



EDITORIAL

Digitalization of smallholder agriculture: Adoption and impacts

Digital technologies are considered to hold transformative potential for agriculture by enhancing productivity, reducing environmental impacts, improving market access, and strengthening farmer livelihoods (Trendov *et al.* 2019; Klerkx *et al.* 2019; Prause *et al.* 2021; Huang *et al.* 2023). Mobile phones can provide real-time weather information and market prices, reducing information asymmetries that have long disadvantaged small-scale producers (Aker and Fafchamps 2014). Precision agriculture technologies, including drones and sensor systems, can optimize input use and reduce costs per unit of output (Wolfert *et al.* 2017). Digital financial services can improve access to credit and insurance, helping farmers manage risks and invest in productivity-enhancing technologies (Suri and Jack 2016). E-commerce platforms may connect smallholders directly to consumers and processors, potentially capturing higher value and margins for producers by bypassing intermediaries (Dannenberg and Lakes 2013; Feng 2024).

Meanwhile, smallholder farmers, while playing a critical role in ensuring food security, face distinct disadvantages in accessing and adopting digital technologies as most of them do not reach the critical operational size beyond which technology becomes profitable. High upfront costs of digital devices, connectivity and capacity building remain prohibitive for many resource-constrained households (Fabregas *et al.* 2019). Furthermore, digital interfaces and technical requirements often exceed the educational backgrounds and technical skills of smallholder farmers (Nakasone and Torero, 2016). Risk aversion, common among vulnerable farming households, can further discourage adoption of unfamiliar technologies (Foster and Rosenzweig 2010). These barriers contribute to a growing digital divide in agriculture, where the benefits of technological advancement increasingly accrue to larger, better-resourced farms while smallholders remain excluded (Jouanjean *et al.* 2017).

China, being both the largest producer and consumer of agricultural products worldwide, features an agricultural sector that traditionally was characterized by high input of manual labor and agrochemicals, but low input of technology. This structure can be considered a heritage of ample rural labor on the one hand and lack of private rural finances on the other hand. For millennia, agriculture served as major

source of income for China's rural population. During the shift from a largely agricultural society to a modern, industrially-dominated society, agriculture remained a fall-back option and essentially a social security for the rural population. Currently though, demographic change (i.e., shrinking and rapidly aging population), deterioration and scarcity of natural resources (i.e., soil, water resources) as well as strategic concerns over food security have driven a fundamental need to modernize China's agricultural sector.

China is currently aiming to modernize farming by expanding rural digital infrastructure, integrating IT and AI into production, strengthening big-data platforms, and upgrading rural industries. With a series of policies, beginning with the *Opinions of the Ministry of Agriculture on Promoting the Development of Agricultural and Rural Big Data* (2015) and the *Internet Plus Agriculture Plan* (2016), China laid the groundwork for spreading digital infrastructure, e-commerce, and precision agriculture. More recent frameworks — including the *Smart Agriculture Development Plan*, the *Development Plan for Digital Agriculture and Rural Areas* (2019–2025), the *National Smart Agriculture Action Plan* (2024–2028), and the *Digital Village Strategy* — set concrete targets for national data platforms, digital-skills training, and integrated rural digital ecosystems. The newly unveiled China's 15th Five-Year Plan (2026–2030) further emphasizes accelerating smart agriculture and digitalization technologies (e.g., AI, Drones, and IoT) to achieve food security, agricultural modernization, and rural revitalization. Together, these policies create a comprehensive roadmap for accelerating digital transformation across China's agri-food sector, and demonstrate the determination of the Chinese government in promoting digitalization in agrifood systems. Compared to other countries, where smallholder-systems are dominating agricultural production, China is leading in digitalization efforts and could offer valuable experiences towards a successful and sustainable digital transformation of the agricultural sectors.

