsidies and crowding out: A double-hurdle model of fertilizer demand in Malawi. *American Journal of Agricultural Economics*, *93*(1), 26–42.

Ricker-Gilbert, J., & Jones, M. (2015). Does storage technology affect adoption of improved maize varieties in Africa? Insights from Malawi's input subsidy program. *Food Policy*, *50*, 92–105.

Rogers, E. M. (1995). *Diffusion of innovations*. New York: Free Press.

Rusinamhodzi, L., Corbeels, M., van Wijk, M. T., Rufino, M. C., Nyamangara, J., & Giller, K. E. (2011). A meta-analysis of long-term effects of conservation agriculture on maize grain yield under rain-fed conditions. *Agronomy for Sustainable Development*, *31*, 657–673.

Schmidt, E., Chinowsky, P., Robinson, S., & Strzepek, K. (2017). Determinants and impact of sustainable land management (SLM) investments: A systems evaluation in the Blue Nile Basin, Ethiopia. *Agricultural Economics*, *48*(5), 613–627.

Sheahan, M., & Barrett, C. B. (2017). Ten striking facts about agricultural input use in Sub-Saharan Africa. *Food Policy*, *67*, 12–25.

Sheahan, M., Black, R., & Jayne, T. S. (2013). Are Kenyan farmers under-utilizing fertilizer? Implications for input intensification strategies and research. *Food Policy*, *41*, 39–52.

Shiferaw, B., Kebede, T., Kassie, M., & Fisher, M. (2015). Market imperfections, access to information and technology adoption in Uganda: Challenges of overcoming multiple constraints. *Agricultural Economics*, *46*(4), 475–488.

Shikuku, K. M. (2019). Information exchange links, knowledge exposure, and adoption of agricultural technologies in northern Uganda. *World Development*, *115*, 94–106.

Shikuku, K. M., Pieters, J., Bulte, E., & Läderach, P. (2019). Incentives and the diffusion of agricultural knowledge: Experimental evidence from northern Uganda. *American Journal of Agricultural Economics*, *101*(4), 1164–1180.

Smale, M., Heisey, P. W., & Leathers, H. D. (1995). Maize of the ancestors and modern varieties: The microeconomics of high-yielding variety adoption in Malawi. *Economic Development and Cultural Change*, *43*(2), 351–368.

Smale, M., & Mason, N. (2014). Hybrid seed and the economic well-being of smallholder maize farmers in Zambia. *Journal of Development Studies*, *50*(5), 680–695.

Suri, T. (2011). Selection and comparative advantage in technology adoption. *Econometrica*, *79*(1), 159–209.

Takahashi, K., & Barrett, C. (2014). The system of rice intensification and its impacts on household income and child schooling: Evidence from rural Indonesia. *American Journal of Agricultural Economics*, *96*(1), 269–289.

Takahashi, K., Mano, Y., & Otsuka, K. (2019). Learning from experts and peer farmers about rice production: Experimental evidence from Cote d'Ivoire. *World Development*, *122*, 157–169.

Teklewold, H., Kassie, M., & Shiferaw, B. (2013a). Adoption of multiple sustainable agricultural practices in rural Ethiopia. *Journal of Agricultural Economics*, *64*(3), 597–623.

Teklewold, H., Kassie, M., Shiferaw, B., & Köhlin, G. (2013b). Cropping system diversification, conservation tillage and modern seed adoption in Ethiopia: Impacts on household income, agrochemical use and demand for labor. *Ecological Economics*, *93*, 85–93.

Tjernstrom, E. (2017). Learning from others in heterogeneous environments. Retrieved from https://www.atai-research.org/wp-content/uploads/(2015)/11/Tjernstrom-(2017)-learning-from-others.pdf

Uphoff, N., & Randriamiharisoa, R. (2002). Reducing water use in irrigated rice production with the Madagascar System of Rice Intensification (SRI). In J. Bouman, B. Hengsdijk, H. Hardy, B. Bindraban, P. Tuong, & T. Ladha (Eds.), *Water-wise rice production workshop* (pp. 71–87). Los Baños: International Rice Research Institute.

