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by Rose, D., Crouch, K., Germundsson, L. B., Gaspard, M., Giller, O., Ortolani, L., and Strong, R.

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Cover Page Footnote

We thank the Centre for Effective Innovation in Agriculture for funding the conference session and to all session attendees.

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Commentary

Supporting the Adoption of Digital Technology On-Farm: Ten Tips for Extension

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Abstract

We held a symposium to exchange lessons from U.S. and European experts on how Extension can be best designed to support adoption of digital agricultural innovation. We highlight 10 tips for an Extension audience in the United States: (a) ensure connectivity between all actors involved in agricultural innovation, (b) utilize the private sector, (c) advocate for adoption costs, (d) shape an enabling digital ecosystem, (e) create a service, not just a technology, (f) update Extension agents' digital skills, (g) support farmer-led innovation, (h) capture everyday farmer practices, (i) monitor and evaluate progress, and (j) offer long-term support.

Keywords: Adoption, Digitalization, Innovation, Skills, Technology

We organized a special symposium at the Landscape 2024 Conference in Berlin (September 2024). Titled *Supporting Agricultural Technology Through a Connected Agricultural Knowledge and Innovation System (AKIS)*, the symposium brought together leading Extension experts from Europe and the United States. The term AKIS is more commonly used to describe the different arrangements across European Extension systems, which have a mix of public and private Extension providers. In essence, however, the AKIS concept simply describes the mix of different actors and institutions, which includes Extension agents and universities, that play a role in interacting with farmers regarding innovation (see Davis, 2019; Knierim et al., 2015; Sutherland et al., 2023). In the U.S. con-

text, Extension agents connected to universities are only one actor through which farmers make decisions about whether and how to use different technologies. The symposium aimed to exchange lessons on how Extension programs could be delivered to optimize farmer technology adoption. We synthesize these lessons into ten top tips relevant to United States contexts. Five scientific presentations were made by co-authors exploring technology adoption and Extension in different countries: the United States, Sweden, the Netherlands, France, Italy, and other European countries. Two discussion sessions invited contributions from an expert audience.

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Ten top tips for extension systems to support technology adoption

Ensure connectivity between all actors involved in agricultural innovation

Examples presented in the symposium illustrated the value of having a connected advisory system. The scientific literature on the AKIS concept has illustrated conclusively that farmers are better able to adopt technology if there are good links between all the people who play a role in farm innovation, such as technology providers, researchers, Extension agents, fellow farmers, and policymakers (Cofré-Bravo, Klerkx, and Engler, 2019; Gebreyes, Assefa, and Mekonnen, 2025). Ultimately, this ensures that technology is designed in a user-centred way so that it is user friendly and relevant, that farmers are connected to sources of advice from Extension professionals and fellow farmers (peer-to-peer learning is crucial), and that the right policy instruments are used (grants, tax breaks, infrastructure investment, skills development, etc.) to create the conditions within which technology can be used. As one of the symposium speakers formerly wrote, connecting Extension agents with other innovators can create a system that can work “optimally and synergistically” to achieve “more than the sum of its constituents” (Blix Germundsson, 2021, p. 1).

Utilize the private sector

In European Extension systems, which are sometimes more privatized, but also in a U.S. Extension context, the private sector is one of the important actors in agricultural technology adoption. Though universities play a partial role in the innovation system, technologies are widely invested in, designed, and delivered by private companies, and they also interact with farmers regarding the purchase of other inputs. Symposium examples suggested that leveraging private support for technology adoption and following an open innovation model was important, which can involve navigating issues of competition and closed IP (Berthet, Hickey, and Klerkx, 2018).

Advocate for support with costs of digital technology adoption

Linking to the previous points, the cost of technology adoption is a key barrier for a farmer (Rose et al., 2016). This is an issue that is largely outside the control of Extension agents but can be raised with policymakers, technology developers (including host universities), and industry groups, who may be able

to provide support with costs, design lower-cost innovations, or adopt different scaling models (e.g., rental models).

Shape an enabling digital ecosystem

Examples in the symposium illustrated that development and Extension efforts can too often focus only on individual agricultural technologies and not on the wider digital ecosystem required for farmers to use them. We know, for example, that technology use in agriculture can be limited by poor rural broadband or low rural digital literacy, including in the United States (e.g., a study from rural Michigan by Hardy & Palmer, 2025). A key lesson is for Extension agents to work with policymakers and others to invest in *business ecosystems*, bringing actors together to articulate demand and support design and scaling; *knowledge ecosystems* to facilitate collaboration and share knowledge; and *innovation ecosystems* to build the digital infrastructure and skills required to use innovation (e.g., broadband).

