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Agricultural digitalization and automation in low- and middle-income countries: Evidence from ten case studies

Background paper for
The State of Food and Agriculture 2022

FAO AGRICULTURAL DEVELOPMENT ECONOMICS TECHNICAL STUDY

25

Agricultural digitalization and automation in low- and middle-income countries: Evidence from ten case studies

Background paper for *The State of Food and Agriculture 2022*

By

Mariette McCampbell
International consultant

Food and Agriculture Organization of the United Nations
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Contents

Tables

Preface

This study aims to help bring digitalization and automation solutions into focus as enablers of precision agriculture in low- and middle-income countries for *The State of Food and Agriculture 2022 – Leveraging automation in agriculture for transforming agrifood systems*. A growing global population, diminishing agricultural workforce and ever-increasing demands for affordable, high-quality food call for more efficient, productive and sustainable agricultural production systems. However, access to digitalization and automation solutions is limited for most agricultural producers in low- and middle-income countries, especially small-scale and subsistence producers, due to high investment costs, scepticism among producers, lack of knowledge and skills around these technologies, the low cost of labour in some world regions and geographic conditions, which can be unsuitable for some equipment.

Based on ten case studies from sub-Saharan Africa, Latin America and the Caribbean, South Asia and Eastern and South-eastern Asia, this report investigates: i) the appropriateness of digital and automation solutions for small-scale agricultural producers; ii) the main drivers and barriers to adoption of such solutions; and iii) the role of policies and regulations in creating an enabling environment to adoption. Each case study focuses on one or more agricultural production system, ranging from crops to livestock, aquaculture and agroforestry. Based on the analysis of the case studies, the report offers guidance to providers, users and policymakers on how to accelerate the uptake of digitalization and automation solutions for more inclusive, sustainable and resilient agrifood systems.

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Abbreviations and acronyms

AI	artificial intelligence
API	application programming interfaces
BXW	Banana *Xanthomonas* Wilt
CSA	climate-smart agriculture
DII	demographically identifiable information
FAO	Food and Agricultural Organization of the United Nations
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
GNSS	global navigation satellite system
GPS	global positioning system
ICT	information and communications technology
IGTF	Igara Growers Tea Factory
IoT	internet of things
IT	information technology
IVR	interactive voice response
ML	machine learning
MNO	mobile network operator
NGO	non-governmental organization
PII	personally identifiable information
UAS	uncrewed aerial system
UAV	uncrewed aerial vehicle
USSD	unstructured supplementary service data

Executive summary

A growing global population, diminishing agricultural workforce and ever-increasing demands for affordable, high-quality food calls for more efficient agricultural production. Digital solutions and automation can plug labour gaps, increase productivity and efficiency, and improve environmental sustainability and resilience. The benefits may be significant, particularly stemming from the use of fully automated equipment. However, access to digital and automation solutions is limited for most agricultural producers in low- and lower-middle-income countries, especially for small-scale and subsistence producers.

A key objective of this study is to investigate the appropriateness of digital and automation solutions for small-scale agricultural producers in low- and middle-income countries. The study examines different agricultural production systems, the main drivers and barriers to adoption of such solutions, and the role of policies and regulations in creating an enabling environment for adoption. Building on the findings from ten case studies in sub-Saharan Africa, Latin America and the Caribbean, South Asia and Eastern and South-eastern Asia, the report relies on in-depth interviews with solution providers and farmers' associations or cooperatives to investigate the barriers and drivers to adoption – including institutional, policy and regulatory barriers. The aim is to suggest entry points for policy, investments, regulatory frameworks, research and innovation that can accelerate the responsible and inclusive uptake of digital and automation solutions for precision agriculture.

The study finds that digital and automation technologies in low- and middle-income countries are largely limited to disembodied solutions, often relying on smartphones and complemented by global navigation satellite systems (GNSS) and artificial intelligence (AI). Most technologies focus on crops, some on livestock and very few on agroforestry. The most important barriers to adoption include high investment costs, lack of digital skills and knowledge throughout the agricultural sector and the lack of a supportive enabling environment for adoption.

However, recent advances in motorized mechanization and partially-automated technologies, combined with the greater availability of GNSS and internet of things (IoT) technologies, and mobile phone applications, have enabled the adoption of new technologies to local contexts, such as by reducing their size, cost and complexity and introducing new machinery hire services. Examples include diesel-operated hand-ploughs, simple drip irrigation systems, as well as all types of tractors and tractor-related equipment that are made available through hiring service platforms. This will be particularly game-changing in sub-Saharan Africa, where uptake remains limited. The emergence of guidelines, strategic plans and policies that regulate and streamline the use of, for example, AI, can accelerate the uptake of digital and automation solutions and should be encouraged. There is also a need to provide agricultural producers, who are often sceptical about new technologies, with clear information and evidence on the benefits, costs, and impact of digital and automation solutions.

Although the case studies presented here cannot provide an exhaustive representation of all the technologies available to small-scale producers in low- and middle-income countries, by choosing various examples across a broad range of agricultural production systems, the study provides a landscape analysis of digital and automation solutions for precision agriculture. Based on this analysis, the study offers guidance to providers, users and policymakers on how to accelerate automation uptake for more inclusive, sustainable and resilient agrifood systems.

1 Introduction

1.1 Study introduction

The agricultural sectors in low- and lower-middle-income countries have long been considered as lagging behind in terms of mechanization and automation, a topic of interest to researchers and developmental organizations (Baudron *et al.*, 2015; Kienzle, Ashburner and Sims, 2013; Sims and Kienzle, 2016). Mechanization refers to the use of diverse technologies, from simple hand-held tools to animal-powered tools and to more sophisticated and motorized equipment (see Annex 1 for a complete list of definitions). The aims of mechanization are to ease hard labour, reduce labour shortages, improve efficiency and agricultural productivity (Charlie *et al.*, 2013). Put simply, mechanization is the (partial or full) replacement of a human with a machine to fulfil a physical activity. Automation is the (partial or full) substitution of physical activities and human decision-making in agricultural operations with machinery and equipment, reducing or eliminating human direct intervention and improving precision in agricultural production systems. Automated technologies are technological systems or machines that have added higher levels of artificial intelligence to an existing machine or have developed a new intelligent machine to replace an existing application. In such systems, some (partly automated, such as drones, tractors with sensors built in, smartphone applications) or all (fully automated, such as automatic crop sorting and packaging, and geo-intelligence services using artificial intelligence [AI]) of the elements can work without human intervention. More progressive forms of automation involve the entire production process and often require more significant changes to the existing process than simple mechanization provides.

Why is there a need for mechanization and automation in agricultural production systems today? It basically comes down to scale and economics: a growing global population and ever-increasing demand for affordable, high-quality food requires that agricultural production becomes more efficient. Additionally, labour is becoming more of an issue worldwide as people leave the agriculture sector and rural areas for jobs in the cities or abroad that are more rewarding in terms of payment and social status. Replacing humans with machines thus becomes a logical solution (Miller, 2021). Automation reduces the demand for labour and, particularly in the case of fully automated equipment, this reduction may be significant. However, while the number of people needed to operate the equipment decreases, the skills and knowledge that they require increases.

Agricultural production on most farms in low- and lower-middle-income countries continues to largely depend on hard manual labour, with mechanization limited to the use of manually-operated hand-held equipment. For example, in Uganda and Rwanda, field preparation is still mostly done by hand. Family members and day labourers invest many hours in hard work, often in tough climatic conditions, to rake the soil with traditional hoes in preparation for a new cropping season. Sometimes, simple hand tools may be complemented or replaced by animal-operated equipment, depending on the country, cultural values and widely adopted practices. For example, in India, farmers commonly employ oxen to pull a plough. A mechanized alternative would be a tractor with an attached plough. However, access to such equipment is limited for most farmers in low- and lower-middle-income countries, especially smallholder subsistence farmers. Another example is the use of donkeys for transporting agricultural produce, a practice that is common in some regions in Kenya. Yet, elsewhere in the country this task still primarily falls to men and women, who carry the goods on their heads or backs, sometimes aided by handcarts.

Reduced labour availability and environmental and climate concerns, combined with a need to improve the efficiency and profitability of agricultural production in low- and lower-middle-income countries, calls for the modernization of agricultural sectors, especially in sub-Saharan Africa (Task Force Rural Africa, 2019). The Food and Agriculture Organization of the United Nations (FAO) has shown that that sub-Saharan Africa is the least advanced agricultural region in the world, when it comes to motorized mechanization, with less than two tractors per 1 000 hectares of cropland, while South Asia and Latin America can claim ten tractors per 1 000 hectares (Bafana, 2019). The lack of such equipment is primarily due to the significant investment required, as well as the absence of a culture that values mechanization, the wide availability and low cost of labour (with family labour often not counted as a cost), the type of farming systems (often subsistence, with small production systems mixing crops, livestock and agroforestry), and the challenging geographic conditions, which can be unsuitable for large mechanized equipment. For subsistence farmers – who primarily produce for family consumption rather than for the global market – the high cost of motorized mechanization and automation technologies cannot be covered by their earnings. These smallholder farmers represent a high percentage of all farmers in low- and lower-middle-income countries.

While the uptake of motorized equipment in low- and lower-middle-income countries has been slow – especially for large equipment like tractors, harvesters, irrigation systems, and livestock and fish feeding systems – that does not mean that mechanization has entirely bypassed the agricultural sectors in these countries. A wide array of adapted motorized equipment has been introduced to farmers over time, including diesel-operated ploughers, mini tractors and simplified drip irrigation systems. Often these tools have been adapted to become smaller, simpler and less costly. Such adapted versions are referred to as "appropriate technology" or "appropriate mechanization". Few of these tools have achieved widespread adoption. Nevertheless, some scholars argue that the potential of these small, multipurpose, and relatively inexpensive sources of mechanized power should be re-examined – at least for sub-Saharan Africa – in light of the need for sustainable agricultural intensification with minimal social and environmental impact (Baudron *et al.*, 2015).

1.2 Problem statement

Considering the limited uptake of motorized mechanization technologies in low- and lower-middle-income countries, it is likely that most farmers are light years away from fully automated technologies. Such technologies are still too advanced and expensive for most smallholder agricultural producers, with an unfavourable cost–benefit ratio for those farmers. Only a small number of producers, most notably large-scale and wealthy farmers, can enjoy the benefits of these technologies in the absence of resource constraints (Daum *et al.*, 2022; Daum and Birner, 2017, 2020). However, partly automated technologies may be accessible to some farmers in low- and lower-middle-income countries, especially when they are adapted to the specific context of agricultural systems in these countries.

There is a great deal of interest in the use of digital and automation technologies in farming systems. This is visible in countless projects and interventions, hackathons, innovation centres, start-ups, and, more recently, the emergence of guidelines, strategic plans, and policies to regulate and streamline the use of technologies such as AI, uncrewed aerial systems (UAS), personally identifiable information (PII) and demographically identifiable information (DII)[1] (see Annex 1 for a complete list of the definitions used in this study).

[1] For examples of guidelines, strategic plans and policies related to technological innovation, see Musoni (2020b) and Hernandez (2021) for the context of Rwanda.

1.3 Study objectives

This study examines the state of the art in digital and automation solutions for the agricultural sector in low- and lower-middle-income countries and analyses the drivers and barriers to the adoption and use of such solutions. Additionally, it explores whether and how digital and automation technologies can support inclusive and sustainable agricultural production in four agricultural subsectors: crops, livestock, aquaculture and agroforestry. Given the previously discussed inaccessibility of digital and automation technologies to subsistence farmers, the study focuses on solutions whose primary users are smallholder farmers with a market orientation. However, the implications of these solutions for smallholder subsistence farmers and other value chain actors receive some attention as well. For similar reasons, highly advanced digital and automation technologies (e.g. full automation and robotics) are considered outside the scope of the study, although their feasibility in the context of smallholder agriculture is discussed briefly in the discussion section of this study. This said, the study focuses on low- to medium-advanced solutions in the following categories:

- disembodied solutions without remote sensing/UAS for decision support;
- disembodied solutions with remote sensing/UAS for decision support (e.g. land mapping);
- disembodied solutions with UAS for farming activities (e.g. spraying fertilizers);
- disembodied solutions with analytics, models, AI, blockchain technology;
- mechanization with digital and internet of things (IoT) and/or global navigation satellite systems (GNSS) components.

1.4 The central role of hand-held digital devices in low- and lower-middle-income countries

In recent years, a vast proliferation of hand-held devices (e.g. smartphones, sensors, IoT devices) has appeared on the scene, largely a result of growing access to mobile networks and internet coverage, even in the world's remotest regions. According to the Global System for Mobile Communications (GSMA) (2020a),[2] in 2020, 69 percent of the population of Latin America and the Caribbean, 64 percent in Pacific Asia and 45 percent in sub-Saharan Africa have use of a smartphone with these percentages expected to increase to 81, 79 and 67 percent respectively by 2025 (GSMA, 2020a). However, these statistics fail to present a contextualized picture of the distribution of smartphones[3] and internet use[4] since they do not reflect the digital divides limiting access by gender, rural-urban status and age. Both governments and the private sector have made massive investments in infrastructure. For example, Google is investing in Africa's first subsea internet cable through its Equiano programme and combining this with a USD 1 billion investment in Africa, including a USD 50 million venture capital start-up fund (Onukwue, 2022). The wide accessibility of mobile devices, together with infrastructure improvements, has created opportunities for a wide array so-called "disruptive innovations", linked to concepts such as "agriculture 4.0",

2 The GSM Association is an industry organization that represents the interests of mobile network operators worldwide.

3 Studies in sub-Saharan Africa show much higher smartphone adoption in the urban areas (Houngbonon, Le Quentrec and Rubrichi, 2021) and extremely low adoption by smallholder farmers in rural villages. See McCampbell *et al.* (2021) for an example on Rwanda.

4 For example, the International Telecommunication Union (ITU) reports that although 86.6 percent of the population in developed countries used the internet in 2019, this fell to 19.1 percent in the least developed countries (LDC), 48.4 percent in Asia and the Pacific and 28.2 percent in Africa and, when it comes to internet use, the gender digital divide is increasing rather than decreasing (ITU, 2019). Data from 2020 show a very large rural–urban divide for internet access in developing countries (65 percent urban access versus 28 percent rural access) (ITU, 2020).

“smart farming”, “data-driven farming” and the “fourth agricultural revolution” (Jiménez *et al.*, 2019; Klerkx, 2021; Klerkx, Jakku and Labarthe, 2019; Mehrabi *et al.*, 2021; Rose *et al.*, 2021; Rose and Chilvers, 2018; Wolfert *et al.*, 2017). Digitalization in the agricultural sector is seen as a game changer by influential donor organizations such as the European Union, the United States Agency for International Development (USAID), the Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ), the Alliance for a Green Revolution in Africa (AGRA) and FAO.

The use of digital technologies and services in the agricultural sector has long been referred to as ict4ag (information and communication technologies for agriculture) a term that is now often replaced by d4ag (digital or data for agriculture). These technologies and services facilitate the collection and exchange of data and information among farmers and other stakeholders in order to support decision-making and enhance effectiveness and efficiency in agricultural production systems (McCampbell, 2021; Steinke *et al.*, 2022). They have received significant attention in recent years from donors and research and development agencies operating in low- and lower-middle-income countries (FAO and ITU, 2022; GSMA, 2020b; Trendov, Varas and Zeng, 2018; Tsan *et al.*, 2019). This has resulted in the development of a huge number of projects, interventions, technologies and services (Porciello *et al.*, 2021). Many of those interventions are based on apps that can be operated via a smartphone, or a call or messaging service.

So-called asset-sharing services (sometimes combined with “pay-as-you-go” solutions) are a subcategory of digital services with a strong link to conventional mechanization. These can be seen as a reformulation of the equipment cooperative model, which is still in use in some countries (e.g. see the Tun Yat case in Myanmar). Such services are of particular interest for this study. Asset-sharing solutions connect equipment owners, and sometimes operators, with farmers needing, for example, a tractor or a drone. Farmers pay the owner per hour or per acre for the use of the equipment, and a percentage or fixed fee goes to the asset-sharing service. The most well-known example of an asset-sharing service is probably Hello Tractor, which operates in seven African countries as well as in Bangladesh, India and Pakistan; the company is often affectionately dubbed “Uber for tractors”. TROTRO Tractor and Tun Yat provide additional examples (see Annex 3 for a detailed description of each case study). Beat Drone is a Nigerian company that provides UAS services for agriculture as well as for oil and gas exploration and infrastructure development (Beat Drone, 2022). The concept is that these services improve the cost–benefit ratio of mechanization equipment by providing farmers with access to the use of equipment at a much reduced cost than would be needed to buy it, while the fees paid by the farmer make the equipment more cost-effective for the owner. Asset-sharing services have seen significant growth in recent years, particularly in sub-Saharan Africa, where the private ownership of motorized mechanization and automation equipment is extremely limited, as previously noted.