At the same time, the current political framework has yet to achieve successful incorporation of smallholders into the digitalization process. Empirical evidence showed that family farms in China remain mostly excluded from digitalization processes at present. The digitalization level of most family

farms, particularly on the production stage, is still low in China. Considering the barriers to smallholder digitalization laid out earlier, an integration of these producers will likely require active policy support. Otherwise, digitalization is likely to act as a catalyst to already ongoing structural change, crowding out smallholders from commercial farming within a matter of years. While farm consolidation processes worldwide since the 1960s showed that agricultural labor can mostly be absorbed by industrial and service sectors, the social consequences of a high-speed, unchanneled sector transformation will be difficult to predict. To direct policymaking towards not just supporting but also guiding this digitalization process in an inclusive fashion, current smallholder-specific empirical evidence into the conditions, drivers and impacts of digitalization are of high need.

General research established that in general, high upfront costs and investment risks remain substantial barriers for digital innovation adoption among smallholders (Pivoto *et al.* 2019; Geng and Liao 2024). Beyond fundamental economic incentives, social and behavioral factors play a critical role, with younger, more educated farmers and those with strong social networks or frequent extension contact demonstrating higher adoption intensity (Pivoto *et al.* 2019; DeLay *et al.* 2021; FAO 2022). From a technological perspective, ease of use and robust digital infrastructure — such as reliable internet and technical support — are essential enablers, with “embodied-knowledge” technologies like automated guidance seeing faster diffusion than complex information-intensive systems (Ofori *et al.* 2020; Damasceno *et al.* 2025). Furthermore, institutional support through government subsidies and targeted policy interventions effectively mitigates financial constraints, whereas environmental motivations currently appear as secondary or inconclusive drivers compared to direct economic benefits (Geng and Liao 2024; Ruslan 2024; Tian *et al.* 2025).

Education and digital literacy emerge as critical factors to reduce adoption costs among smallholders and act as prerequisite for their engagement in agricultural digitalization (Li *et al.* 2025). Digital literacy encompasses not only basic technical skills for using devices and applications, but also the ability to critically evaluate information, adapt digital tools to local contexts, and integrate digital resources into decision-making processes (Salemink *et al.* 2017). Research has shown that farmers with higher digital literacy are more likely to adopt beneficial agricultural technologies, make informed and adaptation production decisions, and achieve better economic outcomes and resilience (Deichmann *et al.* 2016; Bai *et al.* 2026). Conversely, limited digital literacy can lead to misuse of digital information, inappropriate technology choices, and potentially harmful agricultural practices (Birner *et al.* 2021).

The actual or expected impact of agricultural digitalization under smallholders context is another critical research topic. Literature reviews for the grain sector show that both main motivation and impact of digitalization lies within saving labor and other agricultural inputs at given rates of productivity. Meanwhile, international studies have also documented productivity gains from precision agriculture technologies (Lowenberg-DeBoer and Erickson 2019), improved market outcomes from mobile phone adoption (Jensen 2007),

and enhanced financial inclusion through digital payment systems (Suri and Jack 2016). However, research has also identified unintended consequences, including increased input use in some contexts (Fabregas *et al.* 2019) and growing inequality between adopters and non-adopters (Klerkx *et al.* 2019). These mixed findings underscore the importance of understanding not just whether digital technologies work, but how and under what conditions they benefit different types of farmers.

This special focus contributes new empirical evidence to these ongoing discussions, with particular attention to the Chinese context, where rapid digital transformation intersects with the world's largest population of smallholder farmers. The six papers are organized around three complementary themes: behavioral aspects of innovation adoption (Section 1), aspects of digital knowledge and literacy within innovation adoption (Section 2), followed by the actual and expected impacts of digitalization (Section 3).

Section 1: Behavioral adoption drivers

Two papers in this section provide detailed insights into behavioral adoption drivers of agricultural drones, or unmanned aerial vehicles (UAVs), under the smallholder context in China. Although these two papers address the farmers' adoption of same technologies, i.e., agricultural drones, the authors take distinct approaches and pay different attention on the adoption factors.