Van den Broeck, K., & Dercon, S. (2011). Information flows and social externalities in a Tanzanian banana growing village. *Journal of Development Studies*, *47*(2), 231–252.

Vanlauwe, B., Bationo, A., Chianu, J., Giller, K. E., Merckx, R., Mokwunye, U., … Sanginga, N. (2010). Integrated soil fertility management: Operational definition and consequences for implementation and dissemination. *Outlook on Agriculture*, *39*(1), 17–24.

Vanlauwe, B., Descheemaeker, K., Giller, K. E., Huising, J., Merckx, R., Nziguheba, G., … Zingore, S. (2015). Integrated soil fertility management in sub-Saharan Africa: Unravelling local adaptation. *Soil*, *1*(1), 491–508.

Vanlauwe, B., Kihara, J., Chivenge, P., Pypers, P., & Coe, R. (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*, 35–50.

Vanlauwe, B., Wendt, J., Giller, K. E., Corbeels, M., Gerard, B., & Nolte, C. (2014). A fourth principle is required to define conservation agriculture in sub-Saharan Africa: The appropriate use of fertilizer to enhance crop productivity. *Field Crops Research*, *155*, 10–13.

Vasilaky, K. N., & Leonard, K. L. (2018). As good as the networks they keep? Improving outcomes through weak ties in rural Uganda. *Economic Development and Cultural Change*, *66*(4), 755–792.

Verkaart, S., Munyua, B. G., Mausch, K., & Michler, J. D. (2017). Welfare impacts of improved chickpea adoption: A pathway for rural development in Ethiopia? *Food Policy*, *66*, 50–61.

Villano, R., Bravo-Ureta, B., Solís, D., & Fleming, E. (2015). Modern rice technologies and productivity in the Philippines: Disentangling technology from managerial gaps. *Journal of Agricultural Economics*, *66*(1), 129–154.

Weimann, G. (1994). *The influentials*. Albany, NY: State University of New York Press.

Wellard, K., Rafanomezana, J., Nyirenda, M., Okotel, M., & Subbey, V. (2013). A review of community extension approaches to innovation for improved livelihoods in Ghana, Uganda and Malawi. *Journal of Agricultural Education and Extension*, *19*(1), 21–35.

Yamano, T., Luz, M., Habib, A., & Kumar, S. (2018). Neighbors follow early adopters under stress: Panel data analysis of submergence-tolerant rice in northern Bangladesh. *Agricultural Economics*, *49*, 313–323.

Yorobe, J. M., Ali, J., Pede, V. O., Rejesus, R. M., Velarde, O. P., & Wang, H. (2016). Yield and income effects of rice varieties with tolerance of multiple abiotic stresses: The case of green super rice (GSR) and flooding in the Philippines. *Agricultural Economics*, *47*, 261–271.

Zeweld, W., Van Huylenbroeck, G., Tesfay, G., Azadi, H., & Speelman, S. (2019). Sustainable agricultural practices, environmental risk mitigation and livelihood improvements: Empirical evidence from Northern Ethiopia. *Land Use Policy*, 103799.

Zeng, D., Alwang, J., Norton, G. W., Shiferaw, B., Jaleta, M., & Yirga, C. (2015). Ex post impacts of improved maize varieties on poverty in rural Ethiopia. *Agricultural Economics*, *46*(4), 515–526.

Zeng, D., Alwang, J., Norton, G. W., Shiferaw, B., Jaleta, M., & Yirga, C. (2017). Agricultural technology adoption and child nutrition

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enhancement: Improved maize varieties in rural Ethiopia. *Agricultural Economics*, *48*(5), 573–586.

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

How to cite this article: Takahashi K, Muraoka R, Otsuka K. Technology adoption, impact, and extension in developing countries' agriculture: A review of the recent literature. *Agricultural Economics*. 2020;51:31–45. https://doi.org/10.1111/agec.12539