Another group of digital services provide equipment monitoring solutions. These are simple applications that can automate the operation of equipment, such as irrigation pumps (Musoni, 2020a; Viet Nam News, 2021) or GNSS devices that can track the movements of, for example, equipment or animals. These were the first smart farming solutions to emerge for low- and lower-middle-income countries (GSMA, 2020). More advanced are IoT solutions that are used to, for example, monitor and sometimes also (partly) automate decisions about caring for crops, livestock or fish. In both cases, the objective is to optimize decision-making and enhance the precision, efficiency and profitability of production systems, while reducing the time and energy spent on, for example, operating equipment or assessing animal behaviour. This paper includes some case studies that include IoT solutions, mostly from Asia (e.g. Seed Innovations, Aquaconnect).

Following this general introduction to the topics of mechanization, digitalization and automation in the context of low- and middle-income countries, the paper introduces the study's conceptual framework in the next section. Thereafter follows a section that presents and discusses the research findings. Finally, this study provides a conclusion and recommendations for policy and practice.

2 Conceptual framework and methods

KEY MESSAGES

- A total of ten interviews – one for each case study – were conducted in sub-Saharan Africa, Latin America and the Caribbean, South Asia and Eastern and South-eastern Asia. Interviewees were usually the representatives of the solutions.
- Case studies covered novel, yet scalable, digital and automation solutions (including motorized mechanization) that target small-scale producers across different agricultural production systems.
- Secondary data (e.g. documents shared by interviewees, scientific and grey literature) were used to complement the information obtained from the interviews.

For the purpose of this, and a second study conducted by Ceccarelli *et al.* (2022), a joint conceptual framework was developed to support a rigorous, structured analysis of collected case study data. Indicators were developed to: i) assess the state of the art and future vision for mechanization, and digital and automation technologies; ii) identify the drivers and barriers that affect adoption; and iii) establish how policies and regulations can create an enabling or disabling environment for mechanization, and digital and automation technologies. For the detailed framework, see Ceccarelli *et al.* (2022).

2.1 Study methods

The study is based on the analysis of ten case studies from low- and middle-income countries in four different regions (sub-Saharan Africa, Latin America and the Caribbean, South Asia and Eastern and South-eastern Asia). Case studies were based on empirical data from key informant interviews complemented by secondary data and literature.

2.2 Case studies

Ten case studies illustrate how digitalization and automation can transform the use and adoption of machinery. The studies provide the basis for evaluating the drivers and barriers to adopting specific solutions to different types of users in various countries, regions and agricultural subsectors (see Table 1). Each case study represents a single company, start-up, non-governmental organization (NGO) or research organization that has developed and/or implemented a solution for smallholder farms in a specific country or countries. In two cases, the solution came from a farmer organization and a farmer-owned company/cooperative. A solution provider may offer multiple self-standing or bundled solutions, although the case studies generally focus on the most important one(s).

The selection of cases was based on the following criteria: i) the solution provider operates in one or more countries in Latin America and the Caribbean, sub-Saharan Africa, South

Asia and Eastern and South-eastern Asia; ii) the solution represents a novel and scalable approach to digital agriculture and/or agricultural automation and robotics, possibly with an additional element of mechanization; iii) the solution targets smallholder farmers; and iv) the solution relates to one or more production systems: crop production (six case studies, primarily arable staple food crop production); livestock (two case studies); aquaculture (one case study); and agroforestry (one case study). The ten cases include five from sub-Saharan Africa, two from Latin America and the Caribbean, and three from Eastern, South-eastern and South Asia (see Table 2). While the case studies represent the specific technological solutions offered by ten different service providers, by highlighting various technologies across a broad range of agricultural production systems, the study is able to provide a broad introduction to digital and automation technologies in low- and middle-income countries and to signal the influence of these technologies on inclusivity and sustainability in diverse farming systems. Thus, the study aims to represent the breadth of available digital and automation solutions available, while recognizing that it cannot provide an exhaustive demonstration of the diversity that exists within the four criteria.

TABLE 1 Location and agriculture subsector of case studies

Case study	Originated/operating in	Agriculture subsector
Agrinapsis	Bolivia (Plurinational State of), Mexico, Guatemala, Costa Rica, Ecuador	Crops
Coopecan	Peru	Livestock
GARBAL	Burkina Faso, Mali	Livestock
TROTRO Tractor	Benin, Ghana, Nigeria, Togo, Zambia, Zimbabwe	Crops
Igara Tea	Uganda	Crops
ICT4BXW	Rwanda	Crops
Justdiggit	Kenya, United Republic of Tanzania	Agroforestry
Aquaconnect	India	Aquaculture
Seed Innovations	Nepal	Crops
Tun Yat	Myanmar	Crops

Source: Author’s elaboration.

TABLE 2 Overview of the ten selected case studies

No.	Region	Country	Income group	Case study	Production orientation	Type(s) of mechanization, automation, digital technologies	Solution
1	Latin America and the Caribbean	Bolivia (Plurinational State of), Mexico, Guatemala, Costa Rica, Ecuador	Lower-middle	Agrinapsis	Crop production (not crop-specific)	Android application, video training, social media web platform	Platform where farmers, experts and students can share knowledge about agriculture in Spanish
2	Latin America and the Caribbean	Peru	Upper-middle	Coopecan	Livestock (alpaca)	Blockchain	Use of blockchain to trace production of alpaca wool
3	Sub-Saharan Africa	Burkina Faso, Mali	Low	GARBAL	Livestock (pastoralist)	IVR, USSD, SMS, call centre, satellite intelligence, ML algorithms	Call centre, SMS and IVR services for pastoralist livestock producers using satellite intelligence as data input
4	Sub-Saharan Africa	Benin, Ghana, Nigeria, Togo, Zimbabwe, Zambia	Lower-middle /low	TROTRO Tractor	Crop production (not crop-specific: primarily staple crops)	Motorized equipment (tractor, combine, post-harvest processor), drones, Android application, USSD, IoT, GNSS tracker	Mechanization equipment and drone-sharing service via USSD, targeting smallholder farmers
5	Sub-Saharan Africa	Uganda	Low	Igara Tea	Crop production (tea)	Tea processing and packaging factory, ODK forms, drones	Tea factory using simple digital tools to optimize procurement of tea leaves from, and payments to, smallholder farmers
6	Sub-Saharan Africa	Rwanda	Low	ICT4BXW	Crop production/ agroforestry (banana)	IVR, USSD, Android application, WhatsApp chatbot, drones	Suite of digital channels collecting data from, and providing information to, smallholder farmers about BXW disease prevention and control
7	Sub-Saharan Africa	United Republic of Tanzania	Lower-middle	Justdiggit	Agroforestry (regreening)	Drones, satellite intelligence, AI (ML algorithms), Android application	Regreening programmes targeting smallholders and pastoralists through diverse media. Identifying and monitoring tree presence using drones, satellite images

▸▸

TABLE 2 (cont.) Overview of the ten selected case studies

No.	Region	Country	Income group	Case study	Production orientation	Type(s) of mechanization, automation, digital technologies	Solution
8	South Asia	India	Lower-middle	Aquaconnect	Aquaculture (shrimp)	Android application, satellite intelligence	Application to document and monitor input and output of aquaculture production. Market and advisory services. Satellite intelligence for triangulation
9	South Asia	Nepal	Lower-middle	Seed Innovations	Crop production	Android app, satellite intelligence, AI (ML algorithms), free open APIs (application programming interfaces)	Satellite intelligence to monitor crop performance and production threats. Application to provide advisory services to smallholder farmers
10	Eastern and South-eastern Asia	Myanmar	Lower-middle	Tun Yat	Crop production (primarily rice, mung bean, sesame, groundnut, maize)	Android application, IoT, GNSS tracker, laser leveller, GPS, motorized equipment (tractor, combine, post-harvest processor)	Mechanization equipment service accessible via smartphone application, targeting smallholder farmers

Notes: BXW – Banana *Xanthomonas* Wilt; GPS – global positioning system; IVR – interactive voice response; ML – machine learning; USSD – unstructured supplementary service data.

Source: Author's elaboration.

A single interview was conducted with a key informant (9 male, 1 female) representing the service provider (i.e. enterprise, start-up, NGO or research organization) or the farmer association/cooperative that developed and/or implemented the solution in each selected case. Interviews used a semi-structured approach, with separate interview questions for service providers and for farmers' associations/cooperatives (see Table 3 for interview themes, and Annex 2 for the interview guides). The interviews were organized in MS Teams and audio- and video-recorded as well as automatically transcribed by the MS Team software. Transcripts were then manually analysed and coded in MS Word. The analysed data were used to develop case study narratives following a structured outline. Interview data were complemented with data from secondary data resources (see Section 2.3). The author used the conceptual framework to develop a cross-case analysis that was organized according to three pillars of sustainability: economic, environmental and social (Tables 5–7), with an additional focus on social inclusiveness. Annex 3 summarizes each case study, highlighting key information. The full-length case study accounts are available from the author upon request.

TABLE 3 Themes covered in semi-structured interviews

Themes for service providers
Organization and services/solution in general
Unique selling points of intervention/technology/solution(s) covered in case study
Customers and business model
Adoption drivers
Adoption barriers
Future vision

Source: Author's elaboration.

2.3 Secondary data research

Secondary data and impact metrics (e.g. documents shared by interviewees, information gathered from the internet and articles about the case study organizations/companies/solutions, scientific literature, reports from donors and NGOs) were used to enrich case study data and to assess:

- trends in mechanization, digitalization and automation in the four regions included in the study;
- the drivers and barriers to adoption of these technologies, taking account of initiatives by governments, development agencies and NGOs in various agricultural subsectors (i.e. crop production, aquaculture, forestry, livestock production);
- how digital technologies are transforming conventional farm machinery (e.g. tractors, irrigation systems, harvesting equipment, milking machines) and the potential for technological leapfrogging, passing directly from low-tech agriculture to more advanced digital automation technologies;
- the potential for small, hand-held devices (e.g. mobile phones, drones, IoT equipment) in regions with limited accessibility (e.g. due to economic conditions) or unsuitability (e.g. due to farm size, topographic or farm conditions) for large-size mechanization equipment.

3 Results and discussion

KEY MESSAGES

- Digital solutions and motorized mechanization, especially larger equipment, are rarely used by small-scale producers in the study countries, although hire services are slowly accelerating adoption. Fully automated solutions are still virtually non-existent.
- Most solutions were financed by grants and almost half are implemented by NGOs or research institutes. Farmers usually do not pay for the solutions, although data monetization models are beginning to emerge.
- Main drivers to adoption include having: knowledge about the benefits, costs and impacts of the technologies; access to finance, credit and insurance; public interest in modernizing agriculture; and clear policies and regulations.
- Important barriers include political unrest, dependency on donor funding, and a lack of knowledge, skills and of credit and finance by users.

The following section examines the state of digital and automation technologies and the barriers to their adoption by producers, especially smallholder farmers in low- and middle-income countries. Table 4 provides an overview of all the case studies, showcasing for each the category of digital and automation innovation involved, current business model and institutional mechanisms. The study then presents seven broad trends in the development, promotion and adoption of digital, automation and mechanization technologies. These trends were gathered from the case studies and secondary data. Thereafter, the study analyses drivers and barriers to the adoption of digital and automation technologies within the context of economic, environmental and social sustainability. Based on the conceptual framework developed with Ceccarelli *et al.* (2022), the report considers the benefits, costs and trade-offs of adopting particular digital and automation technologies. This section furthermore looks at feasibility of and barriers to adoption for specific (sub)groups within the global agricultural system.

3.1 Showcasing successful innovations and institutional mechanisms

As noted, Table 4 attempts to illustrate the institutional mechanisms involved in each case. Admittedly, the study collected only limited hard evidence of the financial sustainability of the cases and their business models. However, Table 4 can provide an indication of the success of the service providers and their solutions. A first observation is that, in 70 percent of cases, the solution provider at least partly relied on grant funding to develop, pilot, market and sustain the solution. Notably, the Asian cases relied less on donor money and are more profit-oriented. This introduces a second observation: in 40 percent of cases, solutions were developed and implemented by an NGO or research institute which does not aim to profit from the solution. A third observation is that farmers do not generally pay to use the solution, at least not with money. In a few cases, farmers pay indirectly through their cooperative membership or provide data in lieu of payment. Also noteworthy are the various pay-per-use models, used in equipment sharing or when farmers, for example, pay for airtime when they call or message the service provider, creating a small revenue for them.

Unfortunately, we were unable to verify the business case of the selected solutions. Such information is highly sensitive and generally not publicly available, nor did the interviewees feel comfortable with sharing such information. However, it appears that the profitability and financial sustainability of the solutions have been limited, even though the study, to the extent possible, sampled cases in which the service provider and solution had existed for some years and had received multiple donor investments.

The finding that there is very little profit in digital and automation solutions does not come as a surprise. Nor was it surprising to find that – apart from equipment-sharing services – smallholder farmers pay little or no fees to use a service. Time will tell if the sharing model is sustainable and scalable. It may be that farmers will prefer to own their equipment, rather than to use service providers like TROTRO Tractor and Tun Yat as intermediaries.

> So, as mechanization increases as an upward trend across the country, in some villages like, you know, some farmers move from like hanging-in farmers to, let's say, stepping-up … Farmers can then pull money together to buy a tractor or like four or five families might join and chip in to buy a tractor. So, when that happens, obviously we are no longer needed for the tractor service because they can use their own machine (interviewee, Tun Yat).

The inability – or lack of willingness – of smallholders to pay for agricultural services solutions is a widespread concern in low- and lower-middle-income countries and a likely reason why dependence on donor grants is high. Reducing such dependency requires service providers to seek alternatives, such as the data monetization model, in which the solution remains free (or at a very low cost) to smallholder farmers; yet, other actors (e.g. financers, governments) pay to collaborate with the service provider, use the solution, or access data that is generated through the solution.

TABLE 4 Overview of the institutional mechanisms underlying the case studies

Case study (production system and region)	Solution category	Organization profile	Supply/ demand driven	Financial model	Business model	Revenue model	Farmer type(s) targeted	Production system of targeted farmer	Farmer paying for service	Other users/ customers	Readiness to scale
Agrinapsis (general agriculture, Latin America and the Caribbean)	Disembodied, no UAS	Research institute	Supply	Grant funds	Not-for-profit to user	Freemium	All types of farmers	All agriculture	No	Students, extension agents, input dealers, produce buyers, veterinarians	Pilot
Coopecan (livestock, Latin America and the Caribbean)	Disembodied, with blockchain	Farmer cooperative	Demand (export buyer)	Grant funds	Cooperative to farmer	Indirect payments	Small-scale livestock (50–100 animals)	Livestock	No	Extension agents, exporters	Pilot
GARBAL (livestock, sub-Saharan Africa)	Disembodied, with GNSS and analytics	NGO	Demand	Grant funds (30 percent), public–private partnership	Not-for-profit /business-to-farmer	Pay per use	Small-scale crop, small and medium-scale livestock and agropastoralists	Agropastoralist livestock (main), seasonal crops	Yes	Traders, herd owners	Scaling
TROTRO Tractor (crop production, sub-Saharan Africa)	Mechanization, with digital, IoT and GNSS	Private company	Demand	For profit, grant funds (15 percent)	Business-to-farmer, business-to-business	Pay per use	Small-scale crop (average 3 acres, market-oriented)	Seasonal crops	Yes	Medium- and large-scale farmers, private companies and factories	Scaling
Igara Tea (crop production, sub-Saharan Africa)	Disembodied, with UAS for decision support and farming	Farmer-owned company	Demand (farmer and export buyer)	For profit	Business-to-farmer	Indirect payments	Small-scale crop (3.5–4 acres, market-oriented)	Perennial crop	No	Banks, financers	Mature
ICT4BXW (crop production, sub-Saharan Africa)	Disembodied, with UAS for decision support	Research institute	Supply (farmer)/ demand (government)	Grant funds (mainly), public–private partnership, government funds	Not-for-profit /business-to-farmer	Freemium, pay per use	Small-scale crop (subsistence and market-oriented)	Perennial crop	No	Village extension agents, government agronomists, government agriculture department	Scaling

TABLE 4 (cont.) Overview of the institutional mechanisms underlying the case studies

Case study (production system and region)	Solution category	Organization profile	Supply/ demand driven	Financial model	Business model	Revenue model	Farmer type(s) targeted	Production system of targeted farmer	Farmer paying for service	Other users/ customers	Readiness to scale
Justdiggit (agroforestry, sub-Saharan Africa)	Disembodied, with UAS for decision support	NGO	Supply	Grant funds (100 percent)	Not-for-profit to farmer	Freemium	Small-scale crop (subsistence and market-oriented) and agropastoralists	Seasonal crops, agropastoralists	No	Village trainers, city dwellers	Scaling
Aquaconnect (aquaculture, South Asia)	Disembodied, with GNSS and analytics	Private company	Demand	For profit (using equity funds)	Business-to-farmer, business-to-business	Freemium, data monetization, pay per use	Small- (<5 acres) to medium-scale aquaculture (market oriented)	On-land aquaculture	Yes	Corporate farmers (30–60 acres), hatcheries, input dealers, veterinarians, producer buyers, processors, exporters, insurers, financers	Scaling
Seed Innovations (crop production, South Asia)	Disembodied, with UAS for decision support	Private company	Supply	For profit, grant funds (40 percent)	Business-to-farmer, business-to-business	Freemium, data monetization, subscription	Small- to large-scale crop (>1 ha, market oriented)	Seasonal crops, perennial crop	No	Small-scale crop (market oriented)	Pilot
Tun Yat (crop production, Eastern and South-eastern Asia)	Mechanization, with digital, IoT and GNSS	Private company	Demand	For profit	Business-to-farmer, business-to-business	Pay per use	Small-scale crop (market oriented)	Seasonal crops	Yes	Insurers	Scaling

Notes: Column 3 (supply/demand driven) is an estimate by the author. The financial model (column five) describes how the service provider funds their operations. The business model (column six) refers to the type of service provider (e.g. not-for-profit solutions that may bring financial benefits to the user but where service providers do not aim to make a profit) and whether the service caters farmers or other businesses (in this case, business-to-business solutions target other businesses in the agricultural sector; business-to-farmer solutions target farmers instead). The revenue model (column seven) concerns how users pay for the solution and thus contribute to the revenue of the solution provider (e.g. indirect payments, such as through the cooperative membership of farmers; or pay per use where users pay a fee when they make use of the service). In a freemium model, customers use a basic version of a service or application for free with the intention that they will upgrade to a premium version after being convinced of the benefits of the service.