Create a service, not just a physical technology

Here, symposium speakers envisaged a key role for Extension. Presenters argued that research and development efforts can often focus too much on the design of technology, rather than in an advisory system to help farmers use the technology. The research indicates that technology adoption can be stunted by farmer attitudes, lack of digital skills, and poor maintenance (Rose et al., 2016). While some European countries have seen the rise of privatized Extension systems, which have, in some cases, restricted the amount of freely available advice for the farmer, there is a key role to play for an Extension agent in providing a service to farmers that supports technology use long term. This point emphasizes the importance of maintaining funding for freely available Extension advice.

Update extension agents' digital skills

A paper on the skills of Extension agents in Texas in the context of artificial intelligence presented research findings that Extension agents need to continually update their skills to maintain relevance in digital work, or to “make sense in the cloud” (Eastwood et al., 2019). Several papers published in the Journal of Extension have also made the strong case for evolution in the digital skills of Extension agents, for example, to learn how to use digital forms of engagement, how to use new technologies, and how to ensure that the Extension advice is still valued in

a world where advice may be available to farmers through generative artificial intelligence (King, 2018; Taylor & Miller, 2016; Wolfe et al., 2018). However, the paper from Texas illustrated that Extension agents can fall behind in skills development in relation to the fast-paced evolution of agricultural technology. There is a role to play for educational institutions and employers in ensuring that Extension agents have the right skills for agriculture 4.0.

Farmer-led innovation supports adoption

Examples shared in the symposium found greater adoption of innovation when farmers and farming organizations had been involved in the shaping and delivery of projects. In light of the growing literature on farmer-led innovation and on-farm experimentation (e.g., Lacoste et al., 2025), Extension agents can play an important role in expanding the number of farmer-led trials facilitated through universities.

Capture everyday farmer practices

A paper shared in the symposium argued that the everyday practices of farmers were crucial in understanding the challenges they face and the solutions needed for technology adoption. Extension agents have a leading role to play here in capturing the daily implementation of innovative practices by farmers and feeding back to those designing technologies.

Monitor and evaluate progress

Data on technology adoption and the success or failure of individual projects is seldom well captured (Lowenberg-DeBoer & Erickson, 2019). However, symposium discussions argued that it is important to understand better how different technologies are being adopted and at what rate across states, as this will influence support provision. One good example is the work of Terry Griffin (and colleagues) at Kansas State who has long monitored the diffusion of precision crop technologies and has fed into national reports on precision agriculture adoption (e.g., McFadden, Njuki, and Griffin, 2023). Extension agents can play a key role in collecting data from the ground about rates and experiences of technology adoption.

Offer long-term support

Technology adoption is a long process, involving pre-adoption learning and decisions, adoption, and post-adoption, in which farmers may continue to struggle to optimize technologies (de Oca Munguia et al., 2021). The symposium discussions argued that

Extension agents and others within the AKIS needed to support farmers long term with their technology adoption journey, with different farmers needing different types of support.

Concluding remarks

These 10 tips encourage some activities that can be addressed by Extension agents alone, but others require good collaboration and advocacy between Extension agents and other actors who play a role in technology development and adoption. We acknowledge that some of the wider suggestions, such as improving digital infrastructure, are outside the control of individual Extension agents, yet Extension can play a key advocacy and relationship-building role to bring different policy and institutional actors together to co-create the right conditions for technology adoption.

The AKIS concept, which emphasizes the need for connectivity between all of the individuals who play a role in on-farm innovation, combined with the symposium's ten tips, offers U.S. Extension a systems approach to elevate technology adoption by harnessing intellectual and social capital to increase buy-in of actors throughout social systems. Today, knowledge exchange around agricultural technologies is part of multidimensional systems, rather than a linear strategy to communicate science through uncritical theories, such as the diffusion of innovations. Due to the 10 benefits presented here, AKIS should be embedded in U.S. Extension professional development programming and be included in academic programs' curricula designed to develop the next generation of Extension professionals. The systems strategy provided by AKIS could elevate knowledge transfer from research institutions to Extension and Extension to farmers for topics such as, but not limited to, responsive agriculture, precision nutrition, mental health, smart agriculture, water quality, forestry production, invasive species, community development, and artificial intelligence.

Authors contribution

Conceptualisation: DCR and KC led the organisation of the symposium where all authors presented their papers and discussed content used in this paper. All made an equal contribution to the concept of the paper.

Writing - original draft, review, editing: DCR produced the first working draft of the manuscript. All authors made significant contributions to the next

draft of the manuscript, contributing content and editing text, including at revision stage.

Data availability

No datasets were generated or analyzed during the current study.

Conflict interest

The authors declare no conflict of interest.

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