Zhang *et al.* (2026) strived to provide a specific perspective on behavioral aspect by examining farmers' preferences for agricultural drone services rather than ownership, an organizational innovation which allows small holders to use drones without purchasing them. Using a discrete choice experiment among rice producers in Hubei Province, they show that most farmers are willing to adopt drone services under collective hiring arrangements. The study reveals that farmers are willing to pay for drone services, with localness of suppliers valued more highly than contractual arrangements. Farmers strongly prefer local suppliers and contractual agreements, indicating that supplier uncertainty is a major concern in service-based adoption. These findings suggest that service-based models may offer more inclusive pathways for smallholder access to advanced digital technologies, but require careful attention to trust, reliability, local capacity building, and more importantly, the standardization of the services.

Zhou *et al.* (2026) examined the drivers and barriers to UAV adoption among rice farmers in Jiangxi Province, China, using a structural equation model grounded in the Technology Acceptance Model. The study reveals that perceived usefulness and ease of use strongly predict adoption intention, while perceived risk acts as a significant barrier. Importantly, the paper identifies network externalities as a key social factor, with peer influence amplifying adoption likelihood by reducing the perceived risk of innovation adoption. As expected, farm size matters significantly, with larger farms showing higher adoption rates. With their research, the authors provide novel evidence towards the social and psychological process shaped by perceptions,

peer effects, and risk considerations behind drone adoption among Chinese smallholders.

Section 2: Digital literacy as adoption driver

Beyond economic and behavioral drivers, digital knowledge and capabilities emerge as a cross-cutting theme throughout this special focus, warranting dedicated attention. Two papers in this section provide particularly detailed insights into how digital knowledge shapes technology valuation, information use, and agricultural production behaviors. Collectively, these two articles suggest that digital knowledge and literacy are foundational capabilities that determine whether smallholders can successfully participate in and benefit from agricultural digitalization.

Bai *et al.* (2026) focused on climate adaptation, examining whether digital literacy promotes adaptive production behaviors among grain farmers in Sichuan Province, China. The study finds that digital literacy significantly increases adoption of climate-adaptive practices by improving farmers' perception of climate disaster risks. Importantly, the positive effects of digital literacy are stronger where government support is present, including internet training, climate information services, and agricultural infrastructure development. This paper demonstrates that digital literacy can contribute to agricultural resilience, but requires supportive policy environments to realize its full potential.

Amolegbe *et al.* (2026) shifted the focus to Nigeria, Africa, and investigated the relationship between digital technology knowledge and e-commerce valuation among farmers. Using objective measures of digital knowledge rather than self-reported experience, the study reveals significant gaps in basic digital skills despite widespread mobile phone ownership. However, farmers with stronger digital knowledge show substantially higher willingness to pay for digital marketing services. The heterogeneity analysis reveals that digital knowledge benefits vary by age and gender, with young adults and men showing larger increases in e-commerce valuation. These findings underscore that the digital divide extends beyond device access to encompass fundamental differences in capability and knowledge.

Section 3: Impacts and effects

While existing policy may support in leveling adoption barriers and provide innovation incentives for smallholders, research may also guide policy makers with respect to how policy may facilitate digital innovation processes towards reducing undesired effects of digitalization and shaping positive benefit incidence among different user groups. Two papers in this special focus address different dimensions of impacts of digitalization: agrochemical use decisions and income stability.

Liu *et al.* (2026) focused on the socioeconomic perspective by investigating how digital technology use affects income stability of marginalized farm households. Using panel data and multiple estimation approaches, the study shows that digital technology use significantly improves both income levels and income stability among relocated households participating in China's poverty alleviation programs, with stronger effects at higher levels of use. The analysis identifies

information acquisition and human capital accumulation as key mechanisms, showing that digital technology helps households access employment opportunities and develop skills that contribute to stable livelihoods. The paper also reveals that digital technology is particularly effective at stabilizing income for households experiencing downward volatility, suggesting an important insurance-like function.