Source: Author's elaboration.

3.2 Overview of current automation trends in terms of their development, promotion and adoption

The ten case studies encompass many current trends around digitalization and automation in low- and middle-income countries (see Annex 3). This section of the paper examines those trends based on the diverse digital and automation solutions offered or implemented by the NGOs, research institutes, private sector actors and farmer organizations represented in the case studies.

Most of the cases involve digital solutions. There is little adoption of automation technologies at the beginning of the value chain where agricultural production happens. The same is true for mechanization, especially of larger equipment, although sharing services are on the rise. Some solutions (e.g. TROTRO Tractor in sub-Saharan Africa and Tun Yat in Eastern and South-eastern Asia) combine digitalization with conventional mechanization. Others combine a smartphone application (Seed Innovations in South Asia) or a variety of more conventional communication channels (Justdiggit, GARBAL, ICT4BXW in sub-Saharan Africa) with the capacity to automate the analysis of satellite or drone imagery using artificial intelligence. None of the case studies include examples of advanced precision agriculture, whereby optimal care is given to individual crops or animals. Nor are there cases where farming is fully automated or implemented by robots, although several service providers use (e.g. Justdiggit in sub-Saharan Africa) or are experimenting with drones (e.g. ICT4BXW in sub-Saharan Africa) or offer drone services to their customers (e.g. TROTRO Tractor in sub-Saharan Africa). Additionally, smallholders in the areas covered by the study do not practice protected agriculture (i.e. agricultural production in greenhouses or vertical farming), at least not in a mature, non-experimental sense. The reasons for this absence will be discussed further. The following section describes seven trends that are apparent in the case studies.

Eyes in the sky (GNSS and drones to map, analyse and monitor). Seven of the ten cases used drones (TROTRO Tractor, Igara Tea, ICT4BXW, Justdiggit in sub-Saharan Africa) and/or satellite intelligence (GARBAL, Justdiggit, Aquaconnect, Seed Innovations in sub-Saharan Africa and Asia) as part of the solution or offered them as a service (TROTRO Tractor in sub-Saharan Africa). These technologies can collect large volumes of location-specific data, map land boundaries and characteristics, monitor crop and animal performance, and gain insights with high accuracy and timeliness. This data can be used to develop decision-support tools that provide agronomic or climate advice. The technologies are not used directly by farmers but are operated by service providers on their behalf. Additionally, farmers can benefit by gaining access to agricultural finance or insurance when GNSS and UAS imagery data collected by a service provider is aggregated with field-level farm(er) data to develop farm(er) profiles. Such profiles can help with building trust relationships between farmers and financial institutions and gain farmers access to finance.

Sharing is caring (hire services for more inclusive access). Owning mechanization equipment is out of the reach of most smallholder farmers, such that temporal services, resource sharing and pay-as-you-go models have started to be introduced in rural areas of low- and lower-middle-income countries. TROTRO Tractor and Tun Yat are two examples from sub-Saharan Africa and Eastern and South-eastern Asia that show how a shared resource service can make mechanization accessible to more farmers. Meanwhile, the availability of "gig" jobs (i.e. flexible, temporary jobs), such as machine operators, can help convince young people that they have a future in the rural communities. TROTRO Tractor and Tun Yat, and several other service providers, use a pay-per-use model and, although this model suits service providers better in terms of creating revenues than the freemium model,[5] there is a risk that customers (i.e. farmers) will not return, as they may require the service only once. Service providers often use subscription and licencing business models for their private sector customers. For example, Seed Innovations in Nepal aims to maintain the freemium model for farmers.[6] A subscription model is offered to insurance companies to monetize data (e.g. on quantities harvested, sales, etc.) collected from farmers; these data can later be used to devise farmer profiles, in turn used to e.g. determine a farmers' eligibility to access finance and credit services.. However, whether farmers benefit from data sharing is a topic of some debate. Supporters argue that it enhances transparency in the agricultural system and offers opportunities to achieve financial sustainability, while offering digital services at no or a low cost to farmers and reducing the risks for value chain actors, offering (new) services to smallholder farmers. Opponents of data sharing argue that the commercialization of farm data reduces the autonomy of farmers, creates or deepens existing power relationships and leads to larger symmetries regarding who owns and controls the data collected.

Reducing the risks while improving resilience (de-risking agricultural investments by farmers, service providers and financers). The ability to collect diverse data about farmers, agricultural production and the environment can lead to more precision and optimization in the production process. It can reduce risks from pests, diseases, weather and climate uncertainty, market and price fluctuations, and increase resilience by improving farmers' capacity to cope with climatic, environmental, market and political shocks. In three of our case studies (Igara Tea in sub-Saharan Africa, Seed Innovations in South Asia and Aquaconnect in South-eastern Asia), the service providers used data collected by farmers and by themselves (e.g. through drone or satellite images) to develop profiles that could facilitate farmers' access to financial or insurance services. Seed Innovations regards its partnership with an insurance company as critical to achieving large-scale uptake of the PlantSat application – an android application that uses satellite-based analytics to monitor crop performance and to access and exchange agronomic information – and generating revenue. In other cases, using data collected by farmers and service providers was envisioned as a potential future service (e.g. GARBAL, Tun Yat). Several countries have introduced policies that support the introduction of data monetization models by, for example, partly subsidizing insurance premiums (e.g. Nepal). However, in cases where a service provider's business model heavily relies on data monetization in the context of a fragile political and security situation, data security and privacy, and digital rights in general, become a point of concern and a potential barrier to adoption (Neethirajan and Kemp, 2021). Data governance, digital rights and FAIR[7] data are topics of increasing interest to researchers (Bronson, 2018; van der Burg *et al.*, 2022; van der Burg, Bogaardt and Wolfert, 2019; McCampbell *et al.*, 2021; Top *et al.*, 2022), activists and, more recently, donor organizations.[8] Interestingly, concerns about data-related issues were not really visible in the cases studied for this report.

Simple but suitable (adapting to the capacity of users and their access to digital hardware and software). Rural communities in low- and lower-middle-income countries are challenged by access, affordability and ability challenges. Limited mobile networks and internet

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5 In a freemium model, customers use a basic version of a service or application for free with the intention that they will upgrade to a premium version after being convinced of the benefits of the service. In practice, many service providers in low- and lower-middle-income countries are unable to shift from offering a free service to a paid service to farmers, especially smallholders, as the latter are unable to afford.

6 Or an indirect payment model, where farmers indirectly pay for using the service by providing third party access to their data.

7 FAIR: findable, accessible, interoperable, reusable (Go FAIR Initiative, 2016).

8 Digital rights gained attention during the COVID-19 pandemic when governments introduced a wide array of digital surveillance tools to monitor and control the disease. The introduction of these tools, and subsequent concerns about, for example, citizen privacy, security, control and autonomy.

connectivity, the cost of smartphones, and digital illiteracy are all well-known barriers, recognized in many studies (Coggins *et al.*, 2022; Kavya and Sailaja, 2014; Mehrabi *et al.*, 2021; Nakasone and Torero, 2016; Tsan *et al.*, 2019). These barriers are seen as important determinants of a farmer's "readiness" to make use of digital technologies (Adewopo *et al.*, 2021; McCampbell *et al.*, 2021). The service providers in the study – particularly in Africa – have deliberately chosen to base their solutions on communication technologies that are reliable, accessible and affordable to most people. GARBAL and TROTRO Tractor in the livestock and crop production subsectors in sub-Saharan Africa, for example, decided to focus on USSD (unstructured supplementary service data) and call centres instead of an Android application. This choice allows the companies to reduce the need for on-the-ground presence (TROTRO Tractor) and enables them to operate in a volatile context where the internet can be down for weeks (GARBAL). Other service providers started with more advanced technologies before returning to more conventional means or diversifying their communications strategy. Examples include ICT4BXW and Justdiggit, both of which operate in rural East Africa where smartphone penetration and digital literacy are still very low.

> We really need to leverage any tool, any means or process that allows us to reach them [the farmers] in a timely fashion. The keyword is being able to reach farmers on time, at scale, with the right tools or resources. Then that matches their contextual needs (Interviewee, ICT4BXW).

The study shows that the uptake of more advanced technologies is slow and requires a great deal of capacity building. Service providers that have the ambition to scale their solutions therefore opt for technology diversification. This allows them to reach larger numbers of service and adapt to user readiness limitations more quickly.

Adapting to the local context (involving local partners; designing solutions together with users; considering indigenous knowledge; and adapting services and technologies to local needs and conditions). Several interviewees noted that their long-term presence in a country or the decision to team up with local organizations or the government gave them critical understanding about the context in which their solution needed to thrive (e.g. GARBAL, ICT4BXW, Justdiggit in sub-Saharan Africa).

> If we are scaling into a new geographical area, just as the local partners will be different, the strategy will also be different. So, it's all linked to "do you know your market"? What are the key features of your markets and the end-users' needs and habits? (Interviewee, GARBAL)

GARBAL and Tun Yat even acted as intermediaries for organizations in their countries of operation, supporting their activities during political instability. Tun Yat and Aquaconnect have established a presence in the communities, for example through Aquaconnect's AquaHUBs: one-stop shops where farmers can buy inputs, sell produce and receive technical backstopping. ICT4BXW used participatory design approaches to develop their solution together with the users. Justdiggit is doing the same for their new Regreening application, while GARBAL has emphasized the need to consider and include local indigenous knowledge. Although some service providers work closely with users (e.g. Justdiggit, ICT4BXW), which is today a widely recommended practice (Barakabitze, Fue and Sanga, 2017; Cerf *et al.*, 2012; Ortiz-Crespo *et al.*, 2020; Pastorella, Borges and De Meo, 2016; Steinke *et al.*, 2020, 2022), none of the service providers could be characterized as truly grassroots, bottom-up, or locally-led, nor does this study include cases that clearly adopted a responsible innovation approach that anticipate services' potential trade-offs and consequences (McCampbell *et al.*, 2021; Rijswijk *et al.*, 2021).

Upcoming trend: reduce, reuse, recover (conservation agriculture, nature-based solutions, carbon sequestration). Although environmental sustainability does not seem to be a major driver (or barrier) to agricultural digitalization and automation, there appears to be an emerging trend to optimize and reduce the use of inputs (e.g. fish feed in the case of Aquaconnect in Nepal, and operational costs associated with receipt books, pens, paper, etc. in the case of Igara Tea in Uganda). TROTRO Tractor has observed an increasing demand for conservation agriculture services, reportedly due to capacity building activities by NGOs and extension agencies. The Justdiggit interviewee mentioned that the organization's slogan "cooling down the planet" once raised eyebrows among farmers and donors, while today everyone seems to find the link between temperature and the environment to be logical.

> I'm just thinking, one of the slogans, it's "cooling down the planet". And I know it's a pretty bold statement, but it's incredible to see the difference. How much criticism and questions [we] got about that slogan seven years ago. … [P]eople were criticizing or asking questions, and we did have an answer to it. But it triggered people's thinking and it provoked questions. While nowadays everyone just takes that for granted. We all started to realize that our planet is changing, and that we need to do something about it (interviewee, Justdiggit).

Increasingly, farmers are seeking solutions to cope with weather unpredictability and to become more resilient to climate change. Likewise, donors, investors, research organizations, governments and development organizations are looking for ways to mitigate or adapt to climate change, fuelling an interest in regenerative practices and nature-based solutions. Companies and consumers need to meet their sustainability goals through carbon credits, financing and sequestration (Duncan *et al.*, 2022; Tamba *et al.*, 2021).[9] The enthusiasm for regreening, reforestation and agroforestry initiatives appears to be on the rise.

Unintended trend: the power of a crisis. Political instability in countries like Mali, Myanmar and Niger has created immense challenges for service providers. Besides on-the-ground trials, such as cuts to internet services, food insecurity, rising fuel and input prices, service providers face difficulties in securing funding from investors and donors due to the high risk of investing in such countries. These uncertainties make modernization of the agricultural sector difficult. Interestingly, the COVID-19 pandemic was a powerful crisis that, although the negative impacts should not be underestimated, appears to have set positive things in motion:

> They use [the smartphone] to call their friends … [and] play games on it. But when it comes to using other applications, their uptake is a bit slower. However, because of the pandemic in the last two years this has started to shift, so there has been a bit more use of other applications (interviewee, Tun Yat).

The TROTRO Tractor interviewee explained how farmers came to understand the value of digital technologies when the COVID-19 pandemic forced them to reduce contact while still producing food:

> The COVID-19 pandemic has really shown that I can use my phone to get food. I can use my phone to work. I can do so many things with my phone, the things that we didn't do before the pandemic (interviewee, TROTRO Tractor).

Governments have started to realize that they can reach people in rural communities without the need to be physically present, leading to new policies and support for innovations around remote interaction, data collection and monitoring. Farmers have become more familiar with using mobile phone technologies to access all kinds of government services, making them more open to other phone-based services provided by other actors. The COVID-19 crisis

9 In response, service providers like Hyphen have made it their business to provide insights and decision support about climate change impacts, such as carbon emissions, energy and water consumption during a production processes and value chains, to private sector organizations (Hyphen, 2022).

appears to have hastened the uptake of digital financial solutions as well, as more service providers are using mobile money and digital wallets for financial transactions.

3.3 Drivers and barriers to the dissemination and adoption of digital and automation technologies

Tables 5–7 provide an overview of drivers and barriers to the adoption of digital and automation technologies – as identified by the case studies – based on economic, environmental and social sustainability. These key elements of sustainability are presented below.

Economic sustainability

The main expected economic benefits for farmers arising from digitalization and automation technologies relate to production and farmer income and contribution to food security. The case studies provide very limited conclusive evidence of this, which is in line with findings elsewhere (Coggins *et al.*, 2022; Klerkx and Rose, 2020; Omulo and Kumeh, 2020; Porciello *et al.*, 2021). Only a few service providers conducted rigorous studies of the impact of their solutions. Given multiple external factors, it is not easy to say with certainty that a causal relationship exists between, for example, an increase in the quantities of tea leaves procured (as in the case of Igara Tea in Uganda) and the use of digital tools. Nevertheless, digital tools clearly improve the capacity of farmers to predict, monitor and plan agricultural production. They hence support improved efficiency in the agricultural system that could result in higher incomes over time.

Table 5 shows study findings related to financial support, access to finance and insurance as adoption drivers and barriers. The availability or absence of financial support across the value chain can clearly be both a driver and barrier. While development focus is often on increasing access to finance and insurance to enable smallholders to take risks and innovate, the case studies suggest that we need to look beyond the farmer. For example, there is a risk that the demand for mechanization services will grow faster than the number of operators and machines in a country. Service providers can train unemployed youth from rural communities to become operators that buy the machinery and then rent it out to farmers. But these young people will struggle to purchase their own equipment; without machines, the business model becomes unprofitable for both operators and service providers.

> These [young tractor operators], when they go to the banks to request for a loan to buy a tractor, they have zero credits. […] there's no system to allow them to get a tractor to serve farmers, and if we don't have more tractors then we will still get small commissions. And then at some point we just give up and say "there's no profit in this business". But the more we get service providers on the platform, the more our commissions would also come, and then we can continue to do the business (interviewee, TROTRO Tractor).

Another critical barrier is the security situation in a country, as can be seen in both in the GARBAL (Burkina Faso and Mali) and the Tun Yat cases (Myanmar). These service providers faced great uncertainty, while investors were risk-averse and hesitant to invest in these countries. Insecure countries are also not typically target countries for donors investing in digital agriculture or mechanization, which adds another barrier. However, service providers can play an intermediary role, helping to support communities during turbulent times. For example, the interviewee from Tun Yat explained how the company became the link between NGOs and local communities after the military coup. Many NGOs no longer had local presence and their organizational policies did not allow them to work directly with the military regime. Collaborating with Tun Yat as a local operator allowed these organizations to continue their activities in the country.

Regarding drivers, a first observation is that labour does not appear to be the most important determinant of digitalization or automation (nor is it a clear barrier) in low- and lower-middle-income countries. While it is true that an opportunity to reduce labour costs is appreciated by service providers, it was not the most important driver of digitalization. For example, Igara Tea's investment in digitalization in Uganda's export tea sector was mostly driven by a need to build better relationships with farmers and to create more transparency and traceability in the production and procurement of tea. Tun Yat in Myanmar cited an objective to reduce or reverse the migration of men, women and young people to the cities or abroad. Service providers can help realize such objectives by providing the people in their communities with opportunities, for example as machine operators, to keep them in the agricultural sector. A further benefit is that reduced reliance of families on off-farm income from unskilled labour abroad or in urban centres makes communities less vulnerable to shocks like political instability and pandemics. During COVID-19 and the Myanmar coup, many people lost their off-farm jobs and were forced to return to their communities. This led to loss of family income, significant unemployment and more mouths to feed locally.

Thus far, it appears that digitalization and automation technologies have not been used to replace humans or reduce the need for manual labour. However, governments in low- and lower-middle-income countries – perhaps driven by donor ambitions – seem determined to modernize agriculture. To this end, there is a critical need for national and regional policies and regulations to guide the long-term vision and strategies planned for agriculture. It is even more important that these policies and regulations are enforced and actively supported. The influence of policies and strategies of large donors and development organizations should not be underestimated, especially in volatile political contexts.

Environmental sustainability

Environmental sustainability is an emerging trend, embraced by donors, investors in social impact projects and researchers. However, it has not yet become a strong driver of digitalization and automation in smallholder farming in low- and lower-middle-income countries. With the exception of Justdiggit in the agroforestry subsector in East Africa, whose entire organization and business model is built on environmental restoration and nature-based solutions, initiatives like ecosystem restoration, climate change adaptation, integrated pest management and climate-smart agriculture (CSA) are not central to available solutions. This is not to say that the solutions do not contribute to environmental sustainability. For example, the case studies include actions to mitigate climate change, such as through optimization and reduction of the use of inputs.

Many activities start by focusing on a primary product, such as banana, tea, shrimp or alpaca fibre. These are often high-value products that are produced for the export market where they can fetch a premium price. The global market increasingly demands transparency and traceability for agricultural products. This drives digitalization (as can be seen in the cases of Igara Tea for tea production and Coopecan for wool production). Other service providers focus on key staple and food security crops. Tun Yat, for example, offers harvesting equipment for rice (Myanmar's primary food security crop), and mung beans, groundnuts, sesame and maize (the most important rotation crops). The company's choice of crops is motivated by the desires to increase productivity and income for the farmer and to improve national food security.

Given the absence of protected agriculture and highly-controlled environments, none of the cases specifically focused on horticulture and perishable crops. Nor did the cases present examples of highly-intensive monoculture production systems. Thus it remains unclear if the consequences of such cropping systems for the environment are a pressing concern in the countries covered in the study (Ditzler and Driessen, 2022). The nature of smallholder farms – which tend to occupy around 2 hectares in Asia and sub-Saharan Africa, and whose production is meant for home consumption and the local markets – reduces the need for precision agriculture technologies used on large farms. These are costly to smallholder farmers and can require adapting production practices to the technologies. Yet, with sustainability and climate change adaptation and mitigation climbing high on the policy agenda, combined with the ambitions of the new paradigm for agriculture and the use of agricultural technologies (also known as "agriculture 4.0"), one may expect this to change in the coming years. Choices made in the process of designing technologies, solutions, and digital and automation ecosystems will likely determine the impact of those changes on smallholder farming systems (Bohnsack, Bidmon and Pinkse, 2021; McCampbell *et al.*, 2021).

Social sustainability

The case studies reveal several drivers and barriers related to social sustainability and inclusion. Our analysis revealed that it is critical to invest in people's capacity and to provide technical backstopping and support to the communities if inclusive access to technologies is a goal. This was confirmed by interviewees in sub-Saharan Africa and Eastern and South-eastern Asia representing the crop production, aquaculture, and livestock subsectors:

> [F]armers want some handholding for quite some time to get used to … how effectively they can use those tools in their farming operation (interviewee, Aquaconnect).

The service providers responded to these needs in different ways. GARBAL in West Africa used human-operated call centres, ICT4BXW in Rwanda invested in capacity building workshops, and Aquaconnect in Nepal and Tun Yat in Myanmar employed intermediaries and support centres in the communities. All these approaches require significant time and resource allocation from the service provider. However, a physical presence in the communities is seen as an important enabler of trust between service providers and their customers.

Digital illiteracy is, not surprisingly a major barrier to the adoption of digital and automation technologies (Hennessy, Läpple and Moran, 2016; Herdon, Botos and Várallyai, 2015; Hernández, Earle and Fredlund, 2020; Hidalgo *et al.*, 2020). Another barrier is people's attitudes towards new innovations and willingness to change their existing agricultural practices:

> The mindset of farmers is like 'it's going on. It will go on' … They are skeptical about this kind of technology, so they don't use it quite often (interviewee, Seed Innovations).

A deep understanding of the context is vitally important as is the need to build trusting relationships between farmers, service providers and, often, other actors in the value chain. This has been noted in studies of the users to digital services in Kenya, where quality, reliability and trust were seen as critical drivers (Kieti *et al.*, 2021). Not surprisingly, digital literacy appears to be linked to age, where young people are considered more technically savvy and open to change and experimentation, while older farmers are more sceptical towards change. While this is probably an oversimplification, it is very likely that younger generations have greater exposure to modern ideas and are keen to create a prosperous future for themselves. Indeed, studies of the impact of adopting mechanized equipment show different effects on younger and older farmers. For example, a study on the mechanical extraction of *Njangsang* nuts in Cameroon revealed that more young than old farmers adopted the extraction machine (Charlie *et al.*, 2013). However, young farmers may be held back by economic barriers such as the lack of access to loans in the absence of a credit score or land that can be used as collateral.

The case studies suggest that evidence of the benefits of a solution can convince farmers to adopt it. Such benefits might include improved income or food security (through higher or better-quality yields, or higher market prices for produces); greater transparency in the value chain (stronger trust relationships between actors, balancing of supply of demand, improved market performance); reduced need for other investments (in inputs, labour, etc.); and reduced risk of farming as a business (more informed farm management, better insight into the vulnerabilities of a farm, etc.). However, in some cases, such evidence can become a barrier for the service provider, as was the case for Tun Yat in Myanmar. Here, farmers continue to use mechanization services but bypass the matchmaker (Tun Yat), something that was possible because of the pay-per-use business model that sharing services use, which connects machinery owners with users. Yet, services like Tun Yat can empower women – who often face challenges in using technologies since men are usually granted access first – by allowing them to access machinery independently, instead of waiting to use it after a male farmer. However, in areas where women provide all the manual labour, the incentive to automatize tasks may be lower (see Table 7).

TABLE 5 Economic drivers (green) and barriers (red) to adoption

Case study	Agrinapsis	Coopecan	GARBAL	TROTRO Tractor	Igara Tea	ICT4BXW	Justdiggit	Aquaconnect	Seed Innovations	Tun Yat
Economic sustainability (profitability)										
Agricultural production efficiency					Improved capacity to predict and monitor production	Disease affects food security, creating urgency around the problem and willingness to innovate		Improved capacity to predict and plan production		
Farmer income/ capacity to invest		Premium prices for alpaca fibre due to better product quality and traceability			Farmers' capacity to invest in mechanization equipment like tea harvesters		Potential additional income from tree crops	High cost of IoT combined with low farmer capacity to invest		Increased income from same acreage by improving quality and precision; higher resource cost due to *coup d'état*, reduced farmer investment capacity
Food security						Disease affects food security, creating urgency around the problem and willingness to innovate				

TABLE 5 (cont.) **Economic drivers (green) and barriers (red) to adoption**

Case study	Agrinapsis	Coopecan	GARBAL	TROTRO Tractor	Igara Tea	ICT4BXW	Justdiggit	Aquaconnect	Seed Innovations	Tun Yat
Access to credit				Lack of access to credit for machine operators/ machine owners	Using farmer data collected by Igara Tea, farmer profiles can be created and shared with finance service providers, whereby farmers are given a credit score and, consequently, access to finance			Access to credit from a bank with a lower interest rate; loan ceiling too low for aquaculture farmers		Using farmer data collected by Tun Yat (e.g. on land size and harvest), farmer profiles can be created and shared with finance service providers, whereby farmers are given a credit score and, consequently, access to finance
Access to insurance								Premium rates for aquaculture much higher than for crops	Data collected through application used as proof for insurance	
Availability of subsidies			Reducing investment risk in volatile/high risk setting	Government incentives for staple crops	Absence of financial support from governments to implement national policies due to, *inter alia*, lack of finance, of human capacity and skills, and of data policies more generally			Fund allocation by government to modernize agricultural value chains; lack of government incentives for use of data-driven technology	Increasingly high government subsidies for crop insurance	

TABLE 5 (cont.) Economic drivers (green) and barriers (red) to adoption

Case study	Agrinapsis	Coopecan	GARBAL	TROTRO Tractor	Igara Tea	ICT4BXW	Justdiggit	Aquaconnect	Seed Innovations	Tun Yat
Interest from investors/donors			Reducing investment risk in volatile/ high-risk setting; high investment needs for digital solutions			High investment needed to develop and maintain digital solutions	Regreening and climate change adaptation and mitigation is of growing interest to donors			Volatile security situation in country results in few investors
Availability/cost of labour					Reducing the share of labour in production cost					Farmers and youth have moved to cities or abroad
Availability of ICT (information and communications technology)/ connectivity infrastructure	Internet access in remote areas is poor despite government and international efforts to improve it	Poor internet infrastructure forces people to travel long distances for connectivity	Adaptation of solution to country context; connectivity issues with hardware access	Government investment in infrastructure						Connectivity, especially internet, regularly cut off by government
Availability of market/ processing infrastructure			New market opportunities (contract farming)	Government investment in infrastructure	Production is increasing but processing capacity is not					

TABLE 5 (cont.) Economic drivers (green) and barriers (red) to adoption

Case study	Agrinapsis	Coopecan	GARBAL	TROTRO Tractor	Igara Tea	ICT4BXW	Justdiggit	Aquaconnect	Seed Innovations	Tun Yat
Enabling policies/ regulations			Need for a political vision	Presence of digital agendas	Government ambition to combine virtual, physical, and biological interaction; lack of clear regulations, such as on drones	Government introduced vision and policies, for example, on digital agriculture, and welcomes solutions that support policy execution	Ban on firewood protects trees and increases awareness of their importance; land act causes redistribution of land and uncertainty among pastoralists	Policies to support start-up initiatives that promote agricultural modernization	Presence of insurance policy; absence of strict privacy, data protection, intellectual property policies or regulations; no enforcement of data-driven farming approach	Institutional policies from development organizations; government committed to digital policies, but setback due to military coup. Today's policies focus more on surveillance
Security situation in country/global crises			Risk-averse investors	COVID-19 fast-tracked uptake of digital services to reduce human contact						Risk averse investors; opportunities as implementing partner of NGOs without an on-the-ground presence
Capacity to scale			Data management at scale requires automation			Scalable platform needs funds and local capacity				

Note: Cells that are both green and red indicate a factor that can act as both a driver and barrier.

Source: Author's elaboration.

TABLE 6 Drivers (green) and barriers (red) to adoption related to environmental sustainability

Case study	Agrinapsis	Coopecan	GARBAL	TROTRO Tractor	Igara Tea	ICT4BXW	Justdiggit	Aquaconnect	Seed Innovations	Tun Yat
Environmental sustainability (long-term production impact)										
Climate resilience/ adaptation/ mitigation							Responding to rising awareness and demand for practical solutions to climate change and desertification			
Quality standards/ traceability		Increased traceability results in higher fibre prices			Increasing transparency in tea value chain removing option to "double deal"			Solutions create predictability and transparency in value chain		
Demand for conservation agriculture				Growing demand for machinery supporting conservation agriculture						

Note: Cells that are both green and red indicate a factor that can act as both a driver and barrier.

Source: Author's elaboration.

TABLE 7 Social drivers (green) and barriers (red) to adoption

Case study	Agrinapsis	Coopecan	GARBAL	TROTRO Tractor	Igara Tea	ICT4BXW	Justdiggit	Aquaconnect	Seed Innovations	Tun Yat
Social sustainability (impact, capacity, inclusion)										
Capacity of conventional public extension system			Adaptation of solution to country context			Extension system underfunded and understaffed; extension system overburdened in planting season				
Local presence and trusted service provider			Long-term in-country presence; fit solution to local needs and capacity			Developing solutions together with stakeholders	Working with local partners and trainers, who are based in the communities	Local team on the ground to provide backstopping	Making solution as simple as possible to use	Understanding and using the channels that farmers also use; need for local support and backstopping
Possibility of public-private partnerships			Engagement with Mobile network operator (MNO) and the Ministry of Agriculture and Animal Resources; consortium with local organizations			Engagement with government, private sector partners ad diverse research institutes	Making use of private sector media partners to create awareness and raise public funds			

TABLE 7 (cont.) Social drivers (green) and barriers (red) to adoption

Case study	Agrinapsis	Coopecan	GARBAL	TROTRO Tractor	Igara Tea	ICT4BXW	Justdiggit	Aquaconnect	Seed Innovations	Tun Yat
Migration										Solution can reduce migration caused by lack of future prospects in rural areas
Gender/social inequality				Fits needs of women and accessible to female farmers						In remote areas, women provide all manual labour
Youth unemployment				Trains young people as machine operators						
Digital literacy	Digital literacy low especially among older farmers (who are also the majority)	Difficult to find local IT experts, often work with Spanish companies	Digital ecosystem is booming but capacity is low			Digital literacy is low across the agricultural sector	Capacity of farmers is still low	Capacity of farmers is low, with a steep learning curve		Limited digital literacy among farmers

TABLE 7 (cont.) Social drivers (green) and barriers (red) to adoption

Case study	Agrinapsis	Coopecan	GARBAL	TROTRO Tractor	Igara Tea	ICT4BXW	Justdiggit	Aquaconnect	Seed Innovations	Tun Yat
Trust relationships between stakeholders			Trust between users and service providers (call operators, field demonstrations)		Removing uncertainty, improving transparency and timeliness for all stakeholders		Land act in Kenya has created distrust among pastoralists			Access to reliable and affordable mechanization services high farmer priority; little trust in mobile payments
Evidence of benefits of using solution			Bridging indigenous and scientific knowledge	Affordability, availability, reliability of service		Urgency of the disease problem; reducing lags and inconsistencies in information given to farmers	Visibility of impact of climate change and desertification; demand for practical solutions	Perception that technology can support increased productivity and access to finance	Farmers sceptical about adopting new technologies and changing behaviour	Farmers and operators bypassing matchmaker after using it successfully before to bargain for lower price
Tailoring advice to specific farms	Platform in Spanish to target farmers in Latin America and the Caribbean		Advice targeting unique needs of pastoralists			Providing location and farm-specific crop disease advice	Tailoring the media strategy to stakeholders, and to their capacity and interests			

TABLE 7 (cont.) Social drivers (green) and barriers (red) to adoption

Case study	Agrinapsis	Coopecan	GARBAL	TROTRO Tractor	Igara Tea	ICT4BXW	Justdiggit	Aquaconnect	Seed Innovations	Tun Yat
Farmer willingness to change			Adaptation of solution to country context necessary			With adequate resources, a phone is seen as a necessary item; farmers are curious, want to try new things		Farmers slowly becoming more savvy and willing to adopt technologies to increase productivity	Farmers curious about new solutions; mindset that farming will continue with or without modern technology	Most farmers have a smartphone and sim card; limited trust in new solutions like mobile payments; little uptake of agricultural applications

Notes: Cells that are both green and red represent a factor that can act as both a driver and barrier. Regarding the first driver/barrier (capacity of conventional public extension system), the underfunding and understaffing of the traditional extension system can work as a driver for the adoption of digital extension services. However, it can also serve as a barrier since extension agents may not have the capacity to support farmers with the diagnosis and management of agriculture production. Digital services should not replace traditional extension services but rather complement them. Regarding the second driver/barrier (local presence and trusted service provider), the overall lack of digital capacities and skills call for strong user support, preferably in the form of an intermediary present in the communities with whom farmers can interact directly. The need for such support is expected to decrease over time.

Source: Author's elaboration.

3.4 Transformation in agriculture

Are digital technologies transforming conventional farm machinery?

Based on the cases studies considered for this report, it can be said that digital technologies have not yet had much effect on conventional farm machinery such as tractors and harvesting equipment. However, the models around conventional machinery are clearly changing in low- and middle-income countries. For example, the focus has shifted from individual ownership of machines by farmers towards shared ownership and rental and pay-as-you-go services. While asset-sharing models have existed for some time, they were often unsuccessful due to issues with machine maintenance and distrust between farmers, operators and machine owners. Today, they are more such models are more viable, due to the widespread availability and adoption of IoT and GNSS technologies by service providers, including TROTRO Tractor and Tun Yat. These technologies permit easy monitoring of the machinery and thus improve transparency and trust between service providers and users. Perhaps the most important change has been the enhancement of traditional mechanization equipment with IoT devices (i.e. the addition of some digital components), which can improve the effectiveness of the machines. For example, combining modern harvesting equipment accessed through a hiring service with GNSS data and a trained operator to drive the tractor may result in higher yields from the same land with the same inputs.

3.5 The potential of small, hand-held devices

As noted previously, the adoption of traditional agricultural mechanization appears is still limited in low- and lower-middle-income countries, and the uptake of fully automated and robotics technologies is negligible. At the field level, a variety of digital tools and remote sensing and mapping technologies predominate, often in combination with conventional communication technologies. Smartphones are accessible to most people in low- and middle-income countries today. In combination with AI and machine learning (ML) applications, and suitable interfaces, they have the potential to offer highly useful innovations that could have a real impact on smallholder farming. An example is GoMicro, which uses a microscopic lens that can be clipped onto a phone camera in combination with AI to support rapid diagnostics of pest and diseases and facilitate efficient and accurate quality control of agricultural products like cereals and grains, fish, fruits and vegetables (GoMicro, 2022).

The case studies include several initiatives in which satellite or drone data was analysed by an algorithm. The results of such analyses are either used to triangulate data shared by farmers and other actors on the ground or made available to farmers as agricultural advice. There are also examples of IoT equipment, such as developed by TROTRO Tractor in sub-Saharan Africa, that are installed on shared vehicles making them suitable for precision farming. Some service providers also offer a range of mechanized equipment through their sharing platform that can serve farmers with both large and small land holdings. Finally, there are still places, particularly in sub-Saharan Africa, where basic phones with call, SMS, interactive voice response (IVR) and USSD services are the most suitable solution for farmers. Such phones may be used in combination with access to, for example, a pay-as-you-go tractor service and advisory services based on satellite intelligence. In any case, it is critical that the service be tailored to the needs or challenges facing specific types of producers (e.g. water sources and grazing grounds for pastoralist livestock keepers, disease outbreaks for banana farmers).

The following points summarize the current context for digital solutions based on the case studies and secondary data:

- The great majority of farmers in low- and lower-middle-income countries lack digital literacy. Service providers noted the need for significant support and technological backstopping. This means that there is demand for intensive and continuous technological support, at least for as long as many farmers have limited digital and technological skills and literacy. The preference of farmers for face-to-face interaction means that service providers – or their intermediaries – should ideally have an active presence in the communities.
- Nor is the digital literacy of other actors in the agricultural value chain highly developed.
- Basic mobile phones are accessible to almost everyone. Smartphones are very commonly used in South Asia and Eastern and South-eastern Asia although their uptake remains low in sub-Saharan Africa. Several African service providers choose to bundle various communication channels to serve farmer users who only have access to basic mobile phones.
- The relative uptake of smartphones in Africa and Asia also affects the use of social media platforms. In Asia, these platforms are regularly used to engage with farmers and other users, while the use of social media in sub-Saharan Africa remains at an experimental level, reaching only a small number of users. Interestingly, the use of specific agricultural applications appears generally low, although new initiatives are emerging (e.g. the Agrinapsis case in Latin America and the Caribbean).
- Policies to support digital solutions are seen as critical in all regions. Many of the case studies indicate the existence of policies and sometimes regulations as well, but this does not mean that they are implemented or supported with government funding.
- Subsidies and funding (and in some cases insurance) are also seen as critical. Various types of financial support are available for digital solutions. Unfortunately, this support is not always suitable or sufficient for the digital technologies offered by service providers. Limiting factors range from the country's security situation, which can reduce investment, to the type of agricultural production system (e.g. financial support is adapted to the context of crop production but is not suitable for more capital-intensive aquaculture production; see the case of Aquaconnect in India).
- Several service providers mentioned the struggle to scale up their solutions and, more importantly, to maintain their user base. The initial enthusiasm for digital solutions may be high, but users often lose interest or their use of the solution is seasonal or unpredictable.

3.6 Benefits, costs and trade-offs in terms of inclusiveness and productivity

Digital divides and gender inclusion are matters of concern in relation to the use of digital technologies in smallholder agriculture for some time (Galperin, 2010; GSMA, 2019; Hernández, Earle and Fredlund, 2020; Highet, Skelly and Tyers, 2017; Müller, Ortiz-Crespo and Steinke, 2022). Generally, the ambition of donors and service providers, is to be inclusive. In practice, this means that service providers try to make their solutions and services available to all farmers, especially women and youth, while reducing (and preventing) digital divides.

Several of the case studies discussed in this report reveal an ambition to remove data asymmetries. These asymmetries can be in relation to data (control of and access to data), information (extent to which diverse individuals can benefit from access to data) and intelligence (the capacity of different actors to understand data and the algorithms and processes that use data for automated processes) (Verhulst, 2022). In other words, the service providers seek to remove an existing divide or disparity in control over and access to data. The basis is the Francis Bacon's age-old aphorism that "knowledge is power" (1597). Data asymmetries can be a root cause of socioeconomic power inequalities, and removing such asymmetries, as expressed by some service providers, could be a starting point to reducing power inequalities (Verhulst, 2022).

Interestingly, the removal of data asymmetries may come with unintended consequences (McCampbell *et al.*, 2021). The desire to be all inclusive in digital development may be undesirable if it reduces the capacity of farmers to choose how to farm and diminishes diversity in the agricultural production system, while increasing interdependencies in the system (e.g. on data availability and access, or on the use of specific hardware or software). Thus inclusion comes with its own politics and governance challenges (Meagher, 2021). For example, two of the three Asian cases and several of the African cases showed that access to finance and credit and agricultural insurance is an important barrier for the clients of service providers. Since this affects the providers' bottom line, they aim for solutions that link farmers with banks, finance institutes or insurers. In most cases, the solution involves the aggregation of data, for example through the development of farmer profiles. The data are made available to finance or insurance companies (sometimes after algorithmic credit scoring). In one case, a company experiencing weak long-term demand for its products sought to collaborate with insurance companies to increase its profits. The aim was to scale the user base by making it mandatory to use the company's solution, for insurance claim purposes. The consequence of data-driven agriculture in this case is that farmers are forced to comply with a certain model of farming[10] to be included in the dominant agricultural system with access to the facilities available in that system. Farmers unwilling or unable to comply may be excluded from those benefits. It is not unlikely that such processes of inclusion and exclusion, and the redefinition of power relationships will exacerbate (Cinnamon, 2020; Mann, 2018) as smallholder farmers gain greater access to digital and automation technologies and participate in agricultural systems that value precision and control.

Machines like tractors, harvesters and crop-monitoring drones generally require controlled environments to function efficiently, so unpredictable factors must be eliminated as much as possible in industrialized farming. This can mean year after year of monocropping on perfectly level fields with little variation in growth, everything ripening at the same time, and the frequent application of herbicides, pesticides and fungicides to ensure uniformity (Miller, 2021).

Yet, the opposite has been suggested as well: digital and automation technologies could reverse the unwanted impacts of mechanization, for example by following an "eco-technical pathway" with rational use of biotechnology, and modest use of inputs, irrigation and mechanization (Task Force Rural Africa, 2019). The trade-off of large-scale mechanization and automation – and the economic benefits of using these technologies – is that it is necessary to adapt agriculture, ecosystems and the farming to fit the needs of a machine. Digitalization might then support the status quo of the global food system, including production standardization and intensification, monoculture and reliance on chemical inputs, rather than help create a more sustainable food production system that considers the impact of agricultural production on biodiversity, human and animal welfare, pollution and greenhouse gas emissions, soil health, etc. (Lajoie-O'Malley *et al.*, 2020). Another concern is that a strong belief in data-driven farming can erode human oversight (referred to as the "precision trap") and create new "precision divides" if the benefits of precision farming are unequally distributed (Visser, Sippel and Thiemann, 2021). The precision trap refers to exaggerated reliance on data, algorithms and machines replacing knowledge about farming

[10] For example, a production system that values intensification and optimization of production quantities (per acre or animal), making use of high-yielding seed varieties, highly productive animals and chemical inputs, and specializing in the production of a single commodity.

with forecasts and automated responses. The precision divide may exclude certain farmers based on the type of food system and commodities for which precision technologies are being developed. If, for example, the focus is on large-scale production of staple crops, then small-scale producers or producers of other crops will benefit less. Similarly, if the focus is on intensive dairy production, organic farmers with few cattle will be left behind.

4 Conclusion and recommendations

4.1 State of the art in digitalization and automation in terms of their availability and adoption

Our research shows that it is usually necessary to move downstream in the value chain, towards processing and value addition, to find large-scale mechanization and more than partial automation in the regions included in the study. To date, digitalization and automation has largely been limited to disembodied solutions, often relying on a smartphone and sometimes complemented by GNSS and AI solutions. It is also clear that most service providers focus on crop production, especially on arable staple crops and high value perennial crops; agroforestry solutions are not widespread. Livestock solutions are mostly disembodied decision-support services, while the adoption of mechanization and partial automation is uncommon in the subsector. That may be because livestock production in low- and lower-middle-income countries is generally low-intensity: most farmers rear a few animals in stables or keep large migrating herds. It appears also that animal welfare issues relevant in high-income countries (Piñeiro *et al.*, 2019) are of less interest to low- and lower-middle-income countries.

The uptake of mechanization and automation technologies tends to be higher in areas where agricultural products are produced for the market, especially the export market. Many processors are experimenting with new technologies, especially those targeting high-value export markets, which demand high quality, standardization, optimization and traceability. Mechanized equipment is used to add value to the agricultural products and prepare it for sales and export. This can be seen in the Igara Tea case, where the company and farmer shareholders operate their own tea processing and packaging factory. Another example is Business Lab Uganda, which recently started to add value to locally-produced jackfruit (Business Lab Uganda, 2022). The company sources the crop from smallholder women farmers in Uganda, can or dehydrate the fruit locally and export the products to the Netherlands, where it is sold in supermarkets as canned young jackfruit or is used in meat replacement products for vegans, vegetarians and flexitarians (dehydrated jackfruit).

The study would have looked very different if it had focused on post-harvest processing rather than on primary agricultural production. At the latter level, it appears that the costs and benefits of partial or fully automated or robotic technologies – and often of mechanized equipment in general – do not yet lead to a profitable outcome. This is particularly the case if the technologies are owned by smallholder farmers. In the end, the ultimate driver of automation and robotics may be the need to increase the efficiency and effectiveness – in terms of the quantity, quality, time, labour, cost, etc. – of agricultural production in a context where the margins for further optimization have become slim when using traditional mechanization only. Nevertheless, most smallholder farmers still have options for optimizing productivity, input use, labour and knowledge even without automation technologies. In crop production, such options include timely sowing and harvesting, the use of healthy and high-quality seeds and planting material and optimized plant-spacing. In livestock production and aquaculture, they include the use of high-quality fodder and feed in appropriate quantities, improved animal healthcare and disease management. From a technological perspective, it is certainly possible to introduce robots to the fields of smallholder farmers in Latin America, sub-Saharan Africa, South Asia and Eastern and South-eastern Asia. However, the lack of an enabling environment, technological literacy and financial capacity makes it unlikely that this will soon happen to any significant degree.

Considering the pressure that agricultural production places on the environment, combined with the looming impacts of climate change, it might make sense to introduce protected agriculture in low- and lower-middle-income countries. This could create the kind of controlled environment that is needed to optimize production and the use of land and resources, and to reduce climate and environmental influences. However, the study suggests that the enabling environment, technological literacy, financial capacity and the policies and regulations that are currently in place would not support this type of farming in these countries. Today, protected farming is only accessible to a few large-scale operations, often supported by foreign investors. Smallholder farming systems are a long way from full automation and the replacement of human intelligence and labour by machines. The technological and ecological advances predicted by some scholars and action groups (Daum, 2021; Ditzler and Driessen, 2022; Miller, 2021; IPES–Food and ETC Group, 2021) are probably not likely in the foreseeable future in most low- and lower-middle-income countries, at least for smallholder farmers. That is not to say that potential negative impacts of such advances are not receiving attention from service providers, donors and policymakers. The study shows that environmental concerns and a growing interest in conservation agriculture and nature-based solutions are an emerging trend, although the true intentions of those investing in this trend as well as its long-term impact remain to be seen.

4.2 Key considerations and recommendations

- A lack of access to finance and credit and agricultural insurance prevents farmers from investing in the solutions offered by service providers, affecting their businesses. This has led service providers to look for business models that will make their solutions profitable. As seen in the case studies, these include models that tie services to credit and insurance, or farming contracts that guarantee offtake and a fixed price for raw material to reduce production risks and facilitate investment capacity. However, such models may create technological lock-ins (i.e. by requiring farmers to use specific services), unwanted dependencies and power asymmetries, with unintended socioeconomic consequences. They may also coerce farmers (as well as produce buyers and service providers) to undertake agronomic practices that are desired by more powerful market actors, while embedding farmers in a closed, proprietary system[11] (Mann and Iazzolino, 2021). Thus, while more organized and formalized value chain services can help to reduce production risk, they may also limit a farmer's autonomy to decide how to practice farming and can reduce diversity in agricultural production systems.
- Countries with an unstable political and internal security situation provide a more challenging context for service providers to secure investments or grants for their company or project. Many financers and donors rightfully see investing in these countries as high risk. At the same time, as shown by case studies in Mali and Myanmar, show that service providers in politically unstable countries can play an important role to support communities by providing a continuous local presence, and access to inputs, services and markets for smallholder farmers. They may also help implement field-level activities by actors that are temporarily blocked from risky areas. Service providers often have first-hand knowledge about the security situation in communities and have built strong trust relationships with local actors. While investments in unstable countries have a high risk of being financially unprofitable, investors, donors and policymakers may still want

[11] A proprietary system relies on software and hardware equipment for which the right to use, modify or change, or share the software is licenced. In the case of software, it is also referred to as non-free software or closed-source software: the opposite of open-source software. Proprietary systems restrict the freedom of users and may have low interoperability with other systems (e.g. because file formats or protocols are incompatible).

to acknowledge and support service providers in such countries because of their direct and indirect contributions to food and income security.

- Simple, low-tech solutions – like IVR, USSD, SMS and call centres – remain the best choice for most smallholder farmers in low- and middle-income countries. Bundled services and platforms-of-platforms are particularly attractive: these are accessible through various communication channels and types of devices and may combine various subservices, like market information and linkages, climate data and weather forecasts and real-time farm monitoring data.[12] Such solutions are low-cost and low-maintenance, require less technological and digital literacy, limit the creation of digital divides and thus support inclusivity, are less sensitive to infrastructural failure and appear to generate the highest cost–benefit output at scale. An additional positive effect is that they require less energy and data infrastructure than advanced data-driven technologies.
- There is a pressing need for policies and subsidies or financial support systems that promote investments in mechanization equipment, digitalization and automation, and make these technologies more affordable for farmers (e.g. through e-voucher systems, loans and subsidies, as in the case of TROTRO Tractor) as well as for aspiring equipment owners (e.g. young people who have a licence to operate a tractor but lack the credit needed to buy machinery). Several interviewees underlined the importance of enforcing existing policies and regulations, for example, with regard to data security and ownership. The representative of Tun Yat pointed out that policies and regulations in Myanmar facilitate large-scale citizen surveillance but provide no tailored guidance to service providers that wish to operate in the agricultural sector.
- The institutional arrangements and capacity building needed to govern digitalization and automation also require our attention. Experience in other regions has shown that technologies often precede governance systems, with all kinds of unintended consequences. In low- and lower-middle-income countries, there are concerns that the private sector may have too much influence on the development of such systems. Some scholars refer to this as digital colonialism (Kwet, 2019; Pinto, 2018), where power and influence are concentrated in large technical corporations through, for example, proprietary software, data and profits extracted from users. Meanwhile, poorer countries do not get an opportunity to develop a competitive digital industry with their own services and technologies. This requires national and regional capacities to develop governance systems that can guide the development of digital and automation technologies, rather than the other way around.
- There is also a need for further research on emerging power dynamics in low- and lower-middle-income countries due to the growth or digitalization and automation technologies. The roles of major technology companies and other corporate and asset management players in the agricultural sector are of particular interest, as are their commercial interests and the potential implications of those interests for smallholder agricultural production systems in low- and lower-middle-income countries (e.g. concentration of power, exclusion of farmers with small landholdings, redistribution of land, redistribution of wealth, loss or creation of knowledge, skills and labour, etc.).
- Finally, the costs, benefits and true impact of digital and automation technologies requires further research attention. Impact assessments are needed that look beyond number of users and the inclusion or exclusion of different types of users. Evidence is required to show if the big promises and high expectations around digitalization and automation

[12] The subservice could originate from various service providers. Subservices may be bundled using APIs, which allow different products and services to communicate with each other and to use each other’s data and functionality. For this to be possible, the individual services need to be interoperable.

can be realized in practice. Which business models are sustainable in a smallholder farming context? Which farmers, stakeholders and food systems benefit? Which do not? Such evidence can help farmers to choose the solutions and service providers that best serve their needs and aspirations and guide donors, investors, and policymakers in making responsible and effective financial and policy decisions.

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Annexes

Annex 1. Glossary

Agricultural automation: The substitution of physical activities and human decision-making with machinery and equipment that perform agricultural operations, reducing or eliminating direct human intervention and improving their precision. Examples include tractors (both traditional and fully automated) that pull, push or put into action a range of equipment and tools that perform farm operations, as well as more advanced options such as weeding robotics, which can spray herbicides precisely where and with how much is needed, or drones to monitor conditions remotely and apply fertilizers, pesticides and other treatments from above.

Agricultural mechanization: The use of technologies, from basic hand-held tools to more sophisticated and motorized equipment. Mechanization eases and reduces hard labour, relieves labour shortages, improves the productivity and timeliness of agricultural operations, ensures the efficient use of resources, enhances market access and contributes to mitigating climate-related hazards. This study focuses on motorized mechanization, excluding agricultural mechanization technologies that have manual labour or animals as their source of power.

Agricultural motorization: The application of all types of mechanical motors or engines, regardless of energy source, to activities associated with agriculture.

Artificial intelligence (AI): The ability of a computer or computer-controlled robot to perform tasks commonly associated with intelligent beings. AI can behave like humans, operate like humans, think like humans or have its own rational way of processing information and/or behaviour; it can even learn from experience.

Automated technologies/automated equipment: Existing systems, where some or all elements have been automated to work without human intervention, such as for use in transporting, sorting.

Big data: Large, diverse, complex data sets generated from instruments, sensors, financial transactions, social media and other digital means, and typically beyond the storage capacity and processing power of personal computers and basic analytical software.

Climate-smart agriculture (CSA): An approach to transforming and reorienting agricultural production systems and food value chains so that they support sustainable development and can ensure food security under climate change.

Digitalization in agriculture: Part of the agricultural automation process, it refers to the use of sensors, machines, drones and satellites to monitor the performance of animals, soil, water, plants and humans in agricultural tasks. Digitalization encompasses digital devices or tools that are *embodied* in agricultural machinery and equipment (such as precision farming tools) and *disembodied* devices (such as smartphones or tablets) or software tools, such as advisory applications, farm management software and online platforms.

Demographically Identifiable Information (DII): Data that can be used to identify a community or distinct group by demographic factors, such as geography, location, ethnicity, religion, economic status, gender and political ideology (Netherlands Red Cross, 2017; OCHA, 2021).

Disembodied technologies: Primarily software-based solutions and services that instead require limited hardware resources, generally in form of a smartphone and broadband infrastructure. Disembodied technologies contribute most of the digitalization and automation solutions currently employed in the agrifood sector in low- and lower-middle-income countries. They are generally more suited to smallholder farming than are embodied and precision farming technologies.

Drone: Remote-controlled pilotless aircraft that have many applications for agricultural field surveillance and remote diagnostics of agronomic conditions such as plant and crop diseases, water resources and soil quality.

Embodied technologies: Sensors and other devices that are embedded within agricultural machinery, typically involving a computer-based system that is designed to provide decision-support to farmers, in combination with GNSS. Embodied technologies are prevalent in highly-mechanized agricultural production systems and precision farming.

Geodata: Information about a geographical location this is held in a digital format; it is also called geospatial data and information, georeferenced data and information, and as geoinformation.

Gig jobs: Flexible, temporary work done by so-called gig workers (e.g. freelancers, independent contractors, project-based workers, platform workers). Gig jobs are a typical element of platform services, such as mobility providers (e.g. Uber), meal, grocery and mail deliveries and, in the context of agriculture, machine-sharing services. They have changed the classic employer-employee relationship.

Global Positioning System (GPS): A military system developed by the United States of America to show the exact position of an object using satellite signals.

Global Navigation Satellite Systems (GNSS): A generic term describing any satellite constellation, that provides positioning, navigation and timing services. It is also referred to as GPS, which technically only refers to the system developed by the US military. Other GNSS systems include the Russian GLONASS (Global Orbiting Navigation Satellite System), European Galileo, and Chinese BeiDou-2.

High-income countries: The World Bank defines a high-income country having a gross national income per capita exceeding USD 12 056. The gross national income (GNI) is calculated by adding gross domestic product to factor income from foreign residents, and then subtracting income earned by non-residents.

Internet of things (IoT): The interconnectivity of computing devices in everyday objects (e.g. mobile phones, machinery, drones) via the internet, which allows these devices to send and receive data in real time.

Interactive voice response (IVR): An automated phone system that interacts with the caller and can gather information by providing a menu of options and acting based on the caller's answer. IVR is commonly used at call centres, for example, for an automated greeting and to route callers to the right human agent.

Low- and middle-income countries: Low-income countries have a GNI per capita of USD 1 045 or less; lower-middle-income countries have a GNI per capita between USD 1 045 and USD 4 095, and upper-middle-income have a GNI per capita between USD 4 095 and USD 12 695 (World Bank, 2021).

Machine learning (ML): A subfield of artificial intelligence that develops computer systems that can learn and adapt without explicit instructions from humans. Machine learning typically requires the use of algorithms and statistical models to perform complex data analytic tasks and draw inferences from that data.

Mechanization: The use of technologies, from simple and basic hand tools to more sophisticated and motorized equipment, to ease and reduce hard labour, relieve labour shortages, improve productivity and the timeliness of agricultural operations, improve the efficient use of resources, enhance market access and contribute to mitigating climate related hazards. There are three power sources in agricultural mechanization: handtool technology (tools and implements that use human muscles as the main power source); draught animal technology (machines, implements and equipment powered by animals); and motorized technology (mechanization powered by engines and or motors).

Mobile network operator (MNO): A provider of wired and/or wireless voice and data communication services.

Motorized equipment/agricultural motorization: The application of all types of mechanical motors or engines, regardless of energy source, to activities associated with agriculture.

Personally identifiable information (PII): Sometimes also referred to as personal data (e.g. in the European Union's General Data Protection Regulation), PII data is a piece of information through which an individual is directly or indirectly identifiable (see Sara, 2018).

Precision agriculture/precision farming: A management strategy that gathers, processes and analyses temporal, spatial and individual data and combines it with other information to support management decisions for improved resource use efficiency, productivity, quality, profitability and sustainability of agricultural production.

Protected farming: The cultivation of high-value vegetables and other horticultural crops in greenhouses. Protected farming allows farmers to grow cash crops on small plots in marginal, water-deficient areas where traditional cropping is not viable.

Remote sensing: The process of gathering information about objects on Earth from a distance using aircraft or satellites.

Robotics: Systems or machines that have been provided with increased levels of intelligence or a new intelligent machine that is developed for an existing application.

Traditional mechanization: Equipment using engine power, such as tractors, harvesters, threshers and water pumps and sprinklers, among others.

Uncrewed aerial vehicle (UAV): See UAS.

Uncrewed aerial system (UAS): Sometimes also referred to as unmanned aircraft system, and popularly referred to as drone, a UAS comprises a UAV, a remote electronic controller, and a command-and-control data system linking the controller to the UAV. The UAV is controlled remotely with no pilot on board. Autonomous UAVs are possible, although in practice they generally require a human pilot on the ground (often because of national regulations).

Unstructured supplementary service data (USSD): A message service that is more interactive than SMS. Characterized by the use of codes that start with * and end with #, for example, *845# which is the code to access a toll-free service in Rwanda that is operated by VIAMO and MTN Rwanda and provides information on agriculture, health, news, weather, etc. A USSD message can have a maximum of 182 characters.

Annex 2. Interview questions

A. For service providers

The aim of this interview is to learn more about your digital, mechanization or automation solution and each question should be seen from that perspective.

Organization and service in general

1. Can you briefly explain what your organization is and what you do as an organization?
    a. What services do you offer, based on which technologies?
    b. For what purpose are those services used?
    c. Can you briefly explain the geographic market that you serve with your solution?

Unique selling points of intervention/technology/service covered in case study

2. Why do think your solution or solutions are needed?
3. What sets your solution/s apart from the competition?

Customers and business model

4. What type of customers do you have (small-scale producers, medium-scale producers, large scale producers, individual farmers or farmer cooperatives) and/or (service providers, extension agents, governments, agribusinesses, agroprocessors, etc.)?
    a. Can you briefly explain how different types of customers take advantage of your solution/s?
    b. Do you maintain statistics about women and youth users? If yes, can we access those?
5. Are there additional types of clients or users that you would like to become your customers?
6. Can you briefly explain the business model behind your solutions/services, whether this currently results in a profitable business and, if not, how you cope with financial sustainability?
7. What percentage of your 2021 turnover relied on grants?

Adoption drivers

8. What are the scaling trends for your solution (in the specific local context/country/region)?
9. What – in your experience – are the factors that drive the adoption of your solution?
10. Is there any national policy that established an enabling environment for your solution? If so, please cite the policy.

Adoption barriers

11. Did you and/or do you experience barriers to the adoption and use of your solution caused by national and international policies, rules and regulations? If so, please explain.
12. Did you and/or do you experience other barriers for the adoption and use of your solution by your target clientele/users?

Future vision (optional if time permits)

13. What is your future vision for your solution in <enter the context/country/region>

B. For farmers' associations or cooperatives

The aim of this interview is to learn more about the digital, mechanization or automation solution(s) and services that the association/cooperative is using and providing to farmers, and each question should be seen from that perspective.

Organization and service in general

1. Can you briefly explain what your organization is and what you do/produce as an organization?
2. How would you describe your farm/farmer organization in terms of, for example, its size, market orientation, partnerships with other producers and service providers?
3. What is/are the geographic market(s) that you serve with your production?

Use of mechanization, digital, and automation solutions

4. What mechanization, digital, and automation solutions and services do you use?
    a. Can you name the service provider/s through which you obtained these solutions?
    b. Why did you specifically choose the solutions of this/these service provider/s?
5. Can you briefly elaborate the purposes for which these solutions are used?
6. What made you decide that you needed these solutions?

Unique selling points of intervention/technology/service covered in case study

7. Do these solutions give you a competitive benefit over other farmers?
    a. If so, how?

Customers and business model

8. In your opinion, what types of producers can take advantage of and benefit from the kind of solutions that you are using?
    a. <if a farmer cooperative/multiple users> Do you maintain statistics about women and youth users? If so, can we access those?
9. Can you briefly explain the business model behind the solutions/services that you are using? For example, did you purchase them or are they on loan? Does some other entity pay for it? Do you pay monthly membership fees? Do you pay for maintenance?
    a. <if farmer has invested him/herself> How did/do you finance your investment in these services?
    b. <if farmer has invested him/herself> What is your expected return on investment?

Adoption drivers

10. What are the trends that you observe in relation to mechanization, digitalization and automation (in context/country/region)?
11. What are the problems/challenges that you/your company could address through the adoption of mechanization/digitalization/automation solutions?
12. Is there any national policy or financial mechanism that supports investment in and/or deployment of these solutions (in context/country/region)? If so, please cite the policy.

Adoption barriers

13. Did you and/or do you experience barriers to the adoption and use of these solutions caused by national and international policies, rules and regulations? If so, please explain.
14. Did you and/or do you experience other barriers for the adoption and use of the solutions that you use?

Future vision (optional if time permits)

15. What is your future vision for mechanization, digitalization and automation on your farm/in your farmer cooperative?

Annex 3. Case studies

Aquaconnect

Year of establishment: 2018
Operates in: India
Current number of users: 60 000
Target agricultural sector: Shrimp production
Interviewees: Sudhakar Velayutham and Rajamanohar Somasundaram

Biography: Rajamanohar Somasundaram is the chief executive officer and founder of Aquaconnect, a full-stack aquaculture platform consisting of multiple products and services with embedded financial technology, supported by a physical and digital distribution network. Somasundaram is an alumnus of the Indian Institute of Technology – Kanpur. He also holds a diploma from Harvard University and a fellowship from Stanford University, both in the United States of America. The World Economic Forum recognized him as one of the 'Young Global Leaders – 2012' for his exceptional leadership and contribution to 'Mobile4Good' initiatives in emerging markets. Somasundaram also featured in the '40 UNDER 40 EcoSapiens' list by The New Indian Express for promoting sustainable aquaculture practices in India.

Services

Aquaconnect uses digital solutions to monitor and document performance on aquaculture farms, link farmers with input providers and produce buyers and support access to finance, insurance and markets. Most of these services are accessible through android and iOS applications, available from the website and webstore. Farm-level data are complemented by satellite data and artificial intelligence. Besides its digital solutions, Aquaconnect maintains physical centres (AquaHUBs) in communities, to enhance its last-mile connectivity; here, producers can buy inputs, sell produce and obtain advisory services.

Target customers and users

Targets include small- and medium-scale shrimp farmers.

Why Aquaconnect needed to digitize/automate

Until now, aquaculture farmers have not regularly documented their farming practices, input use, productivity and revenues. The lack of data has led to poor productivity and inefficient market linkages. Aquaconnect offers a stack of solutions to optimize pond environment and productivity, from monitoring local and regional performance to enhancing efficiency and reducing risks throughout the value chain, from production to processing. The solutions create predictability and transparency in the value chain and make strategic planning possible.

Business model and financial sustainability

The use of solutions such as Aquaconnect App and webstore are free for farmers. Aquaconnect generates its revenue from the stakeholders – banks, insurers, processors, input providers – with whom it connects farmers. Aquaconnect generates revenue, on a per transaction basis, from these stakeholders for the linking services and data intelligence that it provides. Furthermore, it raises equity funding, which is then used to expand operations. So far, the business model has been profitable.

Scaling target

There are plans to scale out to South and South-eastern Asia in the next 1–2 years. The long-term vision is to expand globally.

Drivers

Low productivity and inefficient market linkages have created a market for Aquaconnect's solution. The growing interest of farmers in digital technologies is an important driver. Having a team on the ground facilitates adoption and enables technical backstopping.

Barriers

The capacity of farmers to operate digital technologies is still limited. The high cost of advanced technology (such as IoT devices) is a barrier. There is a ceiling to the size of loan that farmers can obtain per hectare of land and this is insufficient to invest in equipment and aquaculture production in general. The premium rates for insurance for aquaculture are significantly higher than for crop production.

Policy as a barrier or enabler

The Government of India has allocated USD 3 billion to the modernization of agriculture, including fisheries value chains. The government has shown an interest, supported by policies, to support start-ups that implement technologies across the value chain. However, there are currently no subsidies for aquaculture nor specific subsidies for IoT tools.

Top quotes

"So, we are also experimenting [with] different features, and which [solution] is really getting picked up where, and which [solution] is not working. And we … try to re-engineer that [solution] and again implement it. So, the last phase … is a learning journey for Aquaconnect as well."

"I would say it will take a time for the farmers to adapt to this kind of tools."

"Farmers are slowly, slowly becoming a bit more technological. … [T]hey're taking up these digital technologies. Then there is the realization that your service could support them in getting more insights, increase their productivity, but also access to, for example, finances at a lower interest rate."

"But farmers want some handholding for quite some time to get used to … you know, how effectively they can use those tools in their farming operation."

AGRINAPSIS

Year of establishment: 2020

Operates in: Plurinational State of Bolivia, Costa Rica, Ecuador, Guatemala, Mexico

Current number of users: Unknown

Target agricultural sector: All

Interviewee: Santiago Velez León

Biography: Santiago Vélez León is the representative of the Inter-American Institute for Cooperation on Agriculture (IICA) in the Plurinational State of Bolivia. Previously, he was Coordinator of Management and Regional Integration at IICA Headquarters. He has a PhD in Strategy and Leadership and an MSc in Agribusiness Management and Agricultural Engineering.

Services

A social media platform specialized in agriculture that enables farmers to access knowledge and information by interacting with experts and practitioners. The information is verified and rated by users, so that Agrinapsis ensures it is a trusted and high-quality provider. Agrinapsis also facilitates e-commerce among farmers, enabling them to sell their agricultural output and buy inputs – such as seeds and fertilizers – as needed.

Target customers and users

Mainly small-scale farmers, with a particular focus on women and youth. However, anyone concerned with agriculture – from academics and students to agronomists – can benefit from the solution. Users also include technicians, vendors across the supply chain, suppliers and veterinarians. Use of the e-commerce platform is only enabled for smallholder farmers, and unavailable to large corporate farms.

Why Agrinapsis needed to digitize/automate

There is a wealth of knowledge among smallholder farmers that is not being shared. Agrinapsis enables the exchange of knowledge using crowdsourcing to connect farmers throughout a country and beyond. It is seen as a tool to democratize knowledge and drive social and environmental change.

Business model and financial sustainability

Agrinapsis is funded by the IICA. The organization is non-profit and makes no revenue from the services provided. Due to the recent establishment of this project, it is difficult to give statements about its sustainability.

Scaling target

First regionally, and eventually globally, with a potential market that includes anyone that is in any way connected with agriculture.

Drivers

There is a wealth of knowledge derived from the experiences of small-scale producers, which is not shared. Agrinapsis aims at making this knowledge accessible across countries, after verifying its validity. The platform is a tool to democratize knowledge and drive social and environmental change. Increased digital literacy, particularly among young people, the organization of women in groups (especially the elderly) and the rise of influencers have all played an important role in promoting Agrinapsis, which is believed to be the first agriculture-specialized social media platform in Latin America and the Caribbean.

Barriers

Drivers include the lack of internet access in remote and rural areas, despite national and international efforts to increase connectivity. Digital illiteracy is still high in rural areas, particularly among the elderly. Integration of local languages in order to be inclusive (in the Plurinational State of Bolivia alone there are eight official languages) also challenges the process.

Policy as a barrier or enabler

Political uncertainty can affect the sustainability of the platform since it is funded by IICA, which depends on support from its 34 member states.

Top quotes

“Without knowledge you cannot make productive, social or environmental changes of any kind.”

“Women see technology in agriculture as an opportunity to empower themselves.”

Coopecan

Year of establishment: 2020

Operates in: Peru

Current number of users: 1 500

Target agricultural sector: Livestock (alpaca)

Interviewee: Dagoberto Fernandez Palacio

Biography: Dagoberto Fernandez Palacio has been the General Manager of Coopecan Perú since 2011. He holds a Bachelor of Business Administration, with postgraduate studies in Rural Development, Finance and Planning. He has extensive experience in the preparation, planning and execution of development projects, as well as in the management and direction of companies.

Services

Coopecan provides digital services – ranging from advisory services to alpaca breeders, to pasture monitoring and animal traceability – with the aim of upgrading and certifying animal welfare standards and improving the quality of alpaca fibre. The service uses satellite imagery for pasture monitoring, QR codes for animal monitoring and a blockchain to enhance value chain traceability.

Target customers and users

The company's targets are mainly small-scale breeders in the Peruvian highlands (who account for about 90 percent of all breeders there), with herds ranging between 50–100 animals and annual revenues of between USD 1 500 and 1 800. Also targeted are intermediaries along the alpaca fibre value chain, including distributors, suppliers and consumers that are concerned about the origin of the product.

Why Coopecan needed to digitize/automate

The excessive number of alpacas, worsening climatic conditions and increasingly degraded natural pastures called for technical assistance in managing herds (animal health conditions, etc.); the assistance is complemented by capacity building on how to use the mobile solution. A traceability system permits certification, as well as tracing of fibre history, environmental, labour and social responsibility, improved working conditions, fair payment and animal welfare.

Business model and financial sustainability

Coopecan's cooperative has been successfully running since 2012. Over the past decade, it increased its reach and developed important projects to improve working conditions, fair pay and animal welfare. The digital service (introduced in 2020) is sustained by external funds from donors and is not aimed at generating profit. It is financially sustainable, however technical assistance and capacity building are covered through cooperation programmes.

Drivers

Drivers include the increasing demand for social and environmental responsibility and transparency, and animal welfare standards in the alpaca fibre value chain, which then translates into a higher-valued product.

Barriers

The lack of internet access in remote areas and absence of national information technology (IT) companies to support the service are important barriers. Another barrier is the ageing of alpaca breeders: most are women and elderly people; young people are not interested in alpaca farming due to the working conditions and remoteness. They prefer to transfer to the cities to find better paid jobs.

Policy as a barrier or enabler

Political uncertainty leads to frequent policy changes, which inhibit support to the sector.

Top quotes

“Alpaca is a business for the elderly. This is a barrier. It makes the adoption process longer and makes it more difficult altogether. Basic skills are low. Among farmers, it is difficult to use the last generation of mobile phones.”

“The argument that digital technologies are attracting young people [among farmers but also among extensionists and IT (information technology) experts] does not work in the Alturas, due to their remoteness and hard living conditions.”

GARBAL

Year of establishment: 2017
Operates in: Burkina Faso and Mali, with Niger to come onboard shortly
Current number of users: More than 500 000
Target agricultural sector: Livestock (pastoralists) and arable crops
Interviewee: Catherine Le Come

Services

GARBAL offers an integrated digital solution providing smallholder farmers and pastoralists in the Sahel region with highly contextualized advisory information about suitable grazing lands, herd migration, weather, farming practices and markets. The solution makes use of satellite and other data. It also includes a digital marketplace where clients can obtain fodder and sell milk and cereals. The service is available through a human-operated call centre or interactive voice response.

Target customers and users

Targets are small-scale farmers and pastoralists. Women represent between 22–30 percent of users. Traders and herd owners are also targeted.

Why GARBAL needed to digitize/automate

Agriculture and livestock are the backbone of people's livelihoods and food security in the Sahel. Climate change, uncertainty about the weather and market access and political unrest challenge the traditional knowledge of farmers and herders and threaten their livelihoods. This kind of solution has the potential to improve their access to markets (in turn, making markets more inclusive) and to support their resilience and adaptation capacities against shocks.

Business model and financial sustainability

GARBAL's business model is based on a public–private partnership; this has been crucial to overcoming the risk aversion of donors and funders to developing innovative digital solutions in fragile contexts. The operational costs of GARBAL are principally supported by donor funding and contributions from project partners. Revenues come from calls to the call centre, or modest payments to use the USSD service (revenue generated by airtime). Despite the revenue, which is reinvested in the solution, GARBAL is far from reaching the break-even point. The business strategy is to generate new revenue streams through the digital marketplace and a digital finance solution that is still to be developed.

Scaling target

The GARBAL solution can be adapted to the specific contexts and needs of smallholder farmers and pastoralists throughout sub-Saharan Africa, depending on opportunities and partnerships. The interviewee acknowledged that scaling comes with challenges due to the need for contextualization.

Drivers

The GARBAL solution can potentially improve access to markets and support farmers' resilience and adaptation capacities against shocks. Being a public–private partnership has proved critical to gaining acceptance of the solution by the end users. Capacity building and the penetration of mobile phones – mostly not smartphones – has also enabled adoption. Finally, face-to-face engagement with local farmers and pastoralists and their organizations has been fundamental in gaining trust and increasing outreach.

Barriers

The barriers to adoption differ by country, explaining the need to adapt the solution to the context of each country. Political unrest and insecurity in some countries is a challenge, as is accessibility of the service in places where the internet is regularly shut down. Other barriers include a lack of infrastructure for digital solutions (e.g. energy, connectivity and smartphones), lack of skills and awareness of the benefits of the technology, and lack of data quality and management.

Policy as a barrier or enabler

Support from local ministries has been instrumental in promoting the GARBAL solution; this has included sharing databases and providing content for the advisory service. However, political unrest and insecurity hamper investments in the countries concerned.

Top quotes

"If we are scaling into a new geographical area, just as the local partners will be different, the strategy will also be different. So, it's all linked to 'do you know your market'? What are the key features of your markets and the end-users' needs and habits?"

"Due to the scarcity of the mobile network, [pastoralists, smallholder farmers] already know where they can get the network and when they are making calls to families, they often also make calls to the GARBAL service just to check for up-to-date information. So that's what we also learn from our evaluation, that the GARBAL service is not replacing traditional knowledge. It's being used as an additional source of information to cross check."

ICT4BXW

Year of establishment: 2018
Operates in: Rwanda
Current number of users: More than 7 000
Target agricultural sector: Banana
Interviewee: Julius Adewopo

Biography: Julius Adewopo is Initiative Lead and Advisor for Emerging Technologies with Mercy Corps, and Project Lead and Geospatial Data Scientist at the International Institute of Tropical Agriculture, and Associate Scientist with Bioversity International. In his current role, he leads digital tool development, geospatial data collection and analytical solutions to support scalable solutions for agricultural production in Africa. Adewopo has led several projects and initiatives internationally. In 2014, he was inducted into the University of Florida Hall of Fame and received an Award of Excellence in Forest Science from the International Union of Forestry Research Organization in Vienna. In late 2016, Adewopo was honoured with The Future Africa Award – in the agriculture category. In 2019, he received the Louis Malassis Laureate Award as the Young Promising Scientist from the Agropolis Foundation in Montpellier, France. Julius holds a PhD from the University of Florida and an MSc from the University of Arkansas at Monticello, United States of America.

Services

ICT4BXW offers various advisory and information services on banana production, including e-training. Services for both smartphones and basic phones are available, combined with non-digital information (such as a paper-based crop calendar). The company focuses on the diagnosis and monitoring of Banana *Xanthomonas* Wilt (BXW). It also collects data about farmland (e.g. farm boundaries, land use and cover). The registration of banana farmers through an android application allows them to access ICT4BXW's services and helps extension agents and government officials with disease monitoring. ICT4BXW has used drones to map land under banana production, as well as the varieties grown and diseased banana crops.

Target customers and users

Small-scale banana farmers, local extension agents, and the Government of Rwanda (primarily researchers and technicians from Rwanda's Agriculture and Livestock Development Board) are target customers for ICT4BXW.

Why ICT4BXW needed to digitize/automate

BXW is a bacterial disease that threatens the production of banana, a major food and income security crop in most of Eastern and Central Africa. In Rwanda, banana is one of the country's three most important crops. However, until now there has been no accurate system to diagnose and monitor disease presence and the national extension system struggled to ensure that the right information reached farmers at the right time.

Business model and financial sustainability

ICT4BXW does not currently generate revenue: the service is free to use and relies on donations from the German Federal Ministry for Economic Cooperation and Development. It is hoped that the Rwandan Ministry of Agriculture may invest in the solution in the future. The company has ambitions to move towards a bundled service. Two potential business models are: i) to become the provider of a public good; or ii) to establish the tools in a larger digital ecosystem, provider of a variety of services, with farmers paying a small fee for those services and a percentage of those revenues going to maintain the ICT4BXW services. There are standing partnerships with for-profit companies Arifu – an education technology company – and VIAMO – a provider of communication solutions, primarily via USSD and IVR.

Scaling target

ICT4BXW aims to make its solution available throughout Rwanda, possibly expanding to other countries in Eastern and Central Africa and/or to other crops.

Drivers

There is a growing demand for solutions that diagnose and control BXW, which threatens the production of banana in Rwanda. Digital tools help prevent the lags and inconsistencies in the information provided to farmers. In addition, with the help of, for example, GPS and location data, it is possible to pinpoint disease incidences and provide location-specific advice to make disease control more effective. Increased use of smartphones and government interest in the use of digital technologies for the agriculture sector is facilitating adoption.

Barriers

Despite interest, smartphone penetration and digital literacy in Africa remain limited. Development and maintenance of the digital systems, especially the backend, is a challenge, as is ensuring that everyone that needs to work with these systems understands them.

Policy as a barrier or enabler

The Government of Rwanda is promoting the adoption of smartphones, including by farmers, and digitalization of the agriculture sector (for example through targeted policies). Capacity building is sometimes provided regarding the development and maintenance of digital technologies.

Top quotes

“Whatever happens to banana happens to the overall food system”

“The keyword is being able to reach farmers on time, at scale, with the right tools or resources that match their contextual needs.”

“It's not just about the disease, it's also about making the right decision about banana production to support national food security because everything goes hand in hand.”

“Our guiding philosophy is that technology is a means to an end. It's not the end in itself.”

“We really need to leverage any tool, any means or process that allows us to reach [the farmers] in a timely fashion.”

”Technology … becomes an integral part of solving problems at a larger scale.”

“Essentially, technology is not just anything digital; technology can include hard copy materials that are innovatively designed to foster effective and timely decision support.”

“In this day and age, as I say, information saves lives. Information is power.”

Igara Tea

Year of establishment: 1969. 2017 marked the start of investments in digital solutions

Operates in: Uganda

Current number of users: More than 7 000

Target agricultural sector: Tea

Interviewee: Hamlus Owoyesiga

Biography: Hamlus Owoyesiga is currently Manager for Digital Solutions at Igara Growers Tea Factory Ltd. (IGTF) and a certified uncrewed aerial systems (UAS) operator. Previously, he was IGTF's IT Systems Administrator for eight years and concurrently managed the implementation of European Union-funded digitalization projects (2017–2020).

Services

Using digital technologies, Igara Tea acquires and manages information on tea farmer profiles, farm boundaries, land use and cover; tracks, traces and monitors the production and delivery of tea leaves to processing plants; assesses the health status of tea plants and simulates production capacity; supplies inputs appropriate to each farm type; provides tailored advice and e-extension services; and enables access to credit. In the future, small mechanized devices are expected to improve precision and save the labour of tea leaf pickers.

Target customers and users

Users are primarily smallholder tea farmers (1.5–2 ha), who are shareholders of Igara Tea. About 18 percent of users are women. 65 percent of tea farm labour is done by young farmers. In processing tea leaves, women and youth comprise more than half of the workforce. Banks and credit providers are also targeted.

Why Igara Tea needed to digitize/automate

Digitalization was perceived as necessary when Igara Tea had no means to trace its 7 000 farmer shareholders. Igara Tea had no records about their precise location, size of farm, production and financial capacities, and no parameters to calculate input requirements, etc. Additionally, traceability of the tea leaves and productivity over time was a problem. Digitalization started with support provided from the Technical Centre for Agricultural and Rural Cooperation (ACP–EU) in 2017. In 2018, Igara Tea started mapping and profiling its tea farmers using the Open Data Kit – an open-source mobile data collection platform –, established a farmers' database complemented by a geographic information system and acquired UAS capacities. Further improvements included the issuance of farmers' cards, the deployment of digital scales and point-of-sale devices at collection points for tea leaves.

Business model and financial sustainability

Initially, the digitalization process was financed by grants although Igara Tea currently generates revenue by selling tea on behalf of tea farmers. Igara Tea acts as a provider of technical assistance, advance input supplier, buyer, processor and seller of tea. It adds value and sells tea on local and international markets on behalf of its shareholders, who sell the company their raw material. Digitalization helps to optimize the procurement process, saving up to 70 percent of the costs normally associated with receipt books, pens, paper, etc. The payback time for investments in digital hardware and software was 1.5 years. Today, the company invests – without grant funding – in both hardware and software.

In 2016, before the digitalization process started, Igara Tea farmers delivered a total of 25 623 metric tonnes of tea leaves to the processing plants. In 2021, after the digitalization of the value chain from farm to processing plant was completed, total delivery increased by 56.6 percent, reaching 42 000 metric tonnes of tea leaves.

Scaling target

Currently, the company mostly scales in terms of production per farmer, but it is limited by the capacity of its two processing plants. Igara Tea has been approached by the Government of Uganda and by stakeholder involved in procuring and processing cash and export crops in Uganda (such as coffee, cotton, other tea processors) with requests to share its experiences in digitalization.

Drivers

The demand for increased certainty, transparency and timeliness for the buyer (Igara Tea), farmers and loan providers are the main factors driving the adoption of Igara Tea's solution. Increased labour costs are driving the development of mechanized tea leaf pickers.

Igara Tea has invested in radio and in-person awareness-building and introduced a policy on data protection. Its extension officers (data collectors) have been trained to use digital tools and data. An important factor that helped to convince farmers to register with Igara Tea was the prospect that it would give them improved access to customized services.

Barriers

Limited tea leaf processing capacity is hindering expansion. Worldwide tea prices are low. Farmers lack the financial capacity to invest in machinery, so Igara Tea is looking into developing a sharing scheme for mechanization.

Policy as a barrier or enabler

The Government of Uganda is determined to advance the use of technological solutions to solve the country's development challenges. However, it is still difficult to obtain government financial support. High levels of bureaucracy, which translate into higher costs, act as barriers, as does a lack of clear regulations and policies regarding the use of drones.

Top quotes

"Farmers were double dealing in several banks … using the same property as a collateral."

"Before we could introduce the [geographic information system fed with georeferenced data gathered during the profiling process], there was no way to … [refuse to register a farmer] because everything was really by the use of eyes. So, you would not really … say 'I'm not going to enroll you based on the fact ABC', because in the first place you do not know the boundary of the father and the son [if each have their own land]. So, the only choice you had was to … [register the same farm twice in the system]."

"If you look at the graph of our production right now, the trend is moving up and up and up. In 2017, we were receiving about 28 million [kg of tea leaves]. Last year we received 43 million. This is such a significant progress because of the trust and the confidence created on the on the side of the farmers, who are really suppliers of the raw material to [Igara Tea]."

Justdiggit

Year of establishment: 2009

Operates in: Ethiopia, Kenya, Uganda, United Republic of Tanzania

Current number of users: More than 700 000

Target agricultural sector: Trees and grasses

Interviewee: Sander de Haas

Biography: Sander de Haas is chief technology officer and landscape restoration expert at Justdiggit. He has trained as a hydrogeologist and civil engineer and has wide experience in water harvesting and landscape restoration programmes throughout Africa. At Justdiggit, de Haas works with local partners to select new areas and interventions for restoring degraded landscapes, trains partners in implementation and uses innovative technology to monitor impact of interventions on the environment and people.

Services

Justdiggit employs digital and communication solutions, such as SMS, phone applications, drones, satellite imagery and machine learning, to promote large-scale landscape restoration in Africa. For example, Justdiggit is turning degraded rangelands used by Maasai pastoralists in Kenya into green, fertile land. Justdiggit's solutions inform farmers about landscape restoration options, monitor tree growth and landscape changes over time, and calculate associated carbon sequestration volumes. Justdiggit also helps women to sell indigenous pastoral grass seeds and crops.

Targeted customers and users

Targets include small-scale and subsistence farmers and pastoralists. Justdiggit also works with trainers – half of whom are women – who train farmers in agroforestry and regreening land.

Why Justdiggit needed to digitize/automate

Many organizations use high-tech tools and remote sensing technologies today, primarily for scientific or monitoring and evaluation purposes. Justdiggit also wants to use these technologies to communicate the impact of a growing regreening movement. The organization's mission and vision respond to the growing awareness that the world is changing due to climate change and the willingness of individuals and companies to act.

Business model and financial sustainability

Justdiggit is a non-profit organization that depends on grant funding. It works with a large network of media partners who are active in the Netherlands and in Africa to raise funds and create awareness. Justdiggit receives donations from individual consumers, private companies, donor institutions and funding schemes, and from some family foundations. The organization has seen steady growth. Staff numbers increased from 4 to 40 in about seven years. Justdiggit aims to become less dependent on donations to scale more easily.

Scaling target

Justdiggit is expanding its activities in Africa, mostly through collaboration with other organizations and projects. In 2022, it began working in Ethiopia, Madagascar and Togo, partnering with German development agency GIZ in its Forest4Future project. The ambition is to scale out to West Africa in the near future.

Drivers

Drivers include an increased awareness of the dangers of climate change; growing interest in nature-based and regreening solutions; the increased crop yields and water availability that are triggered by Justdiggit's solutions as well as reduced soil erosion and runoff, which benefits soil fertility and moisture.

Barriers

Barriers are mainly limited smartphone penetration, digital illiteracy, and lack or limited internet access. Trainers often require digital capacity building.

Policy as a barrier or enabler

In Kenya, the Community Land Act can cause distrust,1 since landowners are the ones to decide whether land remains public or becomes privately-owned and subdivided into smaller plots.

Top quotes

"In general, I feel digital is the way to go. And that's probably not us NGOs pushing that, but it's the banking system, it's the opportunities that there are from market access and things like that."

"I'm just thinking, one of the slogans, it's 'cooling down the planet.' And I know it's a pretty bold statement, but it's incredible to see the difference. How much criticism and questions we've got about that slogan seven years ago. … [P]eople were criticizing or asking questions, and we did have an answer to it. But it triggered people's thinking and it provoked questions. While nowadays everyone just takes that for granted. We all started to realize that our planet is changing, and that we need to do something about it."

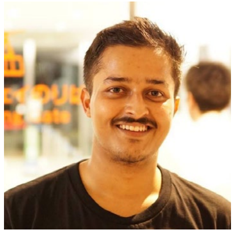
"Nature-based solutions are everywhere. Just the term nature-based solutions, probably I didn't hear it seven years ago."

"We should find a way to work with the legislation that is there. And even if legislation is not there … [we need to provide a digital and automation service] in such a way that it seems fair, reasonable. And I think for us that's relatively easy since we are a non-profit organization; we do it for the regreening aspect and to help … farmers."

"But you can't start debating about 'what if this company wants to offer people [money] if they bring back so many trees?' Well, that's just [the kind of] discussion that will probably … come up in the coming years, and we have to find a way to go about it. And not only purely from a legal perspective, but also [considering] what is a fair perspective."

1 For example, overlapping claims on land by both local and national government authorities, or ability of the government to define land as "public property" and not as "community property" even if it has been claimed, occupied and used by a community for a long time (Alden Wily, 2018).

Seed Innovations



Year of establishment: 2019
Operates in: Nepal
Current number of users: 1 500
Target agricultural sector: All crops
Interviewee: Suman Ghimire

Biography: Suman Ghimire is an agritech entrepreneur on a mission to help farmers in developing countries make climate-smart and satellite-based agricultural decisions. He is the chief executive officer and founder of Seed Innovations Pvt. Ltd. Previously, Ghimire worked as a researcher at the Department of Environmental and Natural Resources Management, University of Patras in Greece. He possesses a strong interest in geospatial technologies, machine learning, entrepreneurship, agriculture and food security.

Services

Seed Innovations provides an android application – PlantSat – that uses satellite-based analytics to monitor crop performance, including the identification of threats, such as water and nutrient deficiencies or surpluses, and to access and exchange agronomic information. Additional advisory services include: the identification of production threats; nitrogen and plant moisture calculators; farm calendar notifications; expert assistance; weather information and the ability to record farm data.

Target customers and users

Targets are mostly medium- to large-scale farmers for satellite-based advisory services and market-oriented smallholders for additional advisory services.

Why Seed Innovations needed to digitize/automate

Seed Innovations' PlantSat application facilitates data-driven agriculture. Access to more advanced technologies (such as satellite-based intelligence) was not mainstream until recently and was primarily reserved for researchers and scientists. Start-ups like Seed Innovation helps farmers to access these technologies, enabling them to optimize the use of resources, such as water and fertilizers, and to make farming more sustainable and profitable.

Business model and financial sustainability

Currently the solution is free for farmers, but the plan is to eventually sell annual subscriptions to insurance companies. This will give them access to the information collected, enable them to monitor crop and farmer performance, and in turn make farmers eligible for insurance pay-outs. Approximately 40 percent of funding comes from grants.

Scaling target

Seed Innovations aims to expand to India in 2025, to South Asia (Bangladesh, Pakistan) thereafter, eventually reaching all of the Global South.

Drivers

PlantSat was developed as a bundled service solution, making the use of the application as simple as possible for farmers, reducing the need for offline data entry, and lowering the costs of operation (e.g., by limiting the server space required to store data points).

Barriers

The major barrier to adoption is scepticism around new technology.

Policy as a barrier or enabler

The Government of Nepal assists low-income farmers to participate in insurance schemes by subsidizing 75 percent of their premium. Nepal has no strict privacy protection, data security or intellectual property policies or regulations that would slow down adoption.

Top quotes

"Everyone was so excited, and they were saying like this is a very big breakthrough ... But when it came to actual implementation, we can't force them [to use PlantSat] and they're sceptical and they don't [use the application]."

"The mindset of farmers is like 'It's going on. It will go on' … They are sceptical about this kind of technology, so they don't use it quite often."

"We can't force them to do the task or we can't force them to like … top dress ... But insurance companies, they have that capability."

"So, then I realized insurance is a very key thing. That [Seed Innovations] need[s] to enter into that channel, because farmers are obliged to follow or obliged to do the works that insurance companies tell them [to]."

"You see like what happens when farmers get engaged in insurance or they are insured is they can take more risks ..."

TROTRO Tractor

Year of establishment: 2016
Operates in: Benin, Ghana, Nigeria, Togo, Zambia, Zimbabwe
Current number of users: 75 000
Target agricultural sector: Arable crops
Interviewee: Kamal Yakub

Biography: Kamal Yakub is co-founder of TROTRO Tractor. He is an experienced CEO with a history of working in the technology and financial services industry. He is skilled in strategy, business management, business development and financial accounting, with a strong start-up mentality.

Services

TROTRO Tractor offers a digital rental platform that matches smallholder farmers with the owners of a vast range of agricultural machinery and equipment, which is offered for hire. Recently, it has also included drone owners, who offer their services in mapping and spraying. All machines are equipped with TROTRO Tractor's IoT tracking device. Customers can access the service via a smartphone application and an USSD service.

Target customers and users

Target are mostly small-scale farmers – with some medium- to large-scale farmers – and increasingly, companies involved in contract farming. Almost 40 percent of the clients are women; the company would like to increase that percentage.

Why TROTRO Tractor needed to digitize/automate

Most farmers in Africa are smallholders who cannot buy tractors and often cannot even afford to rent a tractor for a full day. A rental service, such as TROTRO Tractor, makes tractors and other mechanization appliances affordable for farmers, by breaking down the use–cost to the hectare or acre level.

Business model and financial sustainability

TROTRO Tractor's main revenue stream are the matchmaker fees (10 percent per transaction) that the company receives for the agricultural machinery that is rented out. Additional revenue is generated through the tracker device that TROTRO Tractor requires equipment owners to install on their equipment; TROTRO Tractor sells these devices. The company is profitable in all countries where it operates, except for Ghana, where only about 40 percent of registered users return each season. The company partly relies on grant money, which it mostly uses to expand the business.

Scaling target

The vision is to scale to a model where TROTRO Tractor has mechanization centres in every farming community in the countries where it operates.

Drivers

Most small-scale farmers must resort to rental markets if they are to mechanize. The TROTRO Tractor platform enables transparency and reliability of access, which was not possible using traditional market mechanisms. Women farmers are increasingly using the service, which protects them from the discrimination they often face due to social norms. Young farmers also prefer the service, being more dynamic and open to innovative solutions. Some young people have even trained as machine operators. The COVID-19 pandemic accelerated the digitalization of agriculture and gave a push to the TROTRO Tractor solution. The adoption of drone services is being driven by growing demand from farmers to have accurate land data, since this can help them to obtain finance, credit and insurance.

Barriers

Barriers include increased fuel prices, which make the service inaccessible to some farmers, as well as a lack of credit and finance enabling operators to buy machinery to rent to farmers. Poor road infrastructure also impedes transport and efforts to make the service available in different places.

Policy as a barrier or enabler

Providing subsidies and incentives to farmers to produce staple crops has encouraged mechanization, as have investments in infrastructure and digital technologies.

Top quotes

“The pandemic has really shown that I can use my phone to get food. I can use my phone to work. I can do so many things with my phone, the things that we didn't do before the pandemic.”

“These guys [young tractor operators], when they go to the banks to request a loan to buy a tractor, they have zero credits. … [T]here's no system to allow them to get a tractor to serve farmers, and if we don't have more tractors then we will still get small commissions. And then at some point we just give up and say ‘there's no profit in this business.’ But the more we get service providers on the platform, the more our commissions would also come, and then we can continue to do the business.”

Tun Yat

Year of establishment: 2017
Operates in: Myanmar
Current number of users: More than 20 000
Target agricultural sector: Primarily rice, mung bean, sesame, groundnut, maize
Interviewee: Hujjat Nadarajah

Biography: Hujjat Nadarajah is co-founder and chief executive officer of Tun Yat. He is skilled in agile, lean start-up and change management processes. Nadarajah has grown many organizations, business units and corporate brands, using strategies to develop vision and know-how and effect change. His direct experience is in the start-up, retail, advertising, government and non-profit sectors. He works through community engagement from grassroots to boardroom level.

Services

Tun Yat specializes in mechanization services targeting smallholder farmers in the delta and dryland regions of Myanmar. Tun Yat maintains its own fleet of five tractors and five combine harvesters and acts as a matchmaker between machine owners and farmers. Services include ploughing, land preparation, seeding, combine harvesting with different headers for different types of harvest (e.g. mung beans or maize) and picking (e.g. sesame or groundnut). Tun Yat makes modern and advanced mechanization technologies accessible – for example, laser land level services to create flat fields for planting.

Target customers and users

Targets are mainly smallholder farmers (0–2 ha), although medium-scale farmers (2–6 ha) and farmer groups with medium-scale consolidated farms (> 6 ha) are also prospective customers. Approximately 30 percent of clients are women, and 25–30 percent are below the age of 30. The company targets farmers who do not own and cannot afford to buy a tractor.

Why Tun Yat needed to digitize/automate

Mechanization in the form of two-wheel tractors is widely available, but most households cannot afford them. Four-wheel tractors have been introduced in recent years and are growing in numbers, but their availability was fragmented and the service delivery was unreliable, so better aggregation and organization were needed.

Business model and financial sustainability

Revenue is generated through payment for the service on a per-acre or per-hour basis. Other services include resale of inputs (e.g. fertilizer), credit brokerage, and laser levelling to assist farmers in flood-prone areas who need to level farm plots and develop drainage. It also offers direct purchase from farmer groups of raw material, which is then processed into snacks and sold at convenience stores. The highest margins are generated by proving direct services with their own fleet. Smaller margins come from matchmaking services. Tun Yat also generates revenue by conducting agricultural research in South-eastern Asia.

Scaling target

In the long term, Tun Yat's plan is to offer a bundled service platform, including sales of seeds and fertilizers as well as machinery, and to make the service available across South-eastern Asia and beyond.

Drivers

Farmers are mostly unable to afford their own machinery, yet the demand for reliable and affordable mechanization services is high. Other drivers include unreliable service delivery of mechanized machinery and the increased penetration of mobile and smartphones.

Barriers

Barriers to adoption include: increasing prices for inputs and fuel; limited digital literacy and connectivity; low levels of trust, for example in mobile payments; and the fact that users can bypass Tun Yat's matchmakings service once they now the equipment providers. There is a need for technological support and capacity building.

Policy as a barrier or enabler

The Government of Myanmar is committed to increasing digitalization, but the current uncertain political environment hampers innovation and investment. Furthermore, existing policies related to digitalization and data use more focused on cyber security and surveillance, which can also slow adoption.

Top quotes

"As mechanization increases as an upward trend across the country, farmers move from a hanging-in to a stepping-up stage of development. When this happens, groups of farmers (or relatives) then pool money together to buy a tractor, where four or five families join and chip in …. When that happens, then they no longer need an external service provider like Tun Yat and then themselves use their machines to till/harvest their own lands and rent these out to other villagers in their area. So then, we work ourselves out of this first level of service and look at more complexity – where we supply other inputs, more specialized precision equipment like laser levellers, and start linking harvested crops to offtakers, or process it ourselves, and move towards tech-enabled solutions that link transactions of inputs, to credit profiling and financial institutions interested in financing inputs for these farmers. Therefore, as the cluster grows and becomes more complex, our level of services multiplies and penetrates further, to meet their needs and assist with their growing response and capacity."

"[An i]nteresting point for Myanmar is that there was a huge smartphone penetration in the last couple years. So, we have a very high rate of smartphones, even among farmers, like at least one [person] in every household has got a smartphone."

25

Digital and automation solutions can solve labour bottlenecks, increase agricultural productivity, resilience and efficiency, and improve environmental sustainability. However, access is limited in low- and lower-middle-income countries, especially for small-scale producers. Based on ten case studies in sub-Saharan Africa, Latin America and the Caribbean and Asia, this study investigates the suitability of digital and automation solutions for small-scale producers, the main drivers and barriers to their adoption and the role of policies and regulations in creating an enabling environment.

Findings show that technologies in the study countries are largely limited to smartphones and tablets, and related software tools (e.g. mobile applications). Most digital and automation solutions focus on crops, some on livestock and aquaculture, and a few on agroforestry. The most important adoption barriers include the high investment cost, lack of digital skills and knowledge and a lack of an enabling environment.

Yet, advances in mechanization supported by digital technologies, and the development of hiring platforms foster adoption. The emergence of guidelines, strategic plans and policies that regulate and streamline automation should be encouraged, as should providing producers with information about the benefits and costs of digital and automation solutions.

The FAO Agricultural Development Economics Technical Study series collects technical papers addressing policy-oriented assessments of economic and social aspects of food security and nutrition, sustainable agriculture and rural development.

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Agrifood Economics Division - Economic and Social Development

- ESA-Director@fao.org
- www.fao.org/economic/esa

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