Hu *et al.* (2026), on the other hand, provided a sobering assessment of how online agricultural information affects input use decisions among Chinese farmers. Using propensity score matching with data from 1,833 farms across five provinces, the study finds that online information use increases rather than decreases chemical fertilizer expenditure, particularly among smallholders. This counterintuitive finding highlights potential problems with the quality and targeting of existing digital agricultural information. The authors suggest that much online agricultural content originates from input suppliers with commercial interests in high application rates, and that smallholders may lack the digital literacy needed to critically evaluate such information. This paper serves as an important reminder that digitalization is not automatically beneficial and that information quality and farmer capability are crucial mediating factors.

Concluding remarks

The digitalization of smallholder agriculture represents both an opportunity and a challenge. The papers in this special focus show that digital technologies can indeed contribute to more productive, resilient, and inclusive agricultural systems. However, they also demonstrate that realizing this potential requires careful attention to farmer capabilities, information quality, service delivery models, and supportive policy environments. As the digital transformation of agriculture continues, ensuring that its benefits reach smallholder farmers will require sustained effort across multiple domains of policy and practice.

Future research should continue to examine these complex relationships between digital technologies, farmer capabilities, and agricultural outcomes. Particular attention should be paid to long-term impacts, inequality effects, and the institutional conditions that enable inclusive digitalization. Mixed-method approaches that combine quantitative impact assessment with qualitative investigation of farmer experiences and institutional dynamics would be especially valuable. Further research into processes, trends and projections of digitalization therefore remains of urgent need.

Special care should be given to the interaction between digitalization, structural change and sustainability. Providing a critical advantage to large producers with respect to total factor productivity, digitalization is likely to accelerate structural change. By shifting the production function and the efficient scale of production to a level where smallholders are no longer competitive, commercial smallholder production is critically endangered. While a structural change within China's smallholder farming system is both needed and ultimately inevitable, the challenges lie in ensuring the meaningful engagement of small and disadvantaged farmers and guiding the sustainable transformation of farming system

towards digitalization and sustainability.

This special focus provides a glimpse into the dynamic and emerging field of agricultural digitalization in smallholder contexts, which represents both a compelling scientific frontier and an urgent challenge for sustainable agricultural transformation and global food security. The featured papers collectively offer robust empirical evidence on the heterogeneous effects of digital technologies across different farmer types, technologies, and contexts, moving beyond simple adoption narratives to examine nuanced patterns of use and impact. Additionally, the contributions also shed light on the critical but often overlooked role of digital literacy and information quality in determining whether digitalization benefits or potentially harms smallholder farmers. By demonstrating that digital technologies can both enhance and undermine agricultural outcomes — depending on their design, delivery, and use — this collection underscores the need for more sophisticated approaches that prioritize farmer capabilities alongside technological advancement. We envision this special focus will stimulate further research on agricultural digitalization in smallholder contexts in China and beyond.

Dr. Zhanli Sun

Guest Editor

Leibniz Institute of Agricultural Development
in Transition Economies (IAMO)

Germany

E-mail: Sun@iamo.de

Prof. Hang Xiong

Guest Editor

College of Economics and Management
Huazhong Agricultural University

China

E-mail: hxiong@hzau.edu.cn

Prof. Hongmei Yi

Member of Youth Editorial Board of JIA/Guest Editor

School of Advanced Agricultural Sciences

Peking University

China

E-mail: hmyi.ccap@pku.edu.cn

Prof. Dr. Lena Kuhn

Guest Editor

Leibniz Institute of Agricultural Development
in Transition Economies (IAMO)/

Department of Digitalization and Innovation in Agribusiness
Institute of Agricultural Economics

Kiel University

Germany

E-mail: Kuhn@iamo.de

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this manuscript, the authors used ChatGPT 5.0 and Grammarly to assist in improving the clarity and readability of the language. All content generated was carefully reviewed and revised by the authors as necessary, and the authors take full responsibility for the final content of the article.

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Declaration of competing interest

The authors declare that they have no conflict of interest